Performance Analysis of Manufacturing System at the Operational Level

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***Abstract*—** *In this paper, we propose a method to control of make-to-order (MTO) manufacturing system for the operation level. Control achieved with the proposed method is based on modeling the relationship between cost and time, two very important elements of manufacturing process performance evaluation. In order to better represent the specified goal of manufacturing process we propose (as a novelty) as a criteria the Earning Power (EP). It is both synthetic (because it reflects the essential motivation of manufacturing process) as compliant with the most important five performance aspects, namely: profitability, conformance to specifications, customer satisfaction, return on investment and materials/overhead cost, selected by researchers in order of importance.*

***Keywords*— Control, Earning power, Manufacturing operation, Manufacturing system, Simulation.**

I. INTRODUCTION

By definition, Earning Power is an operating income divided by total assets. Here, operating income is an income resulting from a firm's primary business operations, excluding extraordinary income and expenses. It gives a more accurate picture of a firm's profitability than gross income. Asset is something that an entity has acquired or purchased, and that has money value (its cost, book value, market value, or residual value). An asset can be: something physical, such as cash, machinery, inventory, land and building; an enforceable claim against others, such as accounts receivable; right, such as copyright, patent, trademark or an assumption, such as goodwill. For determination of EP it must be estimated: cost, time, asset, and price. Current methods for estimating the cost and time are based on breakdown of the product into elements, cost estimation of each element and summing of other costs [1,2]. As an element, we can consider one product component, one manufacturing component or one activity component. To estimate the cost for each element there are used element's different features that are closely related to cost. With few exceptions, estimation methods lead to cost estimation without a mathematic model describing relation between cost and element's different features. As a plus, those methods have a slight adaptation capacity to different specific situations because the information that is provided in order to estimate is general and does not adapt to specific case. Therefore, in this paper, cost and time will be estimated by techniques that are based on analytical modeling, neuronal modeling, or k-nearest neighbor regression. Each of these techniques cover a range of specific cases, namely: analytical technique covers process cases with all known regularities. The technique based on neuronal modeling covers cases when a large number of similar products are manufactured, slightly different. Moreover, k-NN regression technique covers cases when there is little data to produce a model (production is diverse and manufactured series are few).

It is not difficult to estimate the asset because in the balance sheet there are quite accurate and updated data. Price estimation goes from costs and represents the company mission in relation to the market.

II. OPERATION MODELING

We consider that we have to manufacture the part from Fig. 1. The technological process needed to process the part consists of the following operations: turning, drilling and welding. In order to evaluate the order EP we have to calculate job EP and operation EP. To do this, the order will be divided in job 1 (rod 1, Fig. 1) and job 2 (plate 2, Fig. 1). To perform job 1 it is necessary to use the turning operation. For job 2 we need drilling and welding operations.

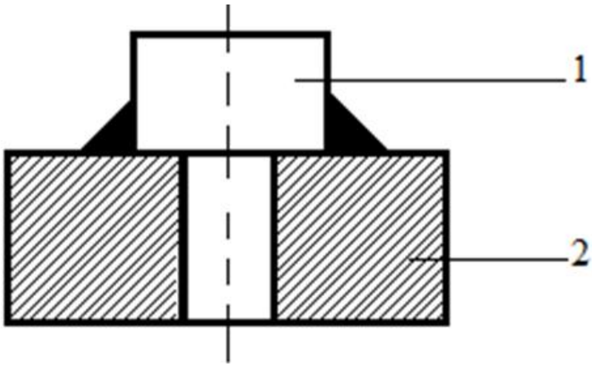

FIG. 1. MANUFACTURING PART: 1 - ROD, 2- PLATE

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

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

where: P_{ijk} is the minimum market price for operation *k* and for job *j* in order *i* [Euro]; $c_{ijk}(p_{jkn})$ 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 make the operation *k* from job *j* [min].

In order to determine EP we must estimate: cost, time, asset, and price. In this paper, cost and time will be estimated by some techniques based on analytical modeling, neuronal modeling, or modeling by k-nearest neighbour regression.

2.1 Analitical Model

The operation of turning will be analytically modeled on the base of the relation:

$$c_{ijk} = C_{am\,ijk} + C_{p\,ijk} + c \cdot S_{ijk} \cdot N_{ijk} \tag{2}$$

where: $C_{am\,ijk}$ is cost for auxiliary labor for carrying out the operation *k* from job *j* [Euro]:

$$C_{am\,ijk} = \frac{C_{m\,ijk} \cdot N_{ijk}}{4} \tag{3}$$

$C_{m\,ijk}$ - cost for labor of operation *k* from job *j*. For turning operation that is part from job 1,

$C_{m\,ijk}$ = 2.75 Euro; N_{ijk} - number of pieces to be processed; $C_{p\,ijk}$ - cost to prepare the operation *k* from job *j* [Euro]. For turning operation, $C_{p\,ijk}$ = 2.7 Euro.

$$c = \frac{c_\tau}{10vs} + \frac{\tau_{sr} c_\tau + c_s}{10Tvs} + \frac{t \cdot c_{mat}}{10} + \frac{K_e c_e}{10000vs} + \frac{C_M}{10K_M} v^{\alpha-1} s^{\beta-1} t^{\gamma} \text{ [Euro/cm}^2\text{]}, \tag{4}$$

where: c_τ is cost for one minute to use the job place, 0.45 Euro/min; τ_{sr} – time to change and sharpening 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 – 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

$$T = \left[\frac{470}{v}\right]^{2.5} \text{[min]}; \tag{5}$$

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

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

$$t_{ijk} = t_{p\,ijk} + t_{a\,ijk} \cdot N_{ijk} + \tau \cdot S_{ijk} \cdot N_{ijk} \quad [\text{min}] \tag{6}$$

where: t_{pijk} – time to prepare the operation, 60 min; t_{aikj} – operation auxiliary time, 4.4 min

$$t_{a\,ijk} = 0{,}2 \cdot t_{u\,ijk} \quad [\text{min}] \tag{7}$$

t_{uijk} - unitary time to perform the operation, 22 min; τ - specific time necessary to remove one cm^2 of material.

$$\tau = \frac{T + \tau_{sr}}{10 \cdot T \cdot v \cdot s} \ [\text{min/cm}^2] \tag{8}$$

It can be observed that EP by cost and time depends on several parameters p_{jkn}.

The optimal control operation is controlled so that the maximum EP be provided that restrictions on the accuracy, surface quality, stability and product ecology are respected. We ask the question: which are the parameters that must perform the operation for EP to be up?

We can observe that cost c_{ijk}, and time t_{ijk} are dependent by a series of variables named by the us parameters p_{jkn}: c_τ, τ_{sr}, c_s, c_{mat}, c_e, K_e, K_M, C_M, v, s, t, α, β, γ

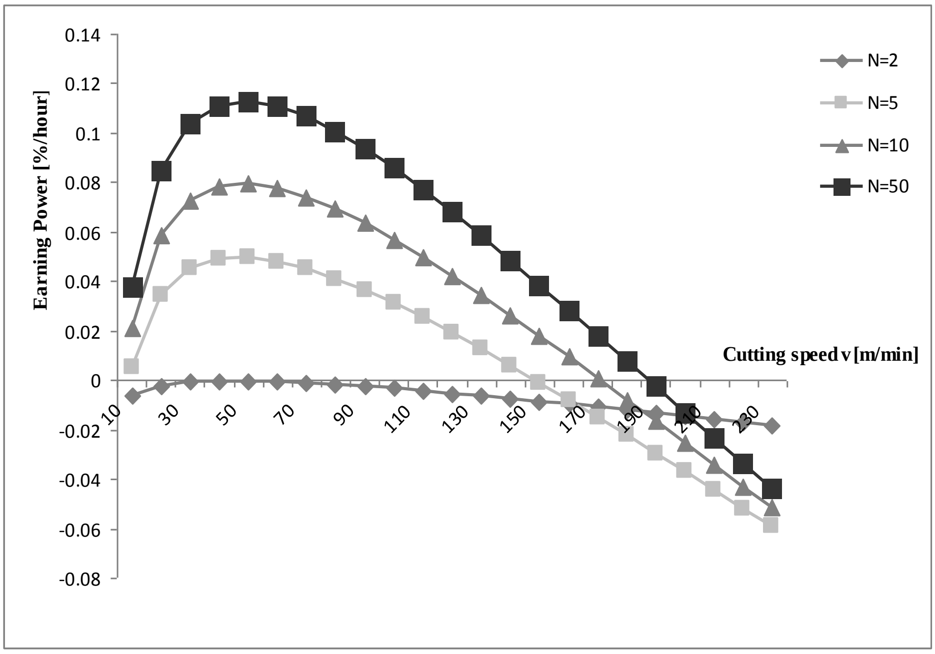

FIG. 2. THE VARIATION OF THE EARNING POWER DEPENDING ON CUTTING SPEED

Part of these variables depends by the workstation (K_M, C_M), others by the tool (τ_{sr}, c_s), others by the process (v, s, t). By these variables, we can control the process, i.e. they can influence the value of EP so that it becomes maximal. Taking into consideration all restrictions imposed by the process, we will have to choose the variables by which we can control the process. For example, for cutting process, the control variable can be cutting speed *v* or/and tool material and then we'll need to know the value for these control variables so that EP becomes maximum. Feed rate *s* could influence EP, but it is determined depending on surface roughness and it cannot be changed during the cutting process to achieve maximum EP.

The cutting depth *t* is restricted because it is considered that the addition of the entire processing must be removed in a single pass. It cannot be taken as control variable. Note that the control variable for the cutting process is cutting speed, *v*. When graphically representing the EP of turning operation according to cutting speed we can see there is a maximum value for EP for a specific optimal value of cutting speed (Fig. 2). For example, for a number of pieces *N=2*, maximum value of EP is -0.0002898 %/hour when *v=40* m/min; *N = 5*, maximum value of *EP=0.0496663* %/hour for a cutting speed *v=50* m/min; for *N=10*, maximum value of *EP* = 0.079419 %/hour for *v=50* m/min and when *N=50*, maximum value of *EP*=0.112742971

%/hour for v= 50m/min. 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 an optimal control of the turning operation.

2.2 Neural Network Modeling

Welding operation for job 2 is modeled by a Neural Network technique. “Best NN model” or the best model provided by a neuronal network is a practical modality to find out causality relations between variables in order to be able to determine the variable clusters. Using neuronal network to compare variables (each by each) we obtain sets/clusters of variables that are in causal relationship. Procuring clusters is a computer application, training the network with all its database values and determining those variables that have causality relations. From database of welding operation variables (Table 1) which we note with *v1*, *v2*,…,*v12*, we’ll take into consideration column 12 containing values of variable *v11*- cost of welding operation. By a neuronal network, are determined the best relationships with the other columns.

TABLE 1
SEQUENCE FROM THE TABLE OF WELDING OPERATION VARIABLE

Item Nr.	Material type	Welding type	Length of welding seam [mm]	Nr. of passes	Current intensity [A]	Rate of welding [mm/s]	Quantity of welded wire [m]	Nr. of pieces	Welding time [s]	Energy consumption [KW/h]	Operation cost [Euro]	Waste quantity [Kg]
-	v1	v2	v3	v4	v5	v6	v7	v8	v9	v10	v11	v12
1	OL 52	corner	501	3	200	10.2	4.2	63	1375	10.521	78.9	15.781
21	OL 37	corner	503.5	9	204	5.1	4.85	103	6758	52.898	388.9	77.791
40	OL 52	corner	490	4	197	8.2	4.60	59	11243	12.656	96.3	19.273
52	OL 42	corner	515	10	188	9.2	5.20	52	2459	27.970	223.1	44.633
64	OL 52	corner	521	11	191	8.15	4.1	92	6066	55.947	439.3	87.875

It is determined the best dependence relationships with the columns *v3*– length of welding seam, *v4* – number of passes, *v6* – rate of welding and *v8* – number of pieces. The result will be a cluster of variables (*v3*, *v4*, *v6*, *v8*). Using the data from cluster of variables database a neuronal network is trained. The trained network is a search model and by interrogation, we can find out the value for variable that interest us to know, *v1*– operation cost. Then, the same steps will be followed but comparing the column 10 that has values for variable *v9* – time of welding operation with the other columns. It will result a cluster of variables, which becomes the pair (*v3*, *v4*, *v6*). Trained network is a search model and by interrogation, we can find out the value for variable that interest us to know, *v1*– operation time. Knowing the cost, time, asset and price gained through negotiation with the client for welding operation, is calculated the Earning Power for welding operation with relation (1). Asset’s estimation is not difficult because in the balance sheet there is enough accurate and updated information. We obtained a curve of EP variation depending on rate of welding considered as control parameter for welding process (Fig. 3).

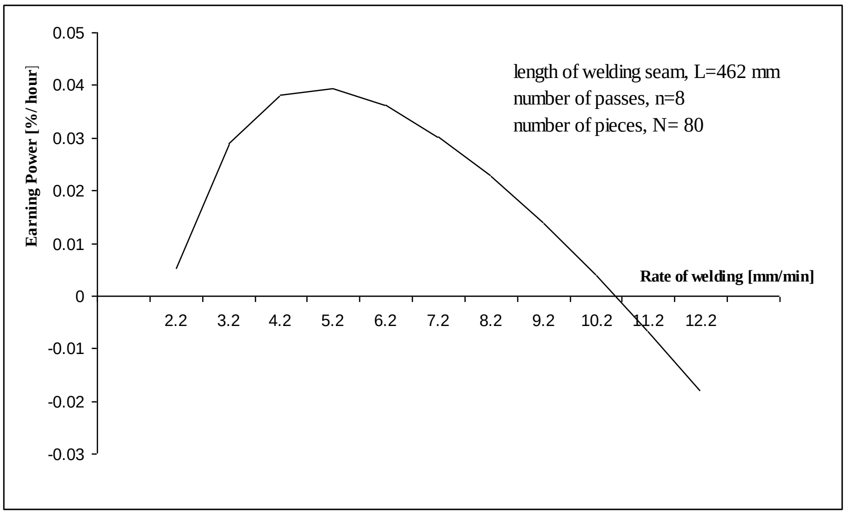

FIG. 3. THE VARIATION OF THE EARNING POWER DEPENDING ON RATE OF WELDING

After analyzing the diagram from Fig. 3, we can emphasize that there is a maximum value for EP for a certain rate of welding, optimal rate of welding. Therefore, when we are welding, the rate of welding can be adjusted so that the efficiency of operation becomes maximum and the economical effect on company will be maximum too. It is made a control of welding operation.

2.3 Data mining technique

Drilling operation for job 2 will be modeled by data mining technique. We will be using a computer program named Visual FoxPro and C++ that needs the mathematical library called MatLab. For start we'll take a random sequence from drilling operation database (Table 2), where we can find the notations *vi*, with *i=1,…,10*.

TABLE 2
SEQUENCE FROM TABLE WITH DRILLING OPERATION VARIABLES

Item Nr.	Material type	Hole diameter [mm]	Nr. of holes	Drilling speed [mm/s]	Drilling feed[mm/s]	Nr. of pieces	Drilling time [s]	Energy consumption [KW/h]	Operation cost [Euro]	Waste quantity [Kg]
-	v1	v2	v3	v4	v5	v6	v7	v8	v9	v10
6	OL 37	17.55	8	3.2	0.75	77	2459	13.17	158.10	75.89
14	OL 37	28.6	6	3.2	0.45	65	2410	29.53	265.8	127.60
31	OL 37	32.6	7	5.1	0.2	70	4011	41.32	433.9	208.30

Consider that customer's requirements are: v1=OL 37; v2=21; v3=6; v6=82. At the operational level, the variables clustering is based on facility "best model" provided by the technique of neuronal networks applied on experimental data set. After using the software, our variables, time and cost: v7 and v9, necessary to calculate the EP for drilling operation are dependent on the following variables: v7=(v2, v4, v5) ; v9=(v2, v3, v4).

For the state clustering those lines for which the common distance will be minimal will be chosen from the database. A set of data will be selected, data that are close to customer's demands and thus, the mathematical model will be linear, resulting mathematical models for time and cost during drilling operation:

$$\begin{aligned} v7 &= a_0 + a_1 v2 + a_2 v4 + a_3 v5 \\ v9 &= b_0 + b_1 v2 + b_2 v3 + b_3 v4 \end{aligned} \tag{9}$$

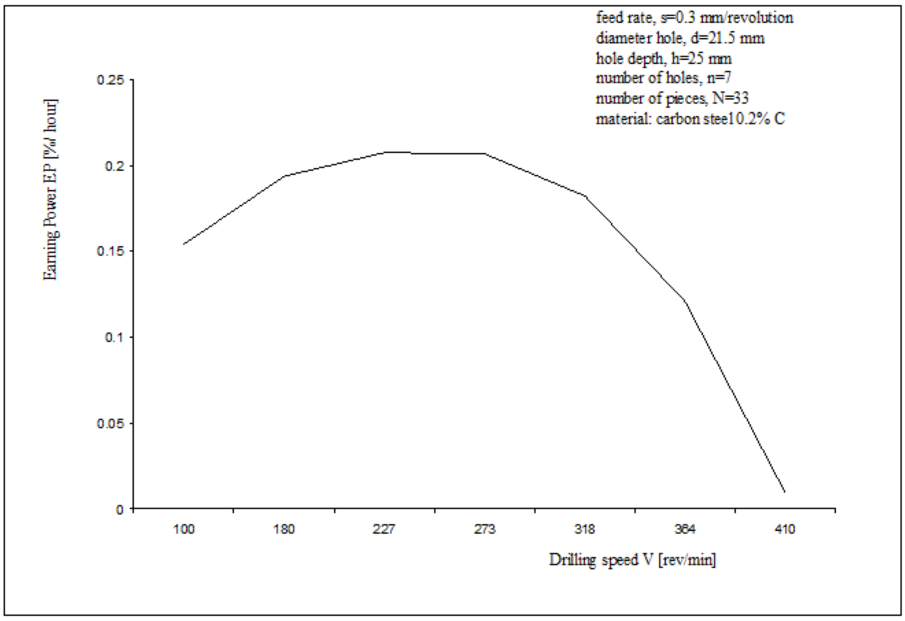

FIG. 4. THE VARIATION OF THE EARNING POWER DEPENDING ON DRILLING SPEED

Having the first four states, k=4, according to algorithm k-NN (Near Neighbour) will be obtained a system mathematic for cost and time. Solving the systems solutions will be obtained for determining the coefficient of the mathematical model. Linear models obtained for the cost and time are local models because they are valid only near the state are queried. They are also ephemeral because after interrogation they are abandoned. The method is very efficient because a mathematical model is built for each input series. Moreover, after practical checking the solution resulted during negotiations with customer, this model will be added in the table with initial experimental data, enriching the database by one new experience.

Taking the drilling speed, v, as a control parameter for the entire process, we represented the EP variation graphically depending on v (Fig. 4).It can be noted that when turning and welding operations as well as for the drilling operation, EP has a maximum value for a certain speed value, i.e. for optimal speed. In case of drilling operation, optimal speed is *v=227 rev/min*.

III. CONCLUSION

The three operations comprising the order were modeled by means of different techniques: turning by analytical method, drilling by data mining technique, and welding by neural network technique. By the three methods there was determined the value of a maximal EP resulting the optimal value of the process parameter, i.e. speed. Thus, for turning operation EP decreases by 34%, for a number of 5 pieces, if $v=100$ m/min to the case when we work with $v=v_{optimal}$=50m/min. For drilling operation, if work speed is $v=100$ rev/min EP decreases by 1.3 times to the case when the optimal work speed is, $v=227$ rev/min. For welding operation, if the process is performed at the speed $v=2.2$ mm/s then the value of EP will decrease 78 times to the case when $v=v_{optimal}$ =5.2mm/s. It follows that, for an operation, the optimal operation control can be made by knowing the maximal EP.

Depending on the maximum value of the order EP, the manager can decide whether to perform all operations to accomplish the job within the company or not. The manager can choose to outsource those operations that EP does not have a positive effect.

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