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ECONOMETRIC MODELLING OF THE MANUFACTURING SYSTEM

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ABSTRACT

According to this new approach, a machining system interacts with the "market" carrying out a certain "service" (machining "service") for a specified "client" (the work piece), it establishes a full economic relationship with. We consider that the machining system has itself a business model and a business plan. The business model has as input the process characteristics, as output the "service" characteristics, while as parameters the system-market relationship characteristics. In this paper, it is presented the generic business model for machining systems, where the cutting conditions are the process characteristics, the cost, the time, the profit rate and the environmental impact are the service characteristics, while the machining operation price is the model parameter. Also it is analysed the price - maximum profit rate relation. A particular business model for an experimental machining system is presented.

KEYWORDS: econometric modelling, integrated manufacturing, business model, machine process system, adaptive optimal control.

1. Introduction

The manufacturing system performance depends on how it is controlled. In more specialized papers [1], references are made to the relationships between the parameters of the cutting processes and the technical performance of the manufacturing system (i.e., purely technical aspects), while in others, equally numerous [2], references are made to the relationship between the product made by the manufacturing system and the market (i.e., economic relations) [3].

In the literature, no attempt to approach the whole manufacturing system – market *assembly* is reported, despite there are significant resources to improve performance which are not used because the technical and economic aspects are dealt with separately.

Also, it is not known an algorithm for the management of the manufacturing system – market assembly, but only algorithms for the technical control of the manufacturing system [4], and tools of economic management of the relationship between the enterprise as a whole and the market.

The dynamic changes and the overall progress of society are reflected at company level by orders many in number, small in volume, very diverse, obtained through frequent auctions with short- term response, which leaves no time for a relevant analysis of said orders. As a result, a long-term management is no longer possible. A sort of fluctuating (just like the market) on-line, fastly responsive, prompt and rapid, however, ephemeral management is called for [5].

The literature reports [6] the concept of Computer Integrated Manufacturing (CIM), which is both a method of manufacturing and the name of a computer-automated system in which individual engineering, production, marketing and support functions of a manufacturing enterprise, are organized.

Consequently, it is a method of manufacturing in which the entire production process is controlled by the computer.

The paper proposes a new concept, "Business Integrated Manufacturing", as result of a particular approach of the computer integrated model.

Business Model is a management tool of the business integrated manufacturing. The proposed concept is based on the idea that the business and manufacturing process are carried out together, that means both processes, physical and economic, coalesce and so resulting the business integrated model [7].

The paper has the following structure: section 2 presents the structure of business integrated manufacturing model, section 3 contains simulations

and discussions and section 4 summarizes the main conclusions achieved.

2. Econometric model

Business integrated model is based on the modelling of the manufacturing operation taking into account its corresponding business operation. On a practical level, the aim is to create the business integrated manufacturing model of the machining system, available for any part operation and its use for either on-line or off-line control.

The machining system interacts with the "market" carrying out a certain "service" (machining "service") for a specified "client" (the work piece), with which it establishes a full economic relationship.

This relationship is characterized by the following variables: the service quality, the service necessary investment, the service profit rate, as well as the environment impact which occur during the service being carried out. The business model has as input the process characteristics, and as output the "service" characteristics, while as parameters the machining system-market relationship characteristics.

In figure 1, it is presented the generic business model, where the cutting speed v is the process characteristic, the cost C_0, the time τ, the profit rate r (for the three levels of the price - P1, P2, P3) and the environmental impact I are the service characteristics while the machining operation price P is the model parameter.

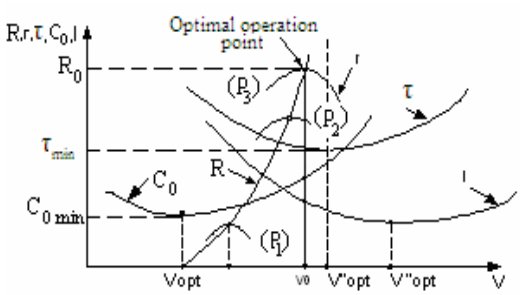

Fig. 1. Business model of the manufacturing system

Service characteristics of the business integrated model developed in this paper are:

- cost c;
- time τ;
- profit rate r
- environmental impact I.

The *cost c* is defined as

$$c = \frac{C_O}{S} \text{ [Euro/cm}^2\text{]} \qquad (1)$$

where:

C_0 – it is the expenses of the manufacturing process;

S - the machined surface area.

Consequently, the cost is given by the following relation:

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

where:

c_τ – it is the sum of all expenses directly proportional with the time;

τ_{sr}- time needed for the tool change and adjustment of the tool [min];

c_s- tool cost between two successive reshaping;

c_{mat} – tooling allowance cost;

c_e – cost of 1Kwh electric energy;

K_e- energy coefficient [wh/min];

K_M - machine-tool coefficient;

C_M - machine-tool cost [Euro];

v – cutting speed [m/min];

s – feed rate [mm/rot];

t – depth of cut [mm];

α, β, γ – coefficients;

T – tool durability, given by the Taylor relation:

$$T = \frac{C^{\frac{1}{m}}}{v^{\frac{1}{m}} s^{\frac{x}{m}} t^{\frac{y}{m}}} \text{ [min] .} \qquad (3)$$

The necessary *time* τ for 1 cm^2 surface area machining is calculated with the formula:

$$\tau = \frac{T + \tau_{sr}}{10Tvs} \text{ [min/cm}^2\text{]} \qquad (4)$$

Another service characteristic is the *profit rate r* and it is defined by the following relation:

$$r = \frac{p - c}{\tau} \text{ [Euro/min],} \qquad (5)$$

where p is specific price, [Euro/cm^2].

Environmental impact on-line control is carried out by on-line evaluation of the $C0_2$ emission, corresponding to the energy and tool material consumption for each unit of the removed material. Technology has affected society and its surroundings in a number of ways.

In many societies, technology has helped more advanced economies to develop (including today's total economy) and has allowed the rise of a leisure class. Many technological processes produce unwanted by-products, known as pollution and deplete natural resources, to the detriment of the Earth and its environment. Various implementations of technology influence the society and new technology often raises new ethical questions. Examples include the rise of the notion of efficiency in terms of human productivity, a term originally

applied only to machines, and the challenge of traditional norms.

The environmental impact I [kg Co_2/cm^2], is given by the formula:

$$I = \left[c_e K_{I_{energy}} + \frac{t\rho K_{I_{mat}}}{10} + \frac{m_{tool}\tau K_{I_{tool}}}{NT} \right] \quad (6)$$

where:

$K_{I\ energy}$, – environmental impact coefficients depend on energy consumption;

$K_{I\ mat}$ - environmental impact coefficients depend on steel consumption through tooling allowance;

$K_{I\ tool}$ - environmental impact coefficients depend on tool material;

ρ– mass density of work piece material [kg/cm^3];

m_{tool} – tool mass [kg];

N – number of reshapings.

3. Simulations and discussions

By means of relations presented above, an example of updated business model was carried out (Fig. 2). Table 1 presentes simulations for 10 business integrated models. In the Fig. 2.a it is represented the structure of the most important expenses: salaries, tool cost, tooling allowance cost, energy cost and machine-tool cost. It is important to note that the minimum cost c_{min}=0.00978 Euro /cm^2 is obtained for the optimal cutting speed v'_{op}=84m/min. Before v'_{op}, the salaries have the greatest influence, but after the v'_{op}, the tool cost influences mostly the total cost. The tooling allowance cost is constant. The weight of the energy cost and machine-tool cost is greater before v'_{op}.

Based on the relation 4, in Fig. 2.b it is represented the time τ. The minimum value of time τ_{min}=0.007min/cm^2, corresponds to a cutting speed v''_{op}=176m/min. Fig. 2.c presents the curves of the profit rate r calculated with the relation 5 for the three levels of the price.

As shown in figure 2.c, there is a maximum R_0=1.8679Euro/min for the price 0.0242Euro/cm^2 and corresponds to a cutting speed v_0=136m/min (optimal operation point). Also, on the diagram, there are negative values of the profit rate r. The cutting speeds associated with maximum profit rates are situated between v'_{op}=84m/min and v''_{op}=176m/min. According as the price increases, the maximum of the profit rate goes to the right, as shown in Fig. 2.c.

Using the relation 6, in Fig. 2.d, it is represented the environmental impact. According to the cutting speed v increases, the values of the environmental impact become lower.

Table 1 includes three columns. In the first, there are the parameters of the business model presented in Fig. 2. The other columns include parameters of two models: one is considered having a more expensive machine-tool and the other one having a more expensive tool. Analyzing the data from the table, we could conclude the following:

1) Minimum cost c_{min} is reduced by 3.5%, for the case with more expensive machine-tool, and it is increased by 50.9%, for the case with a more expensive tool.

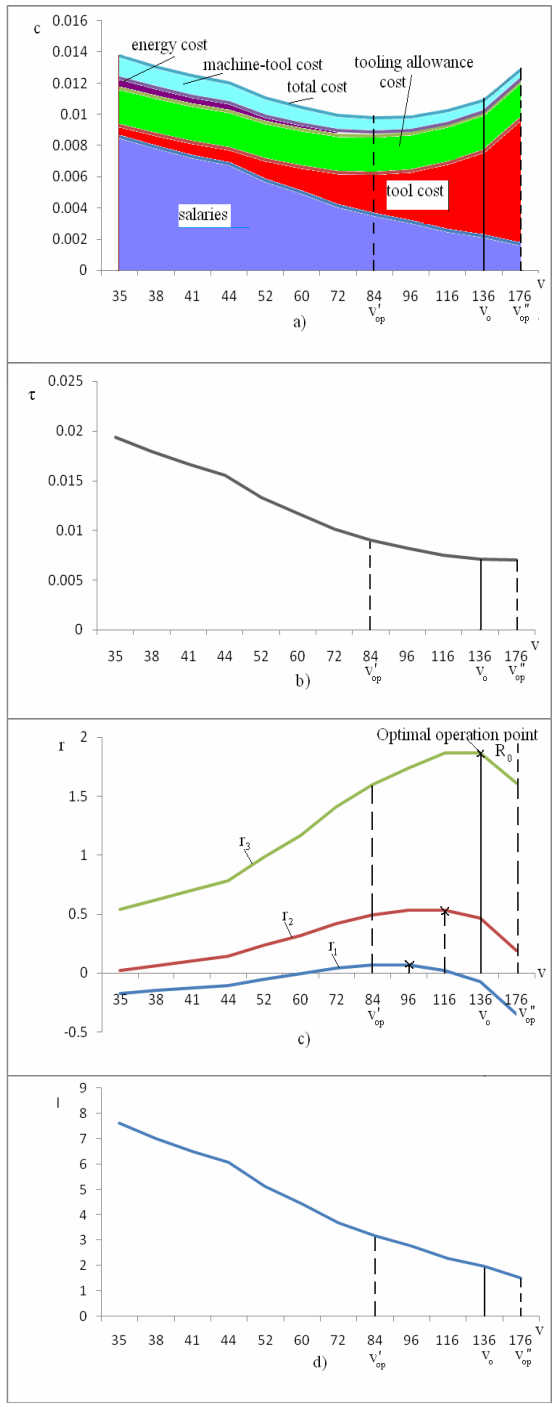

Fig. 2. Business integrated model for a turning process and system: a) expense c structure; b) time τ; c) profit rate r; d) environmental impact I.

The cutting speed v'_{op} is reduced, in the both cases, by 33.7%, respectively by 44.6%;

Table 1. Simulations

Business integrated model parameters	Characteristics of the machine-process system		
	c_τ=0.45; τ_{sr}=10; C_M=100000; c_s= 20; p=0.0242	c_τ=0.20; τ_{sr}=20; C_M=150000; c_s= 40; p=0.02	c_τ=0.45; τ_{sr}=40; C_M=50000; c_s= 90; p=0.032
v'_{op} [m/min]	84	52	44
c_{min} [Euro/cm^2]	0.00978	0.00943	0.01476
v''_{op} [m/min]	176	116	96
τ_{min} [min/cm^2]	0.007	0.009	0.0121
v_o [m/min]	136	84	72
R_o [Euro/min]	1.8679	0.9573	1.2167

2) Time τ_{min} is increased by 28% due to a more expensive machine-tool, respectively by 72%. Consequently, the productivity is reduced. It is observed a reducing of the cutting tool v''_{op} by 34%, and by 47% in the case with a more expensive tool;

3) The profit rate is reduced, less in the second case (by 34.8%) and more in the first case (by 48%);

4) Reduced costs and higher productivity can be obtained adopting the model with a more expensive machine-tool;

5) Profit rate can be increased through implementation of the business model based on the using of a more expensive tool.

As seen in figure 1, through business integrated manufacturing model, machining process becomes transparently because all the technical and economic process characteristics (as cost, time, profit rate and environmental impact) are evaluated. Human/machine interface permanently displays the values of these characteristics and the online updated business model, as well.

This allows the operator to evaluate the operating point position with respect to the business-model and

to correct it aiming an enhanced set of the above-mentioned characteristics values. Along with optimization considering also environmental impact, the productivity can increase reducing the machining time τ as consequence of the process optimization. Through implementation of the business integrated model, the profit rate increases even by 100% (table1).

In the future, on the base of this research, we'll develop the modeling of the manufacturing system competitiveness. A new concept of manufacturing systems management based on behavioral modeling

4. Conclusions

In this paper is defined a new concept, "business integrated manufacturing", based on the modelling of the manufacturing operation taking into account its corresponding business operation.

Evaluation of the cost, time, profit rate and environmental impact allows adjusting of the management policy.

Comparing the performed simulations we conclude:

a) Reduced costs and higher productivity can be obtained adopting a business model based on using of a performance machine-tool (more expensive) for the manufacturing process;

b) Profit rate can be increased through implementation of the business manufacturing model based on processing with a more expensive tool.

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