

## ECONOMETRIC CONTROL OF THE MANUFACTURING MACHINES

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### ABSTRACT

*This paper presents a method of econometric modelling of the manufacturing machines which is based on the machine operation monitoring, the collected data storing and an analytical model building meant to describe the machine economics. It also presents the construction model of the global model of the requested product as well as the way of using this model.*

KEYWORDS: Econometric modeling, manufacturing system, process, control, market, management.

### 1. INTRODUCTION

The most important feature of the present-day market is the high level of customizing the products requested by customers, which brings about a large variety of the requested products and a small volume of the batches in which these products are manufactured [1]. One of the responses industry can give to this challenge is to increase its responsiveness by continuously reconfiguring the manufacturing systems in compliance with the task to be carried out [2].

The manufacturing system is defined as being the ensemble of technological systems which are used for realization of a certain product. Each of these technological systems is made up of machine-tool, tools, apparatus, parts, operator and it executes one of the operations of the technological process [3]. The manufacturing system is made up when the manufacture of the product is started up. After this, when is started up another product, the problem of structure of the manufacturing system is taken again from the beginning. This ad-hoc structure of manufacturing system is always presented to the batches manufacturing, but it isn't to the serial manufacturing (the ensemble of technological systems which make up the manufacture system is for a long time in the same structure) [4], [5].

The performance of the manufacturing system depends on its control. The special literature [6], [7] refers to the relationship between the parameters of the cutting regimes

and the technical performance of the manufacturing system (pure technical aspects) and the other [8], [9] refers to the relationship between the product manufactured by the manufacturing system and the market (relations of economic nature). In special literature there aren't approaches of the ensemble of manufacture system and market. There are important improving resources of the manufacturing system performances because the technical and economic aspects are approached separately.

Nowadays, the manufacturing systems are controlled by means of numerically programmed machine tools which are part of the system [10]. The control is exclusively technical because there is no economic variable, although this is actually the ultimate goal of any processing process.

The dynamic changes and the overall progress of society are reflected at company level by many orders in number, small in volume, very diverse, obtained through frequent auctions with short-term response, which leaves no time for a relevant analysis of the 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 [11].

In this context, an important problem is the management of the customer - company relationship with regard to the product

contracting, on the one side, and the management of the contracted product manufacturing process on the other.

This paper proposes a solution to this problem, which is based on building an economic model of the product requested by the customer [12].

This economic model is to be used in two situations:

- the first situation is the one where the economic model of the product is used in conducting the negotiations between the enterprise and the customer who requests the manufacture of the product in a certain number;
- the second situation occurs after entering upon the contract and starting up the manufacture of the contracted product, when the optimal control of the manufacturing machines is requested during the carrying on of the manufacturing processes.

The present-day solutions to this problem are based on the manufacturing systems modelling and on using these models both for establishing the price quotation and for the operational control of the manufacturing processes. Some of the present-day solutions are given below.

A first example is the one where a model, especially created for small and medium enterprises, is the virtual integrated manufacturing system which starts from the computer-aided integrated manufacture. The architecture of the manufacturing system, even though it is based on three-level structured agents, has the advantage of connecting the agents through the internet [13], [19],[20].

Figure 1 suggests a network of small and medium enterprises that are structured after the model of the virtual integrated manufacturing system based on hierarchically structured agents [14], [15], [16], [17].

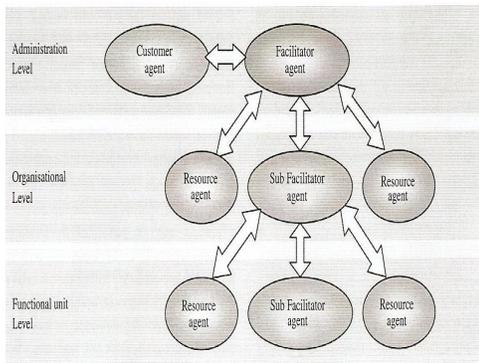


Fig. 1 Model of virtual manufacturing system based on hierarchically structured agents

A second example is the one where a

multi-agent structure using a fictitious market model is used; this structure can be used in programming the CNC equipment of the manufacturing machines. In this structure the agents fulfil the sellers’ and buyers’ assignments on a virtual market.

The method uses the costs and proceeds calculated for every activity of the agents, and, by the price strategy, the coordination of the prices is accomplished. To this purpose [18], the quoted price, the penalty cost and the opportunity cost based on the delay times, the cost for the previously determined time unit based on the task (i) performance times and on the task (i) finishing times at the work site (k) are calculated by such relations as:

$$BP_{i,k} = \text{OperationalCost}_{i,k} + \text{PenaltyCost}_{i,k} + \text{OpportunityCost}_{i,k} \quad (1)$$

$$\text{PenaltyCost}_{i,k} = \delta_i \times \text{Max}(C_{i,k} - D_i, 0) + \varepsilon_i \times \text{Max}(D_i - C_{i,k}, 0) \quad (2)$$

$$\text{OpportunityCost}_{i,k} = \sum_{j \neq i} \delta_j \times \text{Max}(C_{j,k}(i,j) - D_j, 0) - \text{Max}(t + p_{j,k} - D_j, 0) / L_k \quad (3)$$

$$BP_{i,k} = p_{j,k} + \delta_i \times \text{Max}(C_{i,k} - D_i, 0) + \sum_{j \neq i} \delta_j \times [\text{Max}(C_{j,k}(i,j) - D_j, 0) - \text{Max}(t + p_{j,k} - D_j, 0) / L_k] \quad (4)$$

A third example is the one where the concept of “smart product” is elaborated, according to which every product runs its own manufacture, thus allowing the separation of the manufacture from the forwarded order, in the same manner that the physical flow is separated from the informational one.

The smart product requires services from the manufacturing resources and, based on the cooperation logic, aims at fulfilling its own requirements.

Nevertheless, another result pursued is, first of all, dealing with the variety of factory’s resources.

Resources, as well as smart products, can be presented as communication entities. In this case, the organisation is considered to be the cooperation between resources and communication entities, from which calculation entities named rules result.

A meta-model of rules arranging and of performance systems running by the product, as well as its application to the designing is used for the control. Figure 2 suggests an entities

control model [19].

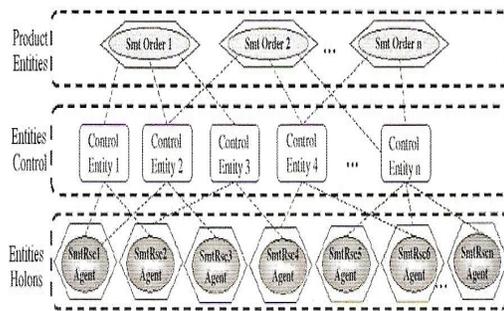


Fig. 2 Entities control model

The solution proposed in this paper consists in:

- the econometric modelling of manufacturing system;
- the econometric modelling of each element in the structure of a manufacturing system and in using the resulted models for building a global model of the product requested by the customer under the assumption that the product will be manufactured by means of that manufacturing system;
- using the global model of the requested product in drawing up successive offers during negotiations;
- using this model for drawing up optimal part programmes related to the manufacturing operations to be performed by the machines that make up the manufacturing system.

This paper presents a method of econometric modelling of the manufacturing machines which is based on the machine operation monitoring, the collected data storing and an analytical model building meant to describe the machine economics. It also presents the construction model of the global model of the requested product as well as the way of using this model.

## 2. ECONOMETRIC MODELLING METHOD PROPOSED

At the conceptual level, the proposed method consists in monitoring and recording the relevant state variables of the manufacturing machine in a data base.

Then the causality relationships between parameters are identified. Based on these relationships, clusters of independent variables are established. Further on, based on the input data to be fed into the model for interrogating it, a cluster of neighbouring states is made up, at the centre of which there is the state to which the respective input data are related.

Finally, a linear model whose variables are the variables of one of the clusters of

identified variables is fitted on the states cluster. The model interrogation will consist in the calculation of the sought variables, depending on the input data that describe the current state of the machine. These input data are the ones which have been previously considered in the procedure of enclosing the states cluster.

It can be noted that, according to the method proposed, the model construction and its operation are accomplished within an integrated algorithm which is run through upon each interrogation of the model.

At the operational level, the variable clustering is based on using the “best model” facility which is offered by the neural networks technique applied to a data set recently obtained from monitoring the model. The state cluster construction, the linear model is fitted to, first implies the use of the 2<sup>nd</sup> rank Minkowski distance for the classification of states, in the increasing order of their distance to the state the data set to be used in interrogating the model belongs to. That is why only the variables representing these input data will be considered in the calculation of Minkowski distance.

The states cluster is to be obtained either by restricting the value of the distance or by restricting the number,  $k$ , of retained states or using these two conditions. The construction of the mathematical model is made by linear regression. It can be noted that this is a local model, as it is only valid in the vicinity of the linking state by means of which the model is interrogated, that this model is meant to be used just once as, after the interrogation, we give it up.

## 3. SIMULATIONS AND DISCUSSIONS

During the experiment, first the data resulted over the last 6 months have been collected, with regard to the manufacturing machines that had been used for manufacturing some important parts in the construction of dump truck bins, namely the attachment plate of the supplementary chassis of the dump truck bin. Data regarding the actual work times, data referring to the modes of operation, data regarding the amounts of resulted wastes, data regarding all types of consumption, as well as data regarding the orders for delivered products were collected.

The case study under consideration is the one where the customer has requested an offer referring to both the manufacture of the part named “Attachment plate of the supplementary chassis of the dump truck bin” shown in figure

3, and to its welding onto the supplementary chassis of dump truck bins.

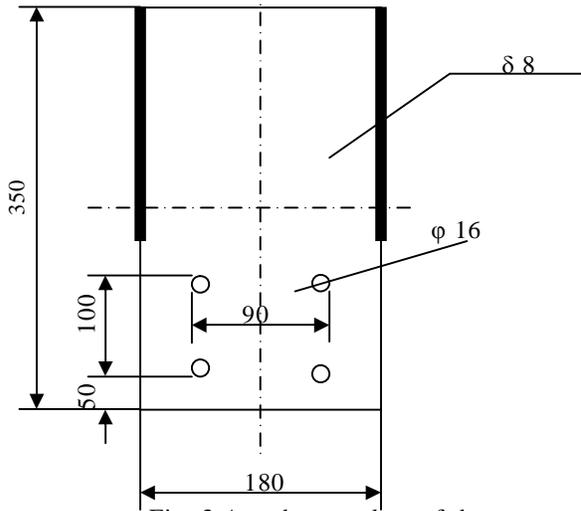


Fig. 3 Attachment plate of the supplementary chassis of the dump truck bin

The number of ordered parts is 80 and the total time for making them is 4.87 hours. The part will be welded on a length of 2x175 mm to the supplementary chassis (three-layer tee weld according to the drawing). The material to be used for making the parts is OL 37.

For the purpose of performing these operations, we will describe the technological flow along with the required processing, tools, equipment and devices to be used and we will present the resulted data hereinafter:

Cutting to dimension from the semi-

finished product:

- a - cutting to the length of 2x350 mm
- b - cutting to the width of 2x180 mm

Equipment: Plasma jet cutting equipment PLASMA Jackle

Verifying tools and devices: Plasma nozzle 1.5 to 1.7;

Compressed air; Acetylene

- 1) Drilling holes having the diameter of 16.4 mm a - drilling one hole after another
- b - positioning for every hole

Equipment: general purpose drilling and milling machine FUS 32

Verifying tools and devices: 16 mm diameter drill

- 2) Weld on the length of 175 mm on both sides, on the

- a - positioning and fixing
- b - 4-pass tee weld

Equipment: welding equipment MAG Jackle

Verifying tools and devices: wire of 1.6 mm.

In order to succeed in demonstrating the viability of the solution to the problem of continuous identification and of adaptive and optimal running of the holonically modelled manufacturing systems, a practical data base resulted from process measurements was obviously required.

For this, some determining, measuring and monitoring of the cutting-off, drilling and welding processes were made, whose results are summarized in the following table, as an example (see Table 1).

For the experimental implementation of the modelling method proposed, an IT product was developed and designed in the Visual FoxPro programming environment, using the function

Table 1

Table Item nr.	Type of material	Type of weld	Length of welding seam	Number of passes	Amperage (A)	Rate of welding (mm/sec.)	Amount of welding wire (m)	Number of pieces	Welding time (sec.)	Power consumption (kW/h)	Cost of operation (RON)	Amount of wastes (Kg)
-	v1	v2	v3	v4	v5	v6	v7	v8	v9	v10	v11	v12
1	OL 52	Tee	501	3	200	10,2	4,2	63	1375	10,52	3.156,29	15,78
2	OL 52	Tee	562	2	198	9,2	5,25	43	3075	5,31	1.611,06	8,05
3	OL 42	Tee	498	10	185	8,2	3,25	57	3705	29,17	9.461,99	47,30
4	OL 42	Tee	589	9	211	10,25	6,2	92	3467	57,16	16.256,3	81,28
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libraries in Matlab and C++.

The simulation implies two data input sequences: a sequence referring to entering the customer’s requirements and the second sequence referring to entering the work restrictions.

Between these two sequences, the distance

calculation sequence, according to the above-mentioned, as well as its comparison to a minimum distance previously established are inserted, so that the values of the variables could concentrate into a vicinity of the values of the customer’s requirements.

Thus, a table arranged according to the

	V1	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	Dist.comună
OL 37	345,00	13,00	204,00	9,15	4,85	59,00	10256,00	29,990	8820,499	44,102	23,388	
OL 37	382,00	7,00	205,00	10,20	5,55	94,00	10956,00	28,627	8378,533	26,294	35,057	
OL 37	390,50	4,00	207,00	9,20	5,60	70,00	7732,00	12,574	3644,666	18,223	41,716	
OL 37	401,00	10,00	204,00	8,20	5,45	73,00	4011,00	33,176	9757,666	48,788	51,827	
OL 37	400,50	13,00	198,00	5,15	6,20	93,00	3877,00	53,262	16140,149	80,701	52,917	
OL 37	401,00	9,00	197,00	6,75	5,05	94,00	7291,00	37,128	11308,199	56,541	53,123	
OL 37	400,50	15,00	199,00	1,20	4,15	63,00	8201,00	41,842	12615,749	63,079	54,408	
OL 37	382,00	5,00	192,00	8,20	3,95	28,00	6758,00	5,704	1782,666	8,913	61,066	
OL 37	301,50	13,00	211,00	5,25	4,95	43,00	8201,00	19,756	5617,949	28,089	61,662	
OL 37	437,00	9,00	203,00	10,20	7,10	132,00	5301,00	58,549	17305,199	86,526	101,479	
OL 37	455,00	4,00	215,00	7,20	6,05	55,00	5432,00	11,956	3336,666	16,683	107,935	
OL 37	475,00	9,00	189,00	9,25	4,15	65,00	9245,00	29,177	9262,499	46,312	125,996	
OL 37	476,50	7,00	197,00	10,20	3,75	63,00	3404,00	22,998	7004,549	35,023	127,672	
OL 37	476,50	4,00	215,00	8,10	5,35	123,00	5643,00	28,002	7814,599	39,072	133,609	
OL 37	499,00	10,00	196,00	10,20	3,95	77,00	4011,00	41,838	12807,666	64,038	149,151	
OL 37	499,00	6,00	209,00	11,25	5,15	90,00	4251,00	31,287	8981,999	44,909	149,349	
OL 37	503,50	9,00	204,00	5,10	4,85	103,00	6758,00	52,898	15558,149	77,791	155,294	

Fig. 4 Table arranged according to the shortest distances

shortest distances, having values under 160 and 17 recordings, results. Thus, the state cluster around the input data the linear model will be fitted to is built (Fig. 4).

The performance of modelling consists in the fact that, using a dedicated data set, the method has been tested by comparing the values of the state variables obtained by interrogating the model to the measured values of those variables.

The modelling errors were within a tolerance range of -15% to + 15%.

Also, the use of the econometric modelling method for the optimal running of the three manufacturing machines making up the manufacturing system related to the item called “plate” has been simulated.

The target function was the cost and the restriction enforced was the total duration of manufacturing the batch of 80 parts.

The optimization had the distribution of the total duration of 4.87 hours to the three operations as its variable and the following five cases were considered (see Table 2).

Table 2

Item nr.	Time allotted for the welding operation (sec.)	Time allotted for the cutting-off operation (sec.)	Time allotted for the drilling operation (sec.)	Total time (sec.)
1	9.500	5.500	2.500	17.500
2	9.000	7.000	1.500	17.500
3	8.500	6.500	2.500	17.500
4	8.000	7.500	2.000	17.500
5	7.500	6.000	4.000	17.500

Figure 5 presents the results which have been obtained after running the algorithm.

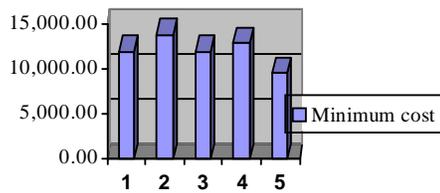


Fig. 5 Histogram of the cost of a part manufacture depending on the time distribution model

#### 4 Conclusion

The method proposed has the advantage of being applicable to any manufacturing machine, regardless the physical nature of the process and the product features.

Furthermore, the result of applying the method is not significantly distressed by the inherent modification of the behaviour of the modelled machine in the long run.

The method provides the extended modelling of the manufacturing machine. The level of extension is only limited by the number of the monitored state variables.

The level of the modelling accuracy satisfies both the exacting requirements specific to a contract negotiation and the ones specific to the operational management.

The implementation of the method implies the implementation of an adequate informational system and the completion of the CNC systems with new facilities by comparison to their present-day versions.

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