Management and Adaptive Control of the Manufacturing System

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Abstract: Competitiveness fully and synthetically characterizes the viability of an enterprise. In the economics literature competitiveness is analyzed in particular in economic and managerial terms with almost no insight into the analysis of the technology role in ensuring and developing competitiveness. Hence the need for manufacturing systems based on behavioral modeling and online learning. The behavioral approach is based on a continuous awareness of the situations and decisions in real time on activities. Thus it can provide solutions to make manufacturing systems develop and be competitive. From theories of knowledge and complexity, we can design a flexible system that will lead to manufacturing processes, flexibly responding to any environmental demand. The behavioral management is characterized by the ability to perceive the environment, to take decision in time, as a result of interaction, with no specific procedures. The system environment provides online data on the actions undertaken which, properly analyzed and correlated, will further generate solutions in order to develop said system and make it competitive. The paper aims, in the field of manufacturing technologies, at approaching issues of manufacturing systems, in order to develop a new concept of management, which is in line with the current market dynamics: the concept of competitive management. The concept of competitive management can offer solutions even to make competitive and develop enterprises as a whole.

Key-Words: competitive management, manufacturing system, competitiveness, online learning, adaptive control, technical-economical characteristics of manufacturing system

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1 Introduction

On worldwide plan, enterprises are confronted with a dynamics more and more an accelerated the unpredictable changes. This is influenced by the technical and scientific progress, dynamic requirements of the customers, science of management and economical economy. These changes enforce an aggressive competition to the global scale what assume the requirement of a new equilibrium between economy, technology and society. To this challenge, the scientific community proposes to answer with a paradigm: Knowledge-based Economy. From theories of knowledge and complexity, we can design a flexible system that will lead to manufacturing processes, flexibly responding to any environmental demand. The behavioral management is characterized by the ability to perceive the environment, to take decision in time, as a result of interaction, with no specific procedures.

The characteristic aspects of the present-day market, in particular case of mechanical components market, are the following: i) continuously decreasing of the current orders, leading to the design of small series production; ii) strong tendency to personalize the products leads to a pronounced diversity of shapes, sizes and other characteristics of the mechanical components required on the market; iii) flexibility, responsiveness and especially an efficient system management tend to become the characteristics that determine competitiveness on the market of components manufacturers and mechanical constructions. The current dynamics of the industrial and business environment is the great global challenge which must be faced.

In literature, an enterprise is a competitive on a certain the market when it obtains certain economic indicator: encipher of business, profits, segments of the comparable market with one have another competitors. Thence, it follows at the current level the
competitiveness is defined by the economical factors and indicators obtained and is more a suggested notion than a numerical evaluated. Don't exist, in this moment, defined an algorithm for the evaluation technical-economical competitiveness, because the factors of technical nature don't take in consideration for the definiteness of competitiveness, although the consumptions and the necessary expenditures of technological process are new generated by technical actions. This in context, the competitiveness notion gets new valences, it gathering factors and which politics determine just the capacity of the enterprises dealt a favorable place on the market, kept that place and of improve continuously the position. The competitiveness characterizes synthetically and complete viability of the enterprises.

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.

One of the responses which can be given to this challenge is to increase its responsiveness by continuously reconfiguring the manufacturing systems in compliance with the task to be carried out. In order to make this happen, manufacturing systems are either for general purpose or reconfigurable.

According to the literature, a company is competitive on a certain market when it succeeds to reach, up to an acceptable level, some economic indicators: turnover, profit, market share comparable or superior to that of other competing companies acting on the same market.

Many approaches to the problem of competitiveness [2] show that, today, competitiveness is defined by the economic factors and indicators obtained and is more a suggested notion than a numerically evaluated one.

The indicator of performance proposed in this paper, for the modeling of these systems, is to be both holistic (in the sense that it takes into account not only the economical but also the technical performance) and synthetic (in the sense that it reflects key aspects of the manufacturing system functionality, namely those that are closely related to the reason for which they were created).

In the context of the competitiveness considered an indicator, both holistic and synthetic, of the technical-economic performance and is used as a criterion for the modeling of manufacturing systems. This paper refers to the manufacturing system management/control, so as to maximize their technical and economical performance. So in other words, to maximize the economic performance of manufacturing system through adequate selection of task assigned.

In the paper it is proposed an algorithm for the economic & technical rules identification and it is presented its application for a drilling process.

The KDD (Knowledge Discovery from Databases) is applied for determines the rules of the drilling process that are further used in the technical-economic model as input data. KDD consists in identification of the clusters of the process parameters that are connected to the other clusters of the market environment.

The aim of modeling is to maximize the economic performance of a manufacturing system by selecting a suitable task assigned.

2 Problem formulation

The manufacturing system performance depends on how it is manage. In order specialized papers, reference is made to the relationships between the process parameters and the technical performance of the manufacturing system (purely technical aspects), while in others, references are made to the relationship between the product made by the manufacturing system and the market (economic relations).

In the literature no attempt to approach the whole manufacturing system – market assembly is reported; therefore, there are significant resources to improve performance which are not used because the technical and economical 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 technological systems-components of the manufacturing system and tools of economic management of the relationship between the enterprise as a whole and the market [1], [3].

The interaction between the economical environment and the manufacturing system is a major source of knowledge about the economic environment and the manufacturing system themselves.

The manager of an enterprise is in the situation that has to make a quotation of price for elaborate an offer in order to negotiate.

Thus, the question that occurs is: how competitive is the product on the market?

To answer at this question, the manager is obliged to establish a link between task and performance or profit of manufacturing system in order to negotiate the contract. The link between task and performance
is built on a mathematical relationship, using datasets, created by the manufacturing system, in situations similar but not identical. In other words, knowing this relationship, the manager will make control based on competitiveness (performance) of manufacturing system and will negotiate the contract in effective terms.

Adaptive control of the manufacturing system occurs when must be obtained a batch of parts in certain circumstances: time, cost, etc. In this case, the mathematical model have to be modified, so to respect the requirements and will modify process parameters. Well, another set of data known, is a new mathematical model (another relationship task-performance) with other process parameters in order to see how to change the behaviour of manufacturing system.

The problem is the following: giving a batch of parts to be manufactured, in terms of working time required and a minimum cost, to evaluate the process parameters to assure compliance (achievement) of these conditions.

3. Manufacturing system competitiveness

In order to survive in the present-day complex and unpredictable environment, the company must feature abilities of quick response and favourably reposition itself on the market. Acquisition and preservation of this capacity is the most difficult step for companies as it involves many endogenous and exogenous factors and the process is continuous, dynamic and hardly predictable. In this context, three elements are highlighted by their relevance: competitiveness, the manufacturing system and the knowledge system.

According to the literature, a company is competitive on a certain market when it succeeds to reach, up to an acceptable level, some economic indicators: turnover, profit, market share comparable or superior to that of other competing companies acting on the same market. Many approaches to the problem of competitiveness [4], [5], [6], [7], [8], [9], [10], [11] show that, today, competitiveness is defined by the economic factors and indicators obtained and is more a suggested/induced notion than a numerically evaluated one. In the world there are prestigious competitiveness research centres, such as: Center for International Development-USA Harvard University, European Institute of Technology with its research center in Cambridge, Geneva, Oxford and Organizational Competitiveness Research Unit of Sheffield University Halle-UK which deals with competitiveness at the global, regional down to enterprise/company level.

However, approaches are of economic and managerial nature, while the relationship with the technical aspects of competitiveness is less noticeable. At this point there is no defined algorithm to evaluate the technical and economic competitiveness, moreover, the technical factors are not considered at a practical level, when defining competitiveness, although consumption and costs incurred by the technological processes are generated by technical actions. In this context, the notion of competitiveness gains new valences, including factors and policies that determine the ability of the enterprise to get a favourable place on the market, to hold that place and continuously improve its position. Only in this way can competitiveness fully and synthetically characterize the enterprise viability.

In the paper, competitiveness will be understood as the capacity (potential) to provide performance (compared with other similar elements), in a very punctual way, within a macroeconomic concrete context and at a certain time. Moreover, according to a meter of competitiveness (considered as an essential performance indicator) it will be assessed the extent to which the company achieves the purpose for which it has been created. Therefore the paper aims at making a numerical and on-line evaluation of the technical-economic competitiveness and the management of the manufacturing system is performed to obtain maximum competitiveness.

The manufacturing system performance depends on how it is run. In more specialized papers [12], [13], reference is made to the relationships between the parameters of the processing regimes and the technical performance of the manufacturing system (purely technical aspects), while in others, equally numerous [14], [15], references are made to the relationship between the product made by the manufacturing system and the market (economic relations).

In the literature no attempt to approach the whole manufacturing system – market assembly is reported; therefore, 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 technological stems-components of the manufacturing system and tools of economic management of the relationship between the enterprise as a whole and the market [9], [10].
Nowadays, the manufacturing systems are controlled by means of numerically programmed machine tools which are part of the system [7], [8]. 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 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 [6].

4 Control algorithm

Control algorithm is based on a numerical model, generally and temporary. Parameters values of casuistic model are determined by “K-nearest neighbour” method, by analyzing a database obtained by experiments.

The manufacturing system behaviour is changing in time for each batch. This change implies modification of both the model parameters and the causal relations between the model variables. Generally, for an adaptive control system the model structure remains unchanged but the parameters of the model are changed in order for a better modelling of the reality.

The proposed algorithm consists in the following steps from figure 1.

1. For each processing batch of parts be monitored the parameters of interest (table 1);
2. Monitored data are stored and form dataset for each processed batch of parts;
3. System identification consists in selection of all variables groups that could have causal relation and which includes the variable of interest. For each variable group;
4. By means of the obtained mathematical models are estimating the process parameters values to manufacturing system to realize the batch of parts in accordance to imposed requirements.

Fig. 1 The proposed control algorithm

The market dynamics is further passed to the mode of operation and management. In a knowledge-based society and economy, operations such as determining the relevant information and aggregating them into pieces of knowledge must be automated, because in such a complex and unpredictable environment, they are indispensable tools for creating, searching and structuring knowledge. The interaction between the economic environment and the manufacturing system is a major source of knowledge about the economic environment and the manufacturing system themselves [12].

Table 1 - Example of experimental data regarding the process variables collected for the drilling process

| Item nr. | Type of material | Hole diameter (mm) | Number of holes | Drilling speed (mm/s) | Drilling feed (mm/rot) | Number of pieces | Machining time (s) | Energy consumption (kwh/operation) | Cost of operation (Euro/operation) | Waste quantity (Kg) |
|----------|------------------|--------------------|-----------------|----------------------|------------------------|------------------|-------------------|-----------------------------------|----------------------------------|-------------------|
| -        | V₁               | V₂                 | V₃               | V₄                   | V₅                     | V₆               | V₇                | V₈                                | V₉                               | V₁₀                |
| 1        | OL 52            | 12,5               | 3                | 1,1                  | 0,7                    | 70               | 7242              | 6,04                              | 0,026                            | 13,12              |
| 2        | OL 42            | 15,55              | 5                | 4,1                  | 0,3                    | 28               | 12033             | 3,76                              | 0,0268                           | 13,54              |
| 3        | OL 42            | 11,6               | 5                | 2,05                 | 0,25                   | 59               | 6255              | 4,41                              | 0,0315                           | 15,87              |
| 4        | OL 42            | 25,6               | 2                | 5,05                 | 0,35                   | 104              | 3404              | 37,86                             | 0,108                            | 54,52              |
System identification implies the following steps:
Step 1: clustering of variables based on the causal relationships;
Step 2: states clustering;
Step 3: building of the mathematical model corresponding to the states cluster and variables cluster set.

Then the causality relationships between parameters are identified. Based on these relationships, clusters of independent variables are established. Further, based on the dataset to be used for the model fitting, a cluster of neighboring states is made up, at the centre of which 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 manufacturing system states cluster. These input data are the ones which have been previously considered in the procedure of enclosing the manufacturing system states cluster.

It can be noted that, according to the proposed method, the model construction and its operation are accomplished within an integrated algorithm which is run through upon each interrogation of the manufacturing system model. At the operational level, the variable clustering is based on the “best NN model” facility which is offered by the neural networks technique applied to a data set recently obtained from monitoring the manufacturing system. The states cluster construction, the linear model is fitted to, first implies the use of the 2nd rank Minkowski distance for the classification of states, in the increasing order of their distance to the state to be used for model interrogation.

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 valid only in the vicinity of the state for which the model is interrogated. This model is meant to be used just once as, after the interrogation, it is given up.

In conclusion, the aim of proposed method is to maximize the economic performance of a manufacturing system by selecting a suitable task assigned. This means, to maximize the effect, using the works of the manufacturing system that bring the greatest profit. Criterion which will be used for modelling the competitiveness of manufacturing system is the profit rate, \( p \), (rel.1) (performance of the manufacturing system), because the profit rate strongly depends on the product characteristics.

\[
p = \frac{(\text{cost} - \text{price})}{\text{time}}
\]

For construction of the task-performance model, which describes the interaction between manufacturing system and market, we achieved the task-cost manufacturing operation model and the task – market model (fig.2).

![Fig. 2 The interaction between task - manufacturing system and between market - task](image)

The method proposed for achievement of the three models consists in monitoring and recording the relevant state variables of the manufacturing system in a database.

5. Developing the competitive management algorithm to be applied to the manufacturing of mechanical constructions

By applying the concept developed to the mechanical construction manufacturing systems, the competitive management algorithm for these systems shall be developed. The block schedule on which the competitive management algorithm is based is illustrated in Figure 3.

The manufacturing system receives contracts after the tenders (competitions) generated by the market offer quotations. The competitive management system means competitiveness assessment, and based on it, an intervention on the manufacturing system through instructions regarding the progress of the manufacturing process in order to obtain maximum competitiveness. On the other hand, after assessing competitiveness, the management system should enable to develop competitive bids for the tenders. To achieve these two objectives, the competitive management system makes use of reinforcement learning to get to know the market and the non-supervised on-line learning technique to get to know the manufacturing system.

The behavioural system modelling is to be achieved, based on which the company management...
may intervene in order to elaborate the necessary instructions to adjust the technological process and elaborate the management policies.

![Algorithm of competitive management](image)

**Fig.3. Algorithm of competitive management**

Following each line of the competitive management algorithm in Figure 3, the following can be noticed:

i) the algorithm for modelling the relationship market-manufacturing system implies using the database from the economic environment (auctions), extraction of knowledge through data mining and model elaboration by reinforcement learning techniques;

ii) to obtain the concrete indicators of competitiveness, database from the competitive environment shall be provided and knowledge shall be extracted in order to assess competitiveness;

iii) the market offer quotations enters the competitive environment to generate the contracts for the manufacturing system;

iv) the modelling algorithm of the manufacturing system is designed starting from the contract specifications and system identification.

Using data mining techniques, data sets on the functional and economic parameters shall be obtained to be further used to obtain the model of non supervised learning techniques.

Based on the above learning processes the behavioural modelling of the manufacturing system - market assembly and the management system implementation are achieved. The manufacturing system receives instructions on the development of the manufacturing processes in order to achieve the maximum level of efficiency (maximum profit).

6. **The advantage of the method compared to the present day methods of manufacturing system management**

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

2. Develop a methodology for mathematical assessment of the technical-economic competitiveness of the manufacturing system;

3. Develop a new concept of manufacturing systems management based on behavioral modeling of the market-manufacturing system assembly and on the implementation of the management to the manufacturing system, which is generally applicable and appropriate to the current market demands;

4. Development of behavioral modelling methods based on non-supervised on-line learning, which enable adaptive-optimal and predictive control of the manufacturing systems;

5. This type of management provides managers: the possibility of rapid price quotations of its products, a software representing the company model and which generates instructions in the progress of manufacturing processes (Fig. 3), the possibility of discovering the 'black holes' in the system and substantiating the investment policies. This new generation of enterprises based on the concept of competitive management will be able to achieve, in an economic environment, customized products at the quality level required by the market.

7. **Simulations and discussions**

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 modelled manufacturing systems, a practical database resulted from process measurements was obviously required.

For this, measuring and monitoring of the drilling process were made, whose results are summarized in the table 1.

Analysis of cluster is a descriptive technique used for grouping similar entities from a data set or equally for entities that present evidence substantial differentiation from the group. Clustering techniques in clusters is based on algorithms from the neural networks.

*Clustering variables* consists in grouping variables which are variables in dependence. Thus using "best NN model", the choice of many consecutive columns and determination of the best links with the 1, 2 or i variable we determine the cluster of
variables which are in the best relationship of dependency. For example, in table 1, considering the drilling process variables that denote the $V_1$, $V_2$, ..., $V_{10}$ and using the “best NN model” facility, results the column $V_3$ - time of drilling, as the most influential variable in determining the cost of operation. There are the best relationships with dependent columns $V_3$ and $V_5$.

**Clustering states:**

Suppose that the manufacturing system is required to execute an operation that $V_3 = 4$, and $V_5 = 0.6$, where you don’t find in our experiment.

Clustering states consists in identifying groups of related records that can be points of departure for further exploration of relationships. In the process of grouping elements is necessary to estimate the minimum distance between those elements with the function:

$$d = \sqrt{(V_3 - 4)^2 + (V_5 - 0.6)^2}$$  \hspace{1cm} (2)

The mathematical model

Mathematically can write a linear relationship:

$$V_5 = a \cdot V_3 + b \cdot V_5$$  \hspace{1cm} (3)

Retaining the first 2 states, so for $k = 2$ according to K-NN algorithm can be written:

$$\begin{cases} a \cdot 4 + b \cdot 0.55 = 4645 \\ a \cdot 4 + b \cdot 0.65 = 2410 \end{cases}$$  \hspace{1cm} (4)

which represents a system of two equations with two unknowns. Finding system solutions are obtained the values for $a$ and respectively $b$ which are replaced in the relationship (3) resulting relationship (5).

$$V_7 = 4234.375 \cdot V_3 - 22350 \cdot V_5$$  \hspace{1cm} (5)

Linear model so determined will be used in modelling task-cost relation ship. This is a local model, that is only valid in the vicinity of the state in connection with which it is interrogated and ephemeral because after the query is dropped. Taking the reasoning again we modelled the relationship between task and price. In this case we found that the influence variable is variable $V_9$, using "best NN model". Similarly on determine:

$$V_9 = 13285.68 \cdot V_3 - 80378.5 \cdot V_5$$  \hspace{1cm} (6)

If consider the price of a constant value that is 20% more than the average cost, we can express the profit rate for each task using relationship (1).

Returning to the our example above, the $V_3 = 4$ and $V_5 = 0.6$, it follows the same steps as in modelling relationships: cost-task and task-price and obtain a mathematical relationship to m odel task-performance, taking the influence variable, $V_8$

$$V_8 = 55.35 \cdot V_3 - 334.9 \cdot V_5$$  \hspace{1cm} (7)

In conclusion, if we introduce variations of the process parameters and a variable restriction we can get a table of solutions that will help to find common solutions through negotiation between the customer's requirements and possibilities of economic and technical producer.

8. Conclusions

Note that we propose to give managers a model so that they can interact with the economic environment (market). Practically, this happens before the actual work of manufacturing system, so we have to do with a function of anticipation. The proposed method has the advantage of being applicable to any manufacturing system, regardless of the physical nature of the process and the product features. The method provides the extended modelling of the manufacturing system.

The level of extension is only limited by the number of the monitored state variables. The level of the modelling accuracy satisfies both the requirements specific to a contract negotiation and the ones specific to the operational management.

The developed algorithm allows the identification of the variables of one model that represents the relation between the output and the input model. This relation represents a technical-economic model that can control a manufacturing process without experiments and based on the extraction of the knowledge from the previous experience.

The obtained mathematical model is used for the manufacturing system control, namely, to check its performances. The adaptive character of the manufacturing system control, namely, to check its performances. The adaptive character of the manufacturing system control is given by the change in the performance of the model depending on the customer requests.

The proposed method consists in determining of the causal relation between one controlled variable and the monitored variables and then predicting its value in order to realize adaptive control of the manufacturing system.

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