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ESTIMATION OF COMPONENTS COST BY COMPARATIVE ASSESSMENT METHOD IN THE CASE OF BEARINGS WITH INTERCHANGEABLE CONSTRUCTION

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Abstract: *Cost reduction strategies have been developed and implemented considering the usage of raw materials in a sustainable manner. For their implementation, suppliers need to develop products and processes which assure raw material and lead time savings, on one side, and maintain the quality, on the other side. Hereby, it becomes important, in bearings case too, that spare parts are available, and the replacement process is fast. To satisfy the customer requirements, the producers have designed and produced bearings with interchangeable construction. This study presents a comparative analysis of data concerning a new order, relative to the already completed ones, by the Comparative Assessment Method, for rapidly delivering the needed quotation. The database was collected from the industrial environment.*
Key words: *interchangeable components, comparative assessment, causal modeling, industrial database, key features.*

1. INTRODUCTION

In the last years, the cost reduction strategies have been developed and implemented considering the usage of raw materials in a sustainable manner. To be able to implement these strategies, the customers ask on their supply chain that the suppliers develop products and processes which assure the savings in raw material consumption and lead time on one side and maintain the quality, on the other side.

In addition to the quality and variety of the product, flexibility, shorter processing time and high level of compliance with delivery deadlines, efficient, effective, and continuously optimized manufacturing processes have become essential factors for success on the market.

To be competitive in the actual global economic context, the requested quantity of products must be delivered by the companies at the requested time.

In make-to-order environments that work only in response to the customer's orders, manufacturers should offer the best price and delivery time for maximizing the profits, [1].

Bearings are one of the most important components used in almost all industrial fields, such as: railway automotive, aeronautical, machine-tools construction industries, as for other dedicated applications.

A bearing in standard construction contains the following basic components as: *one outer ring*, *one inner ring*, a number of balls or rollers and a plastic, metal sheet or brass *cage*, [2].

In Fig. 1 can be observed a radial roller bearing with interchangeable inner ring.

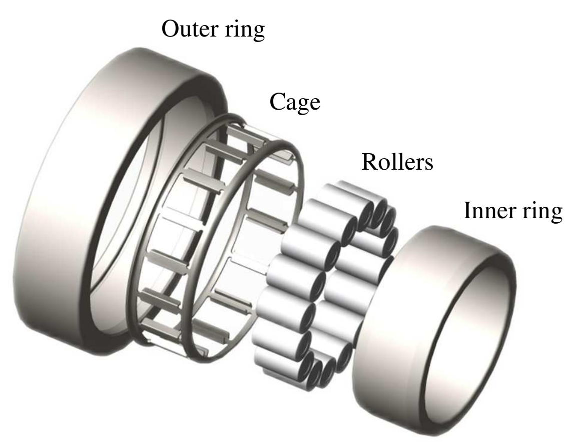

Fig. 1. Radial roller bearing with interchangeable inner ring

Also, some bearings have rivets in their construction. Considering the impact of the bearings on the functioning of the system or machine, the bearings are designed and controlled in order to assure the high carrying capacity and safety performance, [3]. Using some results from bearings production, collected in a database, the manufacturing cost was estimated in [3] by using a couple of procedures, namely: *causal identification* and *comparative assessment*.

For example, the bearings are used in railway industry in case of *i) locomotives* (axles settings of electric and diesel locomotives, traction motors and generators including electrically insulated bearings, transmissions, compressor motors, fans motors, the drive of blowers' exciters, and charging dynamos of electric and diesel locomotives) and *ii) train sets and wagons* (bearing unit for passenger transportation, axle boxes and roller bearings for passenger cars and freight wagons).

Contact fatigue, internal clearance, corrosion, and contamination of the lubricating oil can cause bearing failures. Generally, failures show up as imperfections in the ball race, in the ball/roller or in the retainer, [4]. Another important defect is that the crack of the components. To avoid these defects, the producers use non-destructive testing methods such as: Ultrasonic testing, Eddy current method, magnetic powder inspection. These control methods and also visual and dimensional checks are performed for any bearing component, even the bearing is delivered as a complete product, or the components are delivered separately in case of an interchangeability construction of a bearing.

The interchangeability of the inner or outer ring according to the application requests give the advantage that the cost for the spare part to be decreased. Bearings producers should estimate the production cost for the independent rings and sale these components individually.

The existing cost estimation methods can be divided in two categories: *i) quantitative methods* (based on an analysis of the product design and the corresponding processes) and *ii) qualitative methods* (based on developing a comparative analysis of the new product with historical products to identify their similarities), [5], [6]. Numerous challenges in cost estimations were identified by the many authors in their research papers.

A methodology and a model for cost estimation, in the case of a new product by relative comparison between the characteristics of that new product and the characteristics of a standard product it is presented in paper [7]. An economic model to identify the lower-cost option has been developed in [8], comparing the cost of traditional and selective assembly. An alternative method, which capitalized on the emerging topic area of topological data analysis to select the important variables was presented in paper [9]. These selected variables are subsequently used in linear and non-linear prediction models. A new selective assembly method is proposed in [10] to minimize the clearance variation and surplus parts for a complex assembly which consists of the components piston, piston ring. In this assembly, each component has more than one quality characteristic contributing for the assembly, for e.g., piston diameter will assemble with cylinder inner diameter; piston groove diameter will assemble with piston ring inner diameter. In paper [11] different techniques (qualitative and quantitative) developed over the years, for estimating product costs are detailed. A different approach regarding the comparative assessment is suggested in [12]. This approach consists in the assigning rankings to potential alternatives, by referring them to past cases recorded in a database. This approach is easy to apply and flexible in manufacturing activities, not being specific to the ranking criteria such as cost, timespan, consumed energy etc. The authors investigate in paper [13] a new cost estimation model throughout the lifecycle of a product, especially at the conceptual design phase. This new model is built on top of three functional sub-models: *feature-based association mapping* (to determine feature scope and cost level defined), *data mining* (to identify correlations among tangible data, intangible data, and human inputs for cost estimation), and *semantic modeling* (to map the cost feature attributes with other predefined features – design and machining features).

During last years, costing and calculation methods have undergone important changes so that they can provide accurate information in the shortest possible time. Improving the cost calculation methodology by introducing some modern methods does not represent only the application of a sequence of technical operations, but specifically aims to support the management decisions. These modern calculation methods [14], adapted to advanced industrial technologies, have become alternatives to the classic calculation methods [15], applied in companies.

In this paper, we present a comparative analysis of data concerning a new order, relative to the already completed ones, by the Comparative Assessment Method, for rapidly delivering the needed answer which can be the price of a firm order or the quotation for a customer. The database was collected from the industrial environment.

The comparative assessment method of manufacturing process variants proposes a different approach in performing the evaluation of potentially optimal solutions, based on their ranking criteria that can be, for example, cost, processing time, energy consumed, etc., [16].

The paper is structured as follows: the next section describes the interchangeable bearings components. Section three deals with the comparative assessment method, based on rankings.

An algorithm dedicated to assigning a ranking to a given case is introduced. In the fourth section one can find a case study relying on a database including information recorded from industrial environment (bearing manufacturing sector), illustrating the method application. The last section is for conclusions.

2. INTERCHANGEABLE BEARINGS COMPONENTS

In the actual economic environment, the use of interchangeable spare parts, creates an advantage in front of other competitors.

In bearings manufacturing companies, the use of the interchangeability approach means that the production batch of the bearing components should be produced inside of o designated tolerance field, which assure the fact that the designed clearance can be obtained using for example one inner ring in a peer with a range of subassemblies composed from outer ring, rollers, and cage.

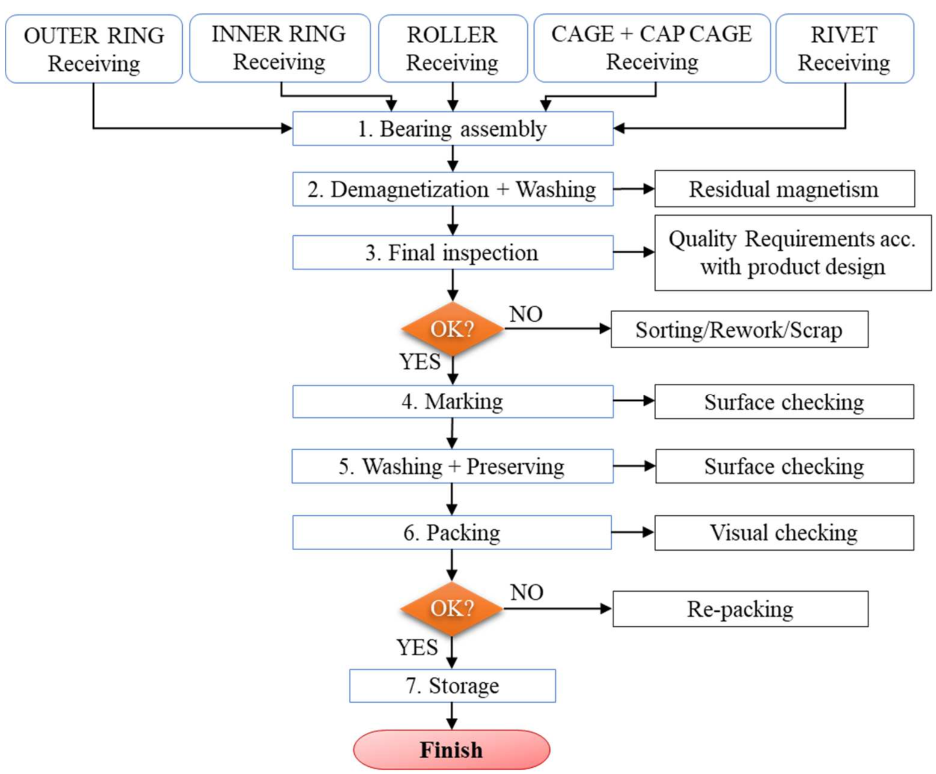

Fig. 2. Production flow diagram.

At the same time, the approach of the parts production in case of the interchangeability requests a dimensional stability inside of the designed tolerances, to ensure the clearance and then a high peering degree.

The designed flow diagrams and then the operation plans or work instruction based on interchangeability approach need to be applied according to peering diagrams. Using the interchangeable parts, the manufacturing process is simplified. The production flow for the assembly process of one bearing with interchangeable components is composed from the steps as described in the flow diagram depicted in Fig. 2.

Regarding the manufacturing cost, the interchangeability approach creates advantage for both customers and suppliers. For customer, the existence of the interchangeability approach means that the supplier could offer only some components in case that the bearing does not achieve the designed lifetime due to some montage or operation environment conditions and the replacement of the entire bearing could cause troubles and supplementary costs. To avoid such problems, the manufacturers came in front of their customers with bearings components that assure interchangeability. This means that the customers pay only the price for the involved component in place of the total cost of one complete bearing.

In the case when during the maintenance cycle the mounting shaft diameter was adjusted, to decrease the radial run-out and/or ovality, to assuring the needed clearance, the supplier can deliver a component with a dedicated inner diameter according to specific customer need, only for the bearings with an interchangeability construction.

To be able to rapidly estimate the cost of the individual component and then to provide a good quotation for potential customers, we propose in this paper a method for comparative analysis of a new order considering the collected data from previous orders or quotations. It is difficult to estimate the cost based on complete bearing calculation because not all auxiliary activities are supposed to be performed in the case of individual components.

3. COMPARATIVE ASSESSMENT METHOD

In this chapter, the **C**omparative **As**sessment **M**ethod (CAsM) of the manufacturing process variants is presented. An innovative approach in the analysis of potentially optimal solutions, based on assigning them rankings is proposed by the CAsM.

The CAsM was designed to assist the decision-making regarding the selection of the optimal options for continuing a manufacturing process, at a certain decision level.

Comparative assessment works based on the establishment of rankings for two or more process variants, according to a specific criterion (such as cost, processing time, consumed energy, etc.).

The assessment in a comparative manner of potential alternatives is performed related to the previous cases parameters which have been registered in the database, [12]. When the value of the criterion is known for all potential alternatives, its evaluation is simple, and the solution of the problem is trivial. The problem is much more complicated when the value of the criteria is harder to find (not to mention the situation of decisions based on the evaluation of several criteria).

The comparative assessment philosophy can be characterized by the enounce: "A set of potential alternatives and a criterion being imposed, the alternatives rankings must be found". Since criteria values are not known, the values of variables causally related to this criterion will be used instead.

Along with the corresponding values of the associated criterion, a set of other variables values is also presumed to be available.

The comparative assessment analysis is performed by keeping in view the following:

- The acceptance for the meaning of the nearness needing to be evaluated between the different cases, assessed on the base of known values of selected effect-variables.
- The nearness function expression must be found by starting from a databased including previous instances.

- The ranking for a given case can be determined by evaluating the nearness calculated relative to other cases from the available data case.
- The possibility of finding successive neighborhoods for the addressed case, with shorter and shorter length, until the assigned ranking is sufficiently precise for making a difference relative to other available cases, [12].

The algorithm according to which the ranking corresponding to a given alternative is assigned, is presented in Fig. 3.

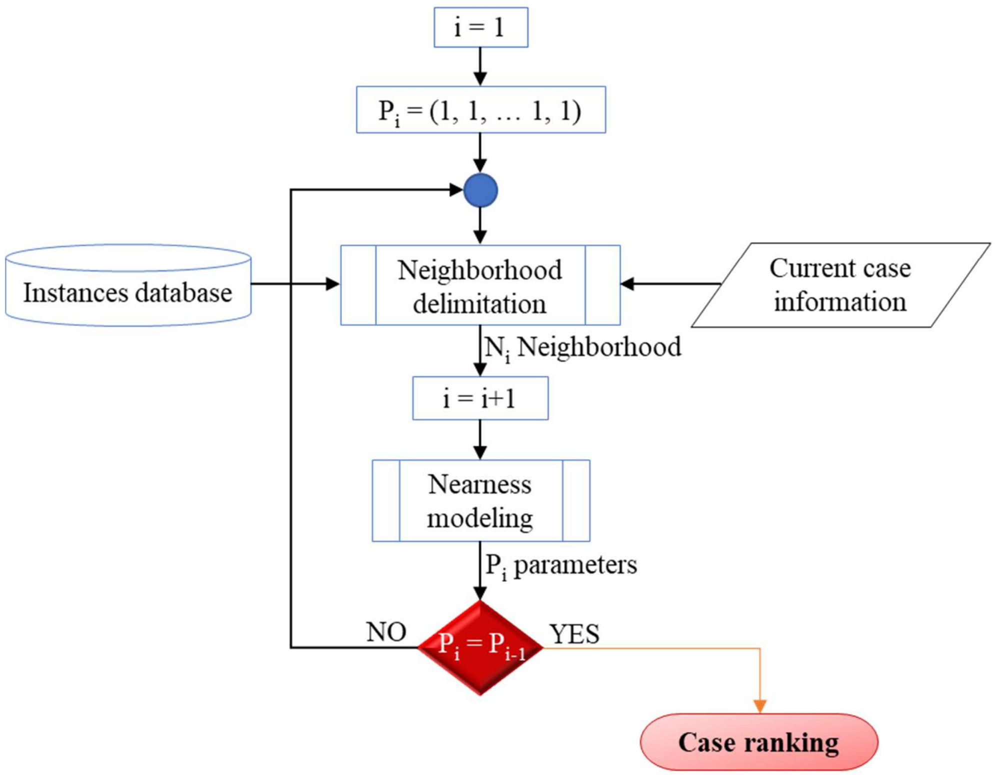

Fig. 3. Ranking assignment algorithm, [12], [16].

A key role in the application of the method is played by the so-called *"nearness function"*, with which the nearness between two cases in assessment. The expression of the proximity function, [12] when evaluating the nearness between the current case and the generic case *k* from database is:

$$d_k = \operatorname{sgn}(x - x_k) \cdot |x - x_k|^{\alpha} \cdot A + \\ + \operatorname{sgn}(y - y_k) \cdot |y - y_k|^{\beta} \cdot B + \cdot \\ + \operatorname{sgn}(z - z_k) \cdot |z - z_k|^{\gamma} \cdot C \quad (1)$$

In which: *sgn* is the known *signum function*; the six parameters can be considered the coordinates of the vector $P = P(\alpha, \beta, \gamma, A, B, C)$, their values resulting from modeling the set of cases considered. The form of the nearness function is determined by modeling a set of cases from the database.

In the here proposed variant, the identification of the nearness function is made based on a set of cases from the database, by determining the values of two parameters for each of the *n* cause-variables considered.

The selection of such a set from the database, meaning a neighborhood of the current case, is made based on the resulting parameter values at the last identification of the nearness function.

The CAsM of the manufacturing process variants is based on two procedures:

i) *The procedure for neighborhood delimitation* and *ii) The procedure for nearness modeling.*

The procedure for neighborhood delimitation - which aims to find a profile of the neighborhood of a potential case through successive comparisons with cases of processes already performed (with known results).

The procedure for nearness modeling - which aims that, after delimiting a neighborhood, the proximity between its instances is modeled to find an improved form of the proximity function. For modeling, we have adopted *nonlinear multiple regression* as the general typology of the proximity function.

The form of nonlinear multiple regression model [12] was chosen according to the proximity function:

$$\Delta T = b_4 \cdot \mathrm{sgn}\Delta x \cdot \left|\Delta x\right|^{b_1} + b_5 \cdot \mathrm{sgn}\Delta x \cdot \left|\Delta x\right|^{b_2} + + b_6 \cdot \mathrm{sgn}\Delta x \cdot \left|\Delta x\right|^{b_3}. \quad (2)$$

The resulting modeling values for the vector of parameters $B = (b_1, b_2 \dots b_6)$ are then transferred to a new form of the vector of proximity parameters $P_i = (\alpha, \beta, \gamma, A, B, C)$ to be further used to delimit a new neighborhood of the current case. The algorithm of the method was implemented in MATLAB.

4. CASE STUDY

A comparative analysis of data concerning a new order, relative to the already completed ones, by the CAsM, for rapidly delivering the needed quotation is presented in this chapter.

The database was collected from the industrial environment in case of the manufacturing process of inner rings which are used in interchangeable radial roller bearings with the profile shown in Fig. 4.

The comparative assessment method was applied in the case of a set of 3 cause-variables, for the interchangeable inner rings, namely: the raceway diameter, *Dr*, the ring width, *W*, and the ring mass, *m*, while components cost *C* was chosen as effect-variables.

Therefore, in the presented situation, the database includes *n* = 100 lines and four columns: three columns for cause-variables, *Dr, W* and m, and the last column - for the effect-variable, *C*.

The values for each cause-variable, as well as those of the effect-variable, were considered as a non-uniform division of the interval [0, 1], randomly distributed, independently generated for each column, scaled and dimensionless.

If the case described by *Dr* = 0.6 mm, *W* = 0.25 mm, *m* = 0.2 kg is considered to be ranked, the pivot Dr_v = 0.5691 mm, W_v = 0.2109 mm, m_v = 0.1843 kg, C_v = 0.1453 RON is firstly chosen. The results of the algorithm iteratively run, for case ranking assignment, are presented in Tables 1 and 2. The modeling has been performed with the help of Nonlinear Multiple Regression tool, available in MATLAB (*Optimization tools* package).

To keep the same neighborhood length, different values for ε parameter were selected at each iteration (here, 21 cases). Using the Root Mean Square Error parameter, the quality of case neighborhood modeling was evaluated.

The algorithm stabilizes rapidly, after only six iterations (the seventh iteration already gives the same results as the sixth). For calculation of the effect-variable (C) value, the relation (2) was used: ΔC = C – Cv = 0.15069, hereby C = 0.00533 and case ranking is R = 30.

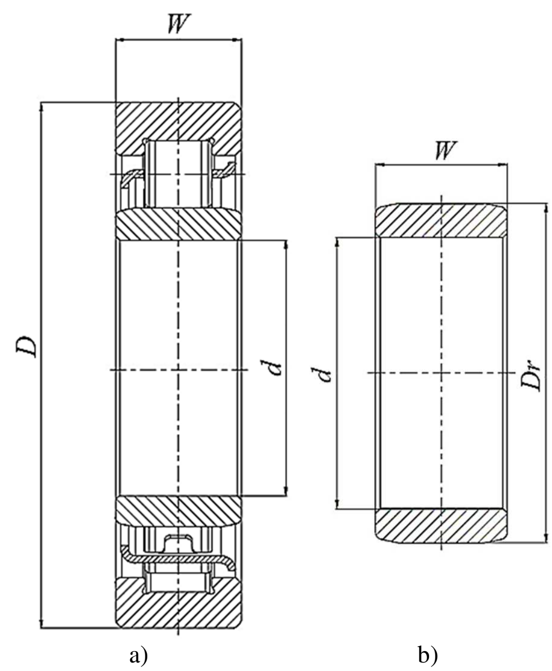

Fig. 4. Interchangeable radial roller bearings profile: a) Complete radial roller bearing; b) Interchangeable component (inner ring).

Table 1

The results of the application of the ranking evaluation algorithm (parameters).

Repetition	A	B	C	α	β	γ	ε	RMSE
1	1	1	1	1	1	1	0.15	0.181
2	0.139	0.095	1.395	1.511	22.814	1.919	0.16	0.17
3	0.008	-0.727	1.669	2.244	30.219	1.889	0.16	0.173
4	-0.899	1.928	37.142	6.525	93.69	2.229	0.1955	0.171
5	-0.647	1.590	6581.7	12.583	107550	4.553	0.35	0.178
6	-0.744	1.790	28.173	6.665	96.124	2.297	0.17	0.178
7	-0.744	1.790	28.173	6.665	96.124	2.297	0.17	0.178

Table 2

The results of the application of the ranking evaluation algorithm (neighborhoods).

The lines in the case database that make up the current neighborhood																					
N_1	2	4	12	15	20	29	34	35	45	54	55	56	64	68	69	70	72	88	95	99	100
N_2	2	12	15	20	34	35	36	53	54	55	56	64	65	66	68	69	70	92	95	99	100
N_3	2	12	14	20	34	35	36	53	55	56	63	64	65	66	67	68	70	92	95	99	100
N_4	2	12	14	34	35	36	53	54	55	56	63	64	65	66	67	68	86	92	95	99	100
N_5	2	12	14	20	34	35	36	54	55	56	63	64	65	66	67	68	86	92	95	99	100
N_6	2	12	14	20	34	35	36	54	55	56	63	64	65	66	67	68	86	92	95	99	100
N_7	2	12	14	20	34	35	36	54	55	56	63	64	65	66	67	68	86	92	95	99	100

5. CONCLUSION

The main conclusions of the presented work are the following:

- In manufacturing, when selecting the best alternative from several potential options, the difference between two cases cannot be assessed according to a single universal criterion (such as the Euclidian distance or, more generally, the Minkowski distance). Instead of this, an appropriate criterion should be used, depending on the specifics of the causal relationship modeled.
- There is a relation of proportionality between the nearness of the analyzed cases and the precision required by the assessment: the greater the nearness, the greater must be the precision.
- CAsM enables to make the difference among a set of analyzed cases by using a minimal initial information and computational effort. The assessment is an iterative process that is completed when the accuracy conditions are fullfilled.
- The Root Mean Square Error (RMSE) has been used as criterion for illustrating the accuracy reached in the neighborhood modeling process, supposed for the application of the CAsM.
- As it was demonstrated in the addressed example, the application of the CAsM is feasible and provides appropriate results.
- Comparative assessment of data concerning a new order, relative to the already completed ones for rapidly delivering the needed answer, which can be the price of a firm order or the quotation for a customer works efficiently. The provided results are truthful and plausible, and they are obtained after a relatively small number of iterations (only six in the case of the set of three cause-variables [*Dr, W, m*]).

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ESTIMAREA COSTULUI COMPONENTELOR INTERSCHIMBABILE ALE RULMENȚILOR UTILIZÂND METODA DE EVALUARE COMPARATIVĂ

Strategiile de reducere a costurilor au fost dezvoltate şi implementate considerând utilizarea sustenabilă a resurselor. Pentru implementarea acestor strategii, furnizorii trebuie să dezvolte procese şi produse care să asigure optimizări ale consumurilor de materii prime, reduceri ale timpilor de livrare şi menţinerea nivelului de calitate. În cazul rulmenţilor, este important să fie disponibile componente ale acestora, ca piese de schimb, rapid de înlocuit. Acest studiu prezintă utilizarea Metodei de Evaluare Comparativă, în cazul unei comenzi noi pentru acest tip de rulmenţi, în raport cu date colectate aferente unor comenzi anterioare, în scopul transmiterii unui răspuns/oferte de preţ către client într-un timp cât mai scurt. Baza de date utilizată a fost construită cu date colectate din mediul industrial.

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