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ECONOMETRIC PATTERNS AND METHODS USED FOR ANALYSIS OF TECHNOLOGICAL INNOVATIONS IN WORKSHOPS AND PRODUCTION DEPARTMENTS EQUIPPED WITH FLEXIBLE MANUFACTURING SYSTEMS

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Abstract: Pursuant to the analysis of the assessment method of the structures of the production process, in the construction of machines, we find that, due to the requirements of diversification of assortments and features of products, criteria of the quality level and work productivity, the reduction of fabrication costs, the structure of the production process develops continuously. Starting from workshops specialized on technological procedures, the structure developed onto production lines in a sole object flow, then onto production lines in a multi-object flow, and, currently, onto flexible production forms.

To this purpose, flexible fabrication cells develop. The latter form develops continuously, but especially after the accomplishment of machine-tools with number command. Thus, we pass from production structures in automatic rigid flow lines, efficient for mass and wide-range production, to flexible structures, especially efficient in low and medium-range production.

Keywords: Analysis, workshops, econometric patterns, flexible manufacturing system

Introduction

For the production of unique pieces, processing is extended on machine-tools with number command, replacing manually operated universal machine-tools. Figure 3 presents the scheme of the current tendencies of the evolution of production structures in the construction of machines and devices.

Considering a flexible fabrication system, we see that it allows the processing of pieces which are different in terms of shape and dimensions, in a determined range. This possibility creates conditions for the accomplishment of variable products, under high saving conditions.

Savings are made because the degree of usage of production means increases, the fabrication time is shortened, the route and duration of transports are reduced, intermediate storage expenses decrease, the area required for production is reduced, the processing process may be systematised, proper conditions for continuous work are created and direct expenses are reduced.

Within the structures of organisation of production means, one of the forms which develop quickly is that of the “cellular” structure, a system presenting the widest conditions for flexible manufacturing.

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At the same time, systems in flow start to develop, provided with computer-assisted management equipment.

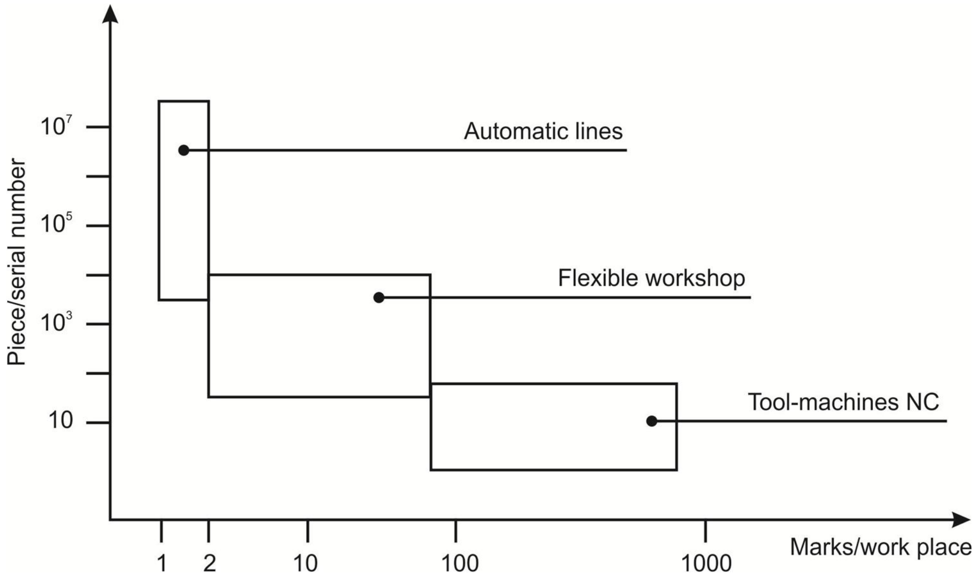

Figure 1. Tendencies in the Development of Production Structures in the Construction of Machines

Organising the multiserving of equipments and machine-tools in cells (workshops, production departments) equipped with flexible manufacturing systems

In the systematic approach of the flexibility issue, we start from the premise that, in industry, production means, work objects, workforce are multitudes of interconnected systems, so that predefined goals may be accomplished. Admitting the cybernetic concept of fabrication activity, where interconnected components act on basis of the reversed connection principle, we are offered the possibility to reunite systems with a heterogeneous structure, keeping the fundamental features of general cybernetic systems, with operative and management functions for the system thus formed.

A principle structure of a flexible manufacturing system is presented in figure 2.

A flexible manufacturing system presents various possibilities of variability of the processing process, given the flexibility of the operations to be performed, of specific devices, processing tools and the transfer system.

Generally speaking, such a complex system is accomplished by combining processing systems with a high degree of automation of the processing and control process, with automatic logistic subsystems. Within the system, there are also used subsystems for computing the integrated system, with command subsystems and management centers.

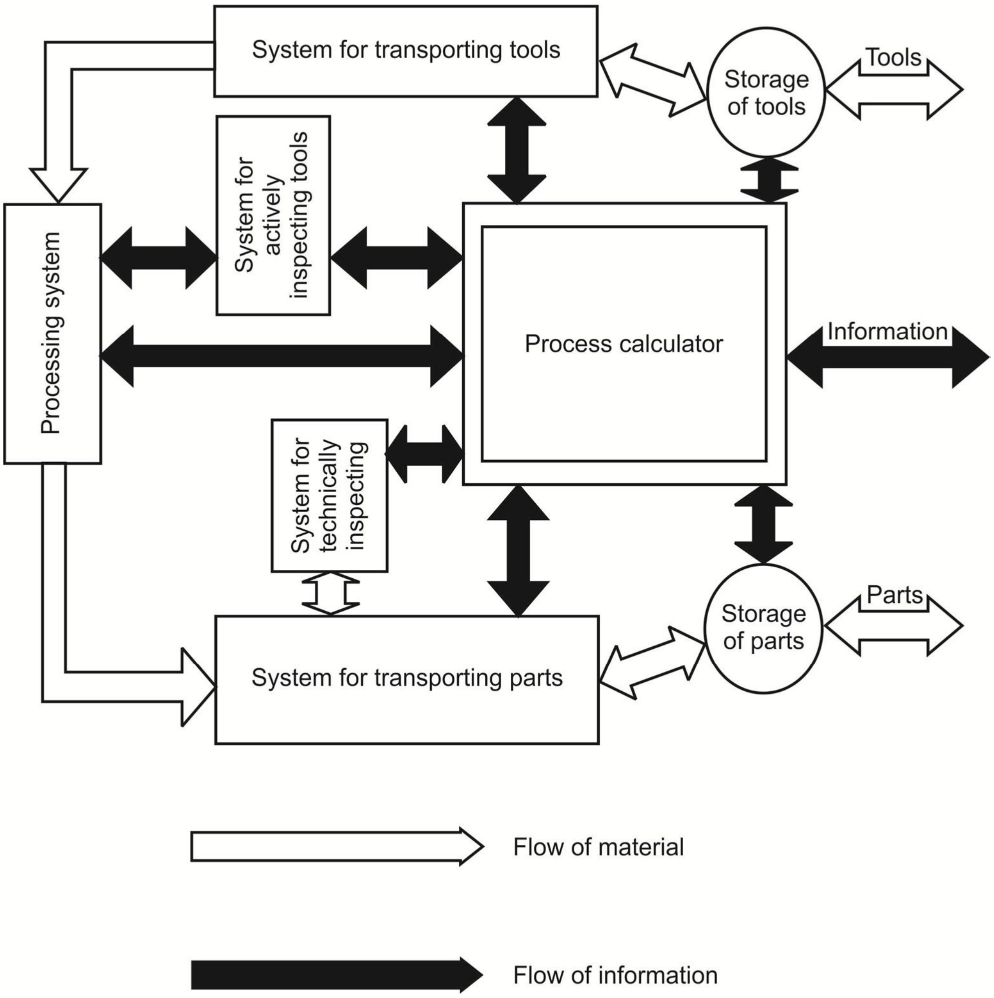

Figure 2. Principle Structure of a Flexible Manufacturing System

For an efficient application of a flexible fabrication subsystem, certain principles must be observed for preparing and organising the implementation thereof.
Among these, the most significant are the following:
- *in terms of the elements (pieces) which are to be processed* we recommend the study of constructive unification possibilities, for increasing fabrication series;
- *for reducing the duration of conception and design of new products*, computer-assisted design shall be used;

- computer typisation and modularisation shall be extended *in the design of technologies and verification tools and devices*;
- *machine-tools shall be equipped by means of standardised verification tools and devices* for reducing the diversity and cost thereof.

Besides, a range of measures refer to the use and management of tools, transport systems etc. To this purpose, we mention the following: the processing process shall be organised so as to ensure the loading of the system means, at the production capacity; the proper management of verification tools and devices, maintenance, repair, storage; a transfer system is adopted which shall ensure the proper supply of materials, half-finished items etc. to work stations; depending on the properties of the transformation system, the transfer system may comprise: transporters, handling installations, flow control devices, positioning-securing device, storage devices etc. To this purpose, we shall take into account the fact that the use of a logistic system for the supply of transformation places, based on the pallet-positioning principle, offers possibilities for the optimal satisfaction of supply requirements.

Such a system, made up of loading-unloading stations and stations for the securing and release of the piece(s) from the pallet ensures an optimal transfer of work objects.

For serving loading and unloading station, this can be made manually or by robots.

For ensuring the processing process, within a flexible fabrication cell, transfer stations are provided with possibilities to maintain pieces in standby, without stopping the system.

The structure of the station for the transfer and guidance of the object to be processed shall be made so as to ensure the transfer between transformation stations.

A flexible transfer system must allow the guidance of transport on the shortest route; actually, the travelled route shall be guided so as to supply the first free station in the cellular system. This requirement may be accomplished by using, for command, a computer connected to the computers which command the processing and handling process.

By using such systems, the real-time command of both pallet movements and work station handlers are ensured.

In fact, the method for transformation and command, in concrete cases, are differentiated depending on the number of stations, the constructive feature and size of pieces, the diversity thereof, the amount of production, number of operations, processing accuracy etc.

It has to be mentioned that the entire system shall operate in optimal conditions, if data collecting and processing systems are used, by means of modern informational systems, interconnected computer network, both for computer-assisted preparation and launch, and for the collection of process data, automated management etc.

For a proper operation of all systems, properly trained operators shall be used.

In terms of the processing process, the flexible system creates conditions for reducing fabrication expenses, especially for low and medium-range production, with an average diversity, as it allows to reintroduce in the manufacturing cycle several elements of the family of grouped products, without consuming time for the re-equipment and re-arrangement of the adjustments of machine-tools.

Analysing the flexibility conditions of a processing system, we find that the technological similitude of selected pieces is important. Generally speaking, in terms of the technological similitude criteria, we may consider two categories of pieces. One of the categories comprises the pieces with high similitude, which, though having dimensional variations, meets a limit regarding the maintenance of forms. Such a category of pieces is considered to form a “closed” family, presenting the same types of processing operations.

The second categories includes pieces with different shapes and dimensions, but requires shared processing operations and conditions. They form the so-called “open” piece family.

We shall mention that, for both families, production means shall present a certain degree of flexibility. For the processing of pieces in the “closed” family, the flexibility of machine tools shall be developed, and th logistic system may have a rigid structure.

For the “open” family of pieces, we require a certain flexibility of the system, production means and logistic system.

The application of the flexible fabrication system also influences the workforce subsystem. Considered as a whole, the effect of the introduction of the flexible system shall result, for the same production task, in an absolute reduction of the size of the subsystem, in the reduction of the number of jobs, in the appearance of new jobs and the change of ponders characterising the structure of the workforce subsystem. Thus, in the evolution of this system, we find a decrease in the total number of staff, a change in the individual requirements of the structure, according to the qualification profile of staff ad hierarchical levels.

The application of the multiserving system within flexible manufacturing cells has specific particularities. These are determined by the characteristics of the production means and the used logistic system. First, we must mention that, in such a cell, several serving variants may be used. Currently, the most frequent is that of using human work. However, serving forms with robots are also developed, which may be robot-only or a combined multiserving between robots and human work. The last variant is especially used for the performance of various operations in the processing process itself. We have to mention that, also in the case of robot-only serving, the programme of serving by robots is established by man, i.e. human force is indirectly used.

Therefore, a flexible manufacturing cell has wide possibilities of adjustment to the application of the multiserving system, also using multi-qualification.

Of course, according to the characteristics of the flexible manufacturing cell, the applicability of multiserving presents substantial differences, from a cell to another.

First and foremost, it is about the composition of the types of machine tools of the cell. If the cell is only made up of universal machine-tools, the cell has a low degree of flexibility, the issue of multiserving, as shown before, shall be similar to the general case of serving of such machine-tools.

However, if cell is made up of machine-tools with number command, aggregated or processing centers, the cell has a higher degree of flexibility, the issue of serving is more complex. In such situations, the efficient solution shall be that of multiserving by a team made up of specialists with different training, according to the requirements of the degree of technicality of the production means contained by the flexible cell, including specialists for the elaboration of the work programmes.

A special feature appears if the flexible cell contains processing centers. As it is already known, several operations are made in a sole securing of the piece, at a processing center. On balance, in such cases, transfer systems are built so as to satisfy work routes and rhythm. Systems are generally used as pallets.

The inclusion of processing centers in the composition of the flexible manufacturing cell raises special economic problems. For this reason, especially under the conditions of multiserving, the time of interruption of production methods has to be analysed, outlining the method and ponder of influence on the processing cost. Based on this data, the way of setting up the cell shall be oriented, so that it is efficient both in terms of productivity and of savings in processing. To this purpose, importance shall also be granted to the elaboration of the groups of pieces to be processed, processing operations, verifications tools and devices, transport systems etc. If several processing centers are interconnected with machine-tools complying with technological requirements, as a succession of operations we may obtain a manufacturing line for low and medium-range production, with a degree of automation similar to the one accomplished until currently, only in high-range manufacturing.

The performance of the optimal activity within a flexible manufacturing cell can be made on basis of the studies performed on all the aspects of the processing process itself, regarding the formation and guidance of the material flow and informational flow.

The use of multiserving in processing centers integrated in flexible manufacturing cells, the equipment thereof with pallet transfer systems ensure a substantial reduction in the processing cost, processing accuracy, increase of productivity.

Econometric methods used in analysing technological innovations

For the analysis of technological innovations, we shall use several mathematical methods regarding the decision of replacement of tools, which shall be presented in the following.

The method of replacing the equipments based on the operation cost-replacement cost interdependence

It implies that, at the beginning of every year, data is collected on a certain machine, regarding operation and replacement costs. The data shows an increase in

the operation cost, because of the damages in certain components of the machine. Some of these components may be replaced, reducing thus the equipment operating cost. The replacement thereof implies costs with materials and salaries and, hence, such costs have to be compensated through the savings which may be obtained pursuant to the reduction of operating costs. Thus, we want to determine an optimal replacement policy, able to minimize the sum of operating and replacement expenses during the period between two successive data collections.
Figure 3 outlines the conflict between the two costs.
Consider: $c(t)$, the operating cost per time unit at the moment *t*, after replacement and c_r, the cost of a replacement. Then, the relation between the operating cost, replacement cost and time is that in figure 3

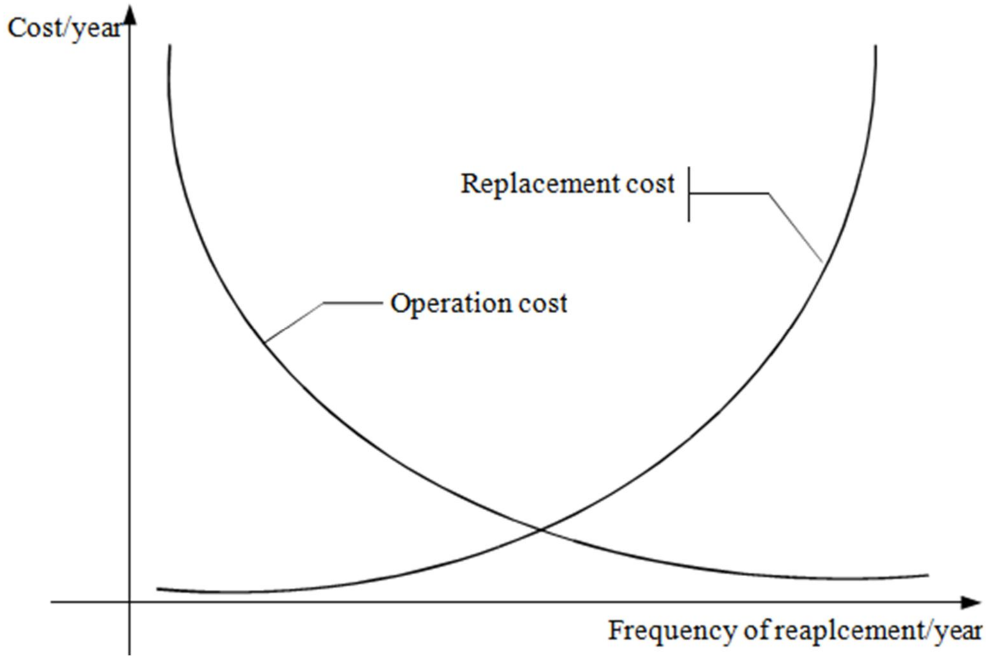

Figure 3. Relation between Operation Cost, Replacement Cost - Time

The replacement policy is presented in figure 4, with the following notations: $[0,T]$, the time interval regarding the collection of data on the machine and t_r, intervals when *n* replacements shall occur.
The proposed goal is the determination of the optimal interval between replacements, so that the sum of the operating and replacement cost $C(t_r)$ is minimal.

$C(t_r)$ is the replacement cost during the period $[0,T]$, plus operating cost during the period $[0,T]$.

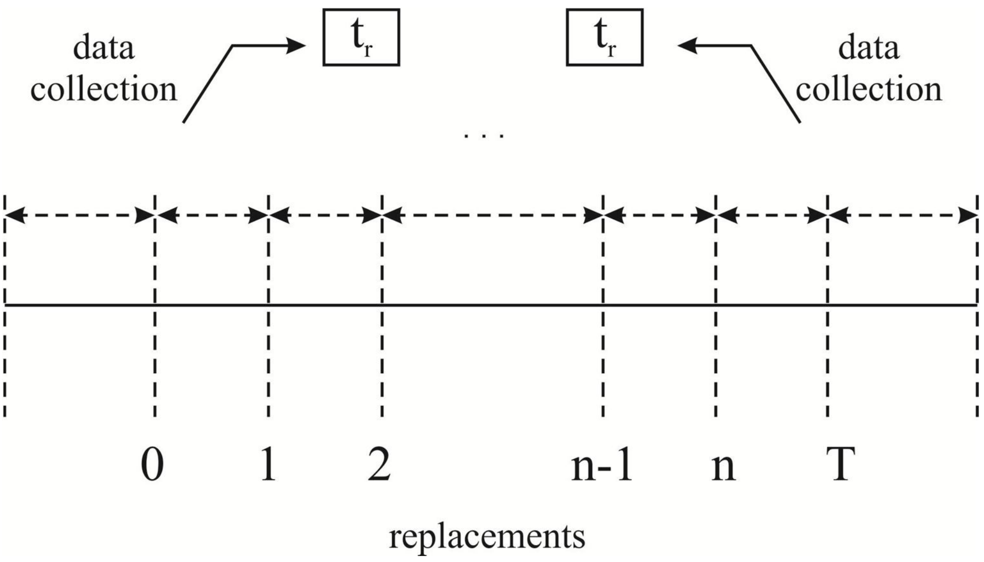

Figure 4. Graphical Representation of the Replacement Policy

Replacement cost by period $[0,T] = n \cdot C_r$ (1)

Thus, n is the name of replacements by period $[0,T]$ şi C_r, the cost of one replacement.

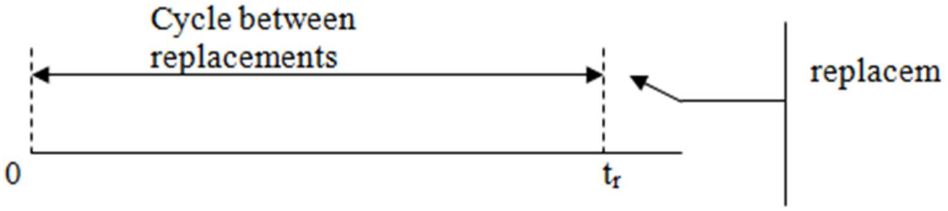

Figure 5. Machine Replacement Policy

The proposed goal is the determination of the optimal interval between successive replacements, so that the operating and replacement cost per time unit is minimal. The total cost per time unit $C(t_r)$, for the replacement performed at the moment t_r is: $C(t_r)$ i.e. total cost in the interval $(0,t_r)$ related to the length of the interval.

The total cost in the interval $(0, t_r)$ is the operating cost plus replacement cost.

$$\int_0^{t_r} c(t)dt + C_r = \left[\frac{\int_0^{t_r} c(t)dt + C_r}{t_r} \right] \tag{2}$$

As we may see, the two methods are similar, because the minimization of $C(t_r)$ is desired, depending on t_r.

Neither of the two methods considers the time required for performing a replacement (figure 6)

If the time required for performing a replacement is considered, equation 2 becomes:

$$C(t_r) = \frac{\int_0^{t_r} c(t)dt + C_r}{t_r + T_r} \tag{3}$$

The method of replacing the equipment at a certain age

We consider that the machine shall be used for a certain number of years. This situation is possible when a certain machine manufactures certain products, according to the production plan. In this case, the goal consists in the determination of the optimal replacement policy, establishing whether, at a certain age of the machine, the latter should be replaced or left to operate continuously, in order to minimize the total operating and replacement cost for a fixed time period.

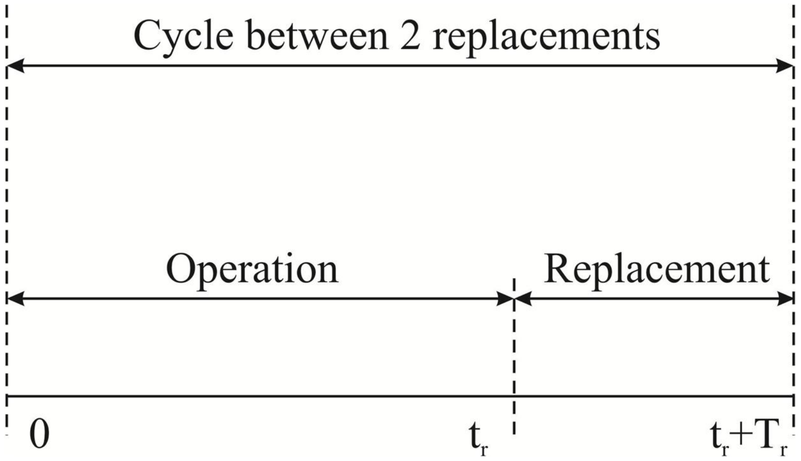

Figure 6. Graphic Representation of the Comparison of Methods

Consider: I, the age of the equipment (from the last replacement, with n time periods of proper operation, until the end of the production plan); $c(a)$, the cost of operating the equipment for a time period, when the equipment has age a; J, the age of the equipment from the moment of the last replacement, having (n-1) operating time periods until the end of the production plan; C_r , replacement cost; $C(I,J)$, total cost during the period when the equipment develops from age I to age J. The proposed goal consists in the determination of a replacement policy, so that the cost of operating and replacing the machine $C_n(i)$, along the following n time periods is minimal.

When $C_n(i)$ has a minimal value, the smallest cost is defined as $f_n(i)$.

Figure 7 presents the replacement policy for a machine whose life is: $I = 3$ weeks, and n = *10* weeks.

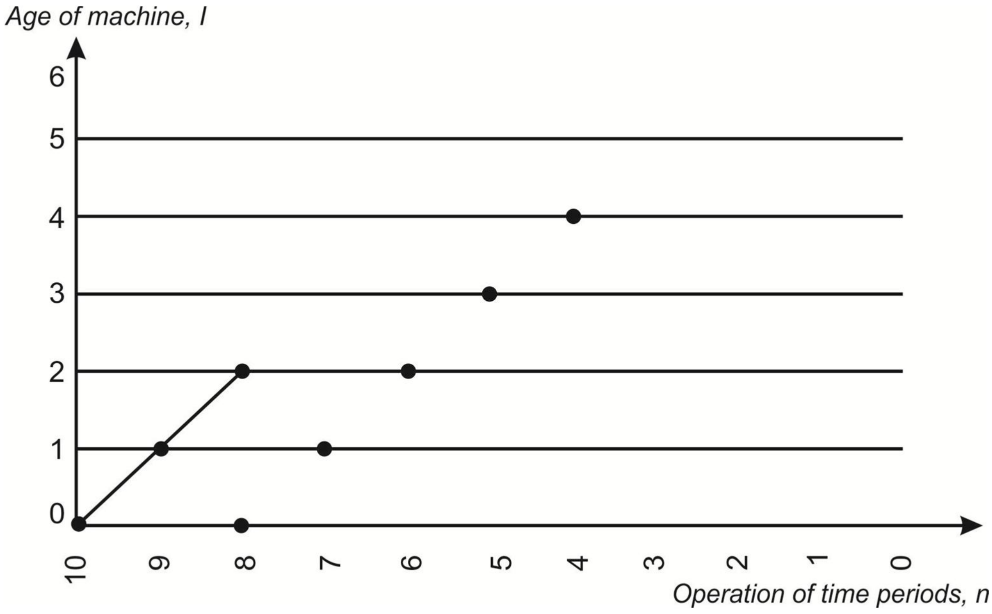

Figure 7. Replacement Policy for a Machine with a Three-Week Life

10 weeks before the end of the production plan, two decisions may be made: continuous use or replacement of the machine. If it is decided that the machine should operate further, the equipment shall have age *4* when a new decision may be made (figure 8).

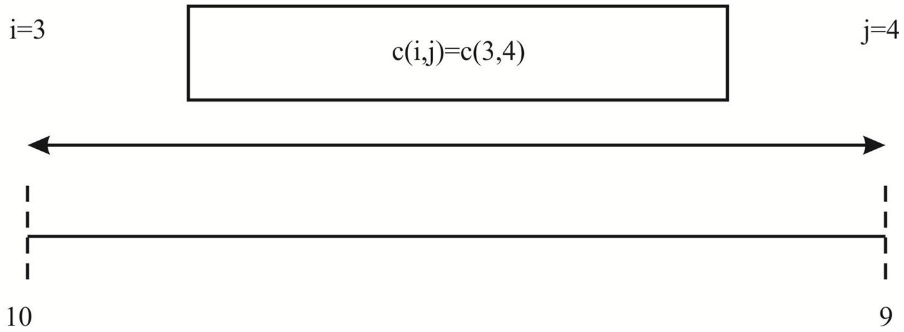

Figure 8. Replacement Policy for the Machine with Age "4"

The total operating cost for the period (10, 9) is:

$$C(3,4) = C(3) \tag{4}$$

If the decision to replace the machine is made (figure 9, then the total cost for the period (10, 9) shall be:

$$C(3,1) = C_r + C(0) \tag{5}$$

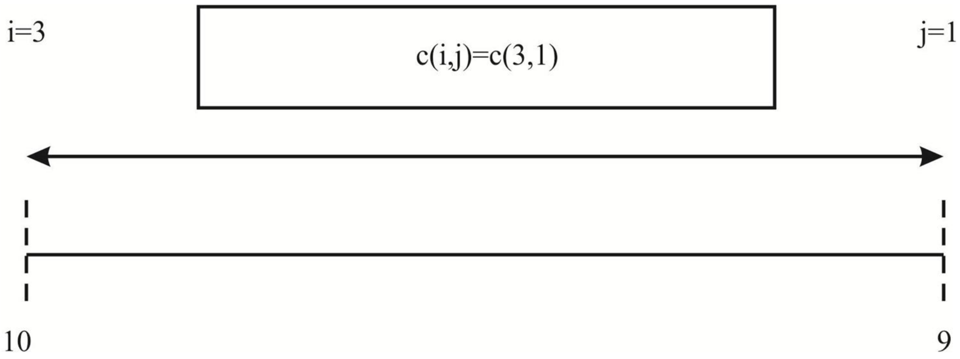

Figure 9. Cost of the Decision of Replacement of the Machine

Thus, C_r is the replacement cost, and $c(0)$, the operating cost for a period, when the machine has age *0*.

The optimal replacement policy is graphically presented in figure 10.

The mathematical model used for identifying this optimal policy has the following form:

Consider: $f_n(i)$, the minimal cost resulting from taking the best decision at the beginning of the period n plus the cost of the best decision taken on the remaining periods (*n-1*); $C(i, j)$, the cost resulting from taking the decision at the beginning of the period *n*; $f_{n-1}(j)$, minimal cost by periods (*n-1*) remaining at the moment when the machine has the age *J*.

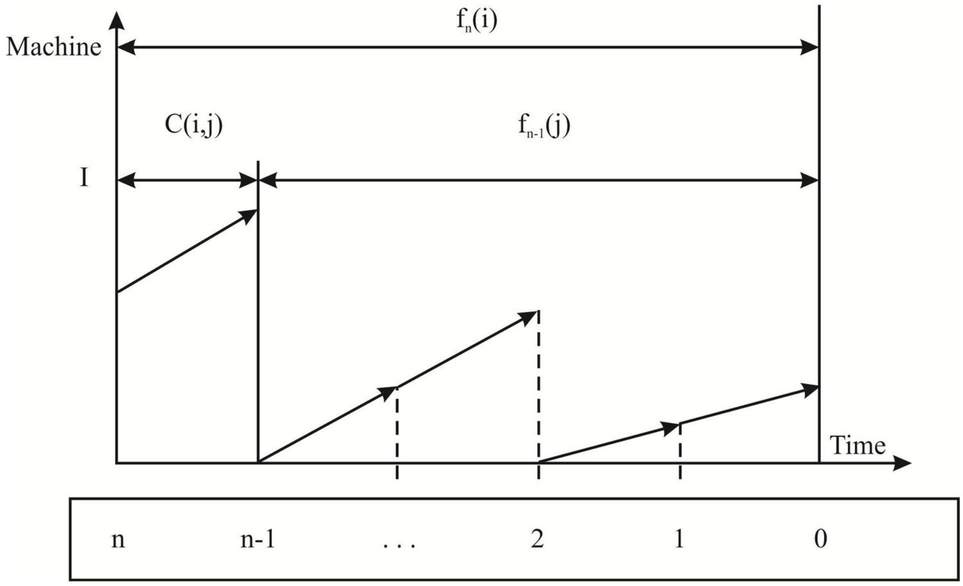

Figure 10. Optimal Replacement Policy

The mathematical model used for identifying this optimal policy has the following form:

Consider: $f_n(i)$, the minimal cost resulting from taking the best decision at the beginning of the period n plus the cost of the best decision taken on the remaining periods (*n-1*); $C(i,j)$, the cost resulting from taking the decision at the beginning of the period *n*; $f_{n-1}(j)$, minimal cost by periods (*n-1*) remaining at the moment when the machine has the age *J*.

The cost by the *n* periods is:

$$C(i,j)+f_{n-1}(j), \tag{6}$$

so:

$$f_n(i)=min[C(i,j)+f_{n-1}(j)] \tag{7}$$

with:

- $f_0(i)=0$

- $j = i + 1$ or *0*

This equation may be solved by means of dynamic programming methods.

The method of replacement based on the existence of an equipment in standby

It implies the replacement of assets provided that the manufacturing flow contains a spare asset, and the operating cost increases with the use of the asset existing in production.

In this case, an optimal replacement policy must be determined, combined for the two assets, which shall minimize the total replacement and operating cost for a fixed time period.

The state of the production system at the beginning of a period shall be noted with *I*, where *I* is equivalent to the pair of numbers (*x, y*), where *x* refers to the asset (*A* or *B*) which is generally used, and *y*, to the age of the asset.

Consider: $C_x(y)$, the operating cost for a period; *j*, the state of the production system at the end of a period, where *j* is equivalent to (*x,y*); C_r = replacement cost, considered equal for both assets $C(i, j)$, total cost of the system between the states of the system *i* and *j*. The time required for the replacement of an asset is a period when the replacement decision is made, then the *stand by* asset becomes operative. The proposed goal is the determination of an optimal combined policy for replacement/operation, so that the operating and replacement cost for the following *n* time periods is minimal. Figure 11 shows such a policy, where *n=10*, the system is in state *I=(B,2)*. At the beginning of period *10*, a decision is made to go on with asset B.

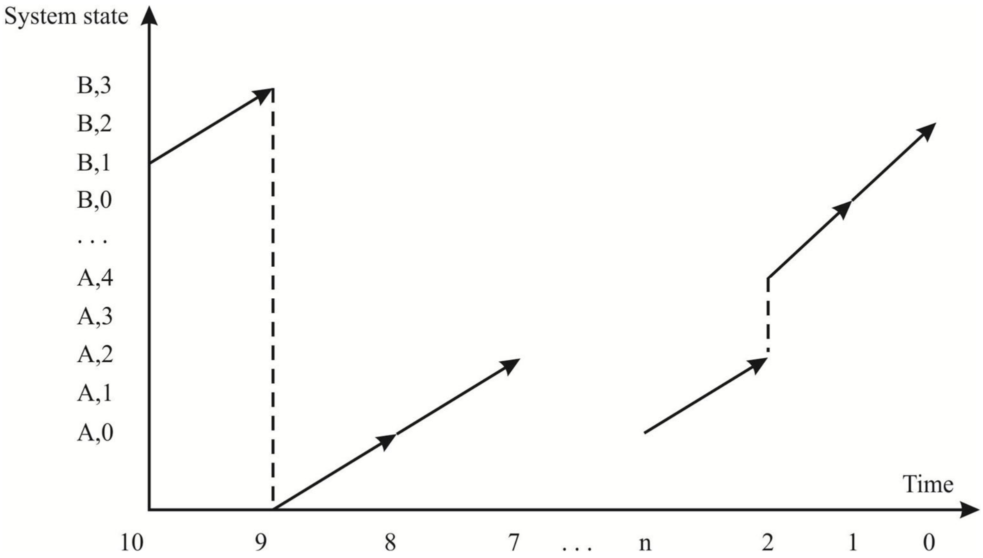

Figure 11. Replacement Policy Given the Existence of the Standby Asset

At the beginning of period *9*, a decision is made to replace asset *B* etc. The total minimal cost for replacement and operation, for the *n* periods is $f_n(i)$.

The cost of the first decision taken at the beginning of the period *n* is $C(i,J)$. At the end of this period, the system is in state *j*, having *(n-1)* operating periods. The minimal cost for the remaining period is $f_{n-1}(j)$:

$$\text{Total cost} = C(i,j) + f_{n-1}(j) \tag{8}$$

$$f_n(i) = min[C(i,j) + f_{n-1}(j)] \tag{9}$$

This equation is identical to equation 32, but the states of the system are different. This equation can also be solved by means of dynamic programming;

The method of replacing equipments based on maximising the net updated benefit

It aims to maximise the net updated benefit, in the case of fixed capital assets. Pursuant to damages in the equipment, the benefit resulting from the obtained production decreases, so that, at a certain moment, a replacement of the equipment is more efficient than continuing to operate the existing fixed asset.

Consider: $b(t)$, the net benefit obtained from using the equipment at the moment *t*, and $c(t)$, the net cost of replacement of the equipment with age *t* (figure 12).

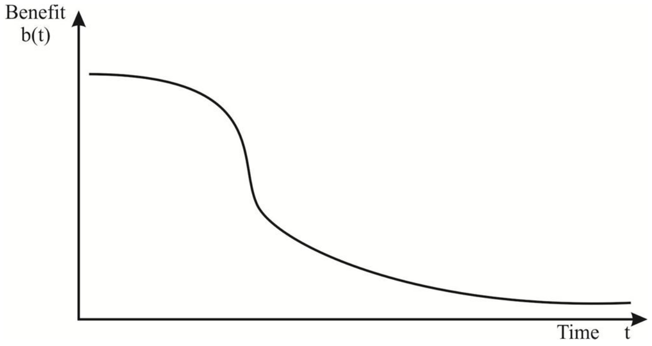

Figure 12. Benefit – Time Correlation

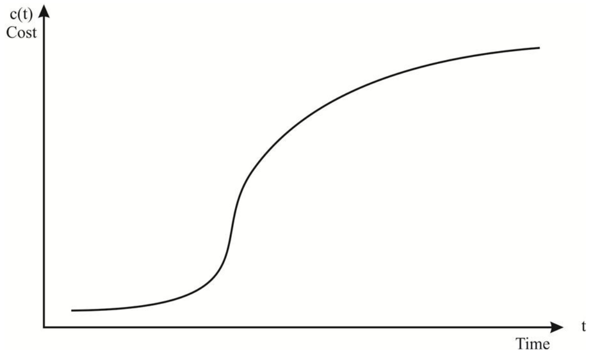

Figure 13. Replacement Cost – Time Correlation

This cost includes the purchase price, plus the installation cost, plus the production cost, which is lost pursuant to such replacement.

Consider: *T*, the time required for the replacement of the equipment; t_r, the age of the equipment when the replacement occurs; $t_r + T_r$, the replacement cycle; $B(t_r)$, the total net updated benefit, pursuant to the operation of the equipment for a period t_r (figure 13).

The proposed goal consists in determining the optimal interval between two replacements, which maximises the total updated net benefit for an infinite period of time.

Let us consider the first operating cycle, as follows: $B_1(t_r + T_r)$, the benefit for the period $(0, t_r)$ updated at its current value minus the replacement cost for the equipment of age t_r updated to the current value; *i,* the update factor, then: the updated benefit for the first cycle is:

$$\int_0^{t_r} b(t) \cdot exp[-it]dt \tag{10}$$

and the updated replacement cost, $C(t_r) \cdot exp[-it_r]$ will be:

$$B_1(t_r + T_r) = \int_0^{t_r} b(t) \cdot exp[-it]dt - C(t_r) \cdot exp[-it_r] \tag{11}$$

Let us consider now the second operating cycle:

$$B_2(t_r + T_r) = \int_0^{t_r} b(t) \cdot exp[-it]dt - C(t_r) \cdot exp[-it_r] \tag{12}$$

$B_2(t_r + T_r)$ is the total net updated benefit at the moment of beginning the second cycle.

For updating it at the moment of beginning the first cycle, we use the formula:

$$B_2(t_r+T_r)\cdot exp[-i\cdot(t_r+T_r)] \tag{13}$$

Similarly, we calculate the following:

$$B_3(t_r+T_r)\cdot exp[-i\cdot 2\cdot(t_r+T_r)] \tag{14}$$

$$\ldots$$

$$B_n(t_r+T_r)\cdot exp[-i\cdot(n-1)\cdot(t_r+T_r)] \tag{15}$$

The total net updated benefit will be given by the sum of the expressions above:

$$B(t_r)=B_1(t_r+T_r)+B_2(t_r+T_r)\cdot \exp[-i\cdot(t_r+T_r)]+B_3(t_r+T_r)\cdot \exp[-i\cdot 2\cdot(t_r+T_r)]$$
$$+\ldots+B_n(t_r+T_r)\cdot \exp[-i\cdot(n-1)\cdot(t_r+T_r)] \tag{16}$$

because:

$$B_1(t_r+T_r)=B_2(t_r+T_r)=\ldots=B_n(t_r+T_r) \tag{17}$$

$$B(t_r)=B_1(t_r+T_r)\cdot\{1+exp[-i\cdot(t_r+T_r)]+\ldots+[-i\cdot(n-1)\cdot(t_r+T_r)]\} \tag{18}$$

the expression in the accolades is a geometrical progression, tending to infinite. The expression becomes:

$$B(t_r)=\frac{B_1(t_r+T_r)}{\{1-exp[-i\cdot(t_r+T_r)]\}}=\left\{\frac{\int_0^{t_r} b(t)\cdot exp[-it]dt - C(t_r)\cdot exp[-it_r]}{\{1-exp[-i\cdot(t_r+T_r)]\}}\right\} \tag{19}$$

With mathematical processing, the formula becomes:

$$B(t_r)=\left(\int_0^{t_r} b(t)\cdot exp[-it]dt - C(t_r)\cdot exp[-it]\right)\cdot\left\{\frac{\{1-exp[-n\cdot i\cdot(t_r+T_r)]\}}{\{1-exp[-i\cdot(t_r+T_r)]\}}\right\} \tag{20}$$

As the expression in the second brackets is constant, by solving the first equation, we will obtain the optimal value t_r, for which $B(t_r)$ is maximum (figure 14);

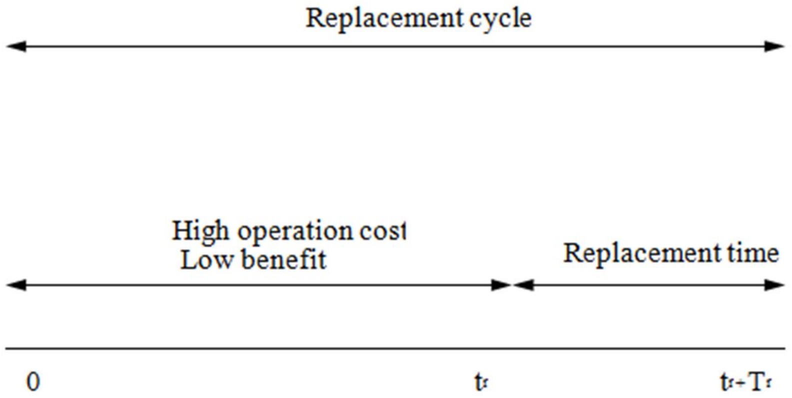

Figure 14. Operating Cost, Benefit – Time Correlation

The method of replacing the equipments based on minimising the total cost

It aims to determine the optimal replacement interval for fixed capital assets, provided that the total cost is minimised.

The data of the problem are similar to those of the previous method, with the difference that, by this method, we try to minimise the maintenance and replacement cost for a long period of time, and the cost is considered to be a discrete variable (not continuous).

Consider: *A*, cost of purchase of the equipment; C_i, maintenance cost in the period *i* (to be paid at the end of the period); *i* = *1*, *2*,...*n*; S_i, remaining value of the equipment at the end of period *I*; *r*, update factor; *n*, the age (no. of periods) of the equipment, at the moment of replacement thereof; $C(n)$, the total updated maintenance and repair cost for a long period of time, considering that replacements occur after *n* periods of use.

The proposed goal is the determination of the optimal interval between replacements, so that $C(n)$ is minimal.

We present the replacement policy in figure 15.

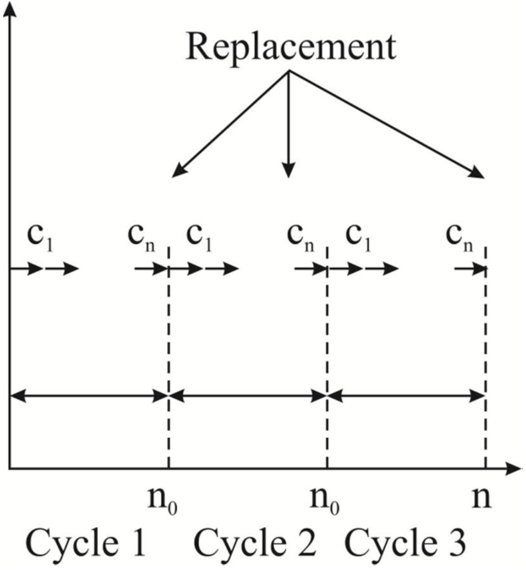

Figure 15. Replacement Policy

Let us consider the first operating cycle.

The total cost for this first cycle, considering that the equipment is already installed, is:

$$C_1(n)=C_1\cdot r+C_1\cdot r^2+\ldots+C_n\cdot r^n+A\cdot r^n-S_n\cdot r^n=\sum_{i=1}^{n}C_i\cdot r^i+r^n\cdot(A-S_n) \quad (21)$$

For the second cycle, the total updated cost at the beginning of the cycle is:

$$C_1(n)=\sum_{i=1}^{n}C_i\cdot r^i+r^n\cdot(A-S_n) \quad (22)$$

After the update of such costs at the beginning of cycle *1*, the formula for the total updated cost becomes:

$$C(n)=C_1(n)+C_2(n)\cdot r^n+C_3(n)\cdot r^{2n}+\ldots++C_n(n)\cdot r^{(n-1)n} \quad (23)$$

as:

$$C_1(n)=C_2(n)=\ldots=C_n(n) \quad (24)$$

is a geometrical progression, which results in the following formula, for an infinite period:

$$C(n)=\frac{C_1(n)}{1-r^n}=\frac{\sum_{i=1}^{n}C_i\cdot r^i+r^n\cdot(A-S_n)}{1-r^n} \quad (25)$$

The issue was again reduced to a quite simple equation, which may be solved by means of a simple mathematical calculation;

The method of replacing the equipments based on technological improvement in finished time horizon

Considers that the replacement of an old machine by a new one not always is an exact copy of the old one, but that the latter is better, so that operating and maintenance costs are smaller, efficiency is higher etc. The following model aims at determining the way how the new available machines may be used with a successful purpose, considering that the time period is fixed and finite.

Consider: *n*, the number of operating periods (periods when the machine must operate); $C_{p,i}$, maintenance cost of the current equipment in the period *I* (*i=l,2,...n*); $S_{p,i}$, sales value of the current equipment at the end of the time period; *A*, purchase cost for the new, better equipment; $C_{t,j}$, maintenance cost of the new machine in the *dj* period after installation (*j = l,2,...n*); $S_{t,j}$, sale value of the new equipment at the end of the operating period *j; r* – update factor.

The method aims at determining the value *T* when replacement should be made with the new, better machine (figure 16)

T = 0, 1,2,....,n.

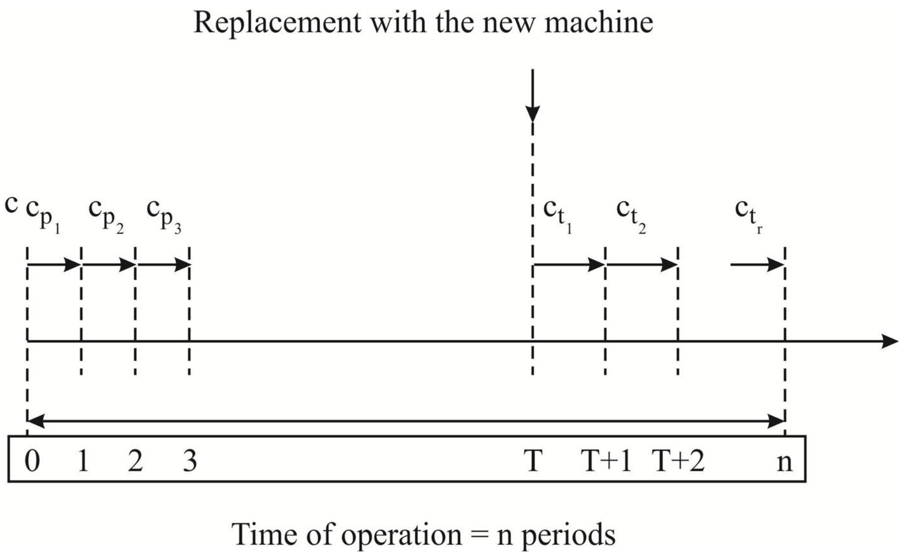

Figure 16. Graphical Calculation of T Value

The total updated cost for the *n* periods when replacement occurs at the end of the *T* period is: $C(T)$, updated cost for the maintenance of the current machine in the period $(0,T)$, plus the updated maintenance cost of the new machine in the period (T,n), plus the updated purchase cost of the new machine, minus the updated sale value of the current equipment at the end of the *T* time period, minus the updated sale value of the new equipment at the end of period *n*:

$$C(T)=\left(C_{p,1}\cdot r^{1}+C_{p,2}\cdot r^{2}+\ldots+C_{p,T}\cdot r^{T}\right)+\left(C_{t,1}\cdot r^{T+1}+C_{t,2}\cdot r^{T+2}+\ldots+C_{t,n-T}\cdot r^{n}\right)+ \\ A\cdot r^{T}-\left(S_{p,T}\cdot r^{T}+C_{t,n-T}\cdot r^{n}\right) \tag{26}$$

Hence,

$$C(T)=\sum_{i=1}^{T}C_{p,i}\cdot r^{i}+\sum_{j=1}^{n-T}C_{t,j}\cdot r^{T+j}+A\cdot r^{T}-\left(S_{p,T}\cdot r^{T}+C_{t,n-T}\cdot r^{n}\right) \tag{27}$$

As the sole unknown variable is *T*, the minimisation of $C(T)$ depending on *T* does not raise special issues.

Econometric patterns used for adopting the decision of replacing the equipments and machine-tools

The models used for the replacement of fixed assets include both tangible and intangible factors and generally proceed from Western literature. We talk about the models to be approached in the following paragraphs.

The pattern of simple score

It implies taking the following steps: assessment of each machine on basis of a set of factors (*1*- if the machine complies with such factors, *0* - if the machine does not comply with such factors); summing up the value attached to these factors for each type of machine; selecting the machine with the highest score.
Table 1 presents this pattern, which is easily applied, but there are certain disadvantages regarding the selection of these criteria and their importance.

Table 1.The Pattern of Simple Score

No.	Decisional factors	Machines		
		1	2	3
1	Net value	1	1	0
2	Increased productivity	0	1	1
3	Increased flexibility	1	1	0
4	Increased quality and reliability	1	1	1
5	Compatibility	1	0	0
TOTAL SCORE		3	4	3

The pattern of balanced score

It considers the importance of the two criteria presented in the previous model. Thus, the most important criterion shall have value *1*, the following *0.9*, and as follows. Table 2 presents the application of this model.

Table 2. The Pattern of Balanced Score

No.	Decisional factors	Ponderosity of the decisional factor	Machines		
			1	2	3
1	Current net value	1.0	1.0	0.9	0.4
2	Increased productivity	0.9	0.4	1.0	0.8
3	Increased flexibility	0.8	0.4	0.7	1.0
4	Increased quality and reliability	0.8	0.7	0.7	1.0
5	Compatibility	0.6	1.0	0.6	0.5
TOTAL SCORE			2.84	3.28	3.02

$$S_i = \sum_{j=1}^{n} w_{ij} \cdot x_{ij} \qquad (28)$$

Thus, S_i is the total score for machine *i*; w_j, the weight of factor *j*; x_{ij}, the place of machine *i* depending on the factor *j*; *n*, the number of decisional factors; *j* = *l,...n*

This model also considers intangible factors, such as: safety of workers, the impact of machines on social relations, ergonomic issues, psychological state of workers pursuant to the use of machines, life quality and the workers' easiness to understand new technologies.

Patterns for optimising the assignment of resources
It was conceived by Saad, who developed a linear programming model, trying to optimise the assignment of resources for the purchase of various machines.
Consider: *j*, the index for the new machines to be bought; *j =1, 2,...n; i*, index for financing sources, *i = 1,2,...m*; π_j, average income for the machine *j*; C_i, capital cost under *I* financing conditions (it also includes the interest for the borrowed funds and the profit reinvested by the company); U_{ij} ,the risk associated to the use of the financing source *I* for purchasing machine *j*; $V_{ij} = \left(\pi_j - C_j\right) \cdot U_{ij}$, integrated variable of probability $\left(\pi_j - C_j\right)$ and risk $\left(U_{ij}\right)$; x_{ij}, capital from source *I* used for machine *j*; A_i, accessible capital from source *I*; R_j, required capital for purchasing the equipment *j*.

We have to maximise:

$$Z = \sum_i \sum_j V_{ij} \cdot x_{ij} \tag{29}$$

provided that:

$$\sum_i x_{ij} = R_j \quad ; \quad j=1,2,\dots,n \tag{30}$$

$$\sum_j x_{ij} < A_i \; ; \quad j=1,2,\dots,n \tag{31}$$

$$x_{ij} > 0, \quad for\, any\, i, j$$

Table 3. Pattern for Optimising the Assignment of Resources

Specifications			Using the financial resources for the period				Available funds
			T_1	T_2	T_j	T_n	
Source of financing	Internal financing	Profit retained for investments P1	P_{11}	P_{12}	P_{1j}	P_{1n}	F_1
		Attracted capital P2	P_{21}	P_{22}	P_{2j}	P_{2n}	F_2
		Total	$P_{11}+P_{21}$	$P_{12}+P_{22}$	$P_{1j}+P_{2j}$	$P_{1n}+P_{2n}$	$P=F_1+F_2$
	External financing	Long-term credit C_1	C_{11}	C_{12}	C_{1j}	C_{1n}	F_3
		Short-term credit C_2	C_{21}	C_{22}	C_{2j}	C_{2n}	F_4
		Total	C_1	C_2	C_j	C_n	$C=F_3+F_4$
Capital necessary for purchasing the equipment			R_1	R_2	R_j	R_n	$\sum_{i=1}^{n} F_i$ $\sum R_j$

Table 3. represents the matrix equality between available funds $\left(\sum F_i\right)$ equal to the funds required for purchasing the machine $\left(\sum R_j\right)$.

The implementation of new machines is difficult because of problems such as:

- *workers' resistance, as they are used to the old machine;*
- *lack of will to change the workstyle;*
- *fear of the unknown, i.e. workers are scared that they will lose their jobs pursuant to the introduction of new technologies or that they won't be able to adjust to the new working requirements;*
- *lack of support regarding specialized documentation;*
- *difference of opinions regarding the operation of the equipment;*
- *complexity of the machine.*

The Western literature contains various management models, providing solutions for this issue. These are only valuable in certain economic and cultural contexts, which is why the Romanian manager must use them selectively.

The first model proposed by Western literature is the ***model of the 9 steps***.

These steps are:

- *analysis of the machine's impact on workers and work management;*

- pheasibility analysis of the machine's goals;.
- analysis of the machine's relevance;
- collective training of all the persons who shall use the machine after commissioning and education thereof regarding calibration and proper use;
- analysis of the machine's variability;
- proving the machine's value not only in economic, but also in social terms;
- changing some features of the machine, depending on the requirements of workers;
- implementation of systems which will control the variables related to the technological process.

The second model proceeds from the researches of Meredith and Green, who elaborated the ***model of the 4 steps*** applied in the implementation of new machines, which includes the following steps:

- the management team must try to change the organisational enterprise culture, simultaneously with the new technology;
- the management team must accept that the new machines can also have negative effects;
- a higher degree of oral communication between the manager and performers regarding the new machines;
- a change in the company's strategy, as the new machines are used.

Graynor proposes another model, known as the ***model of the 3 steps***, which implies:

- all the workers who will work with the new equipment must understand the tasks they must fulfil, as well as their contribution at the enterprise level;
- higher attention to key factors and problem factors which may prevent the success of the new tool;
- critical and continuous evaluation of the issues which arise and the solutions thereof.

The success of implementation of the new machines, using any of the presented models, implies teamwork and dedication from all those involved in the process.

Summary

The replacement of machines is based on certain mathematical methods for explaining such replacement, but these methods do not consider tangible factors.

The issues related to the machine's replacement, considering the degree of knowledge thereof may be: determinist issues, probabilistic ~ stochastic issues.

Determinist issues are those when the time and implications of the replacement action may be certainly determined (known). For instance, the situation of a machine whose operating costs increase in direct proportion to the duration of use. In order to reduce this cost, the machine must be replaced, so that the operating cost shall tend to increase, as shown in figure 17.

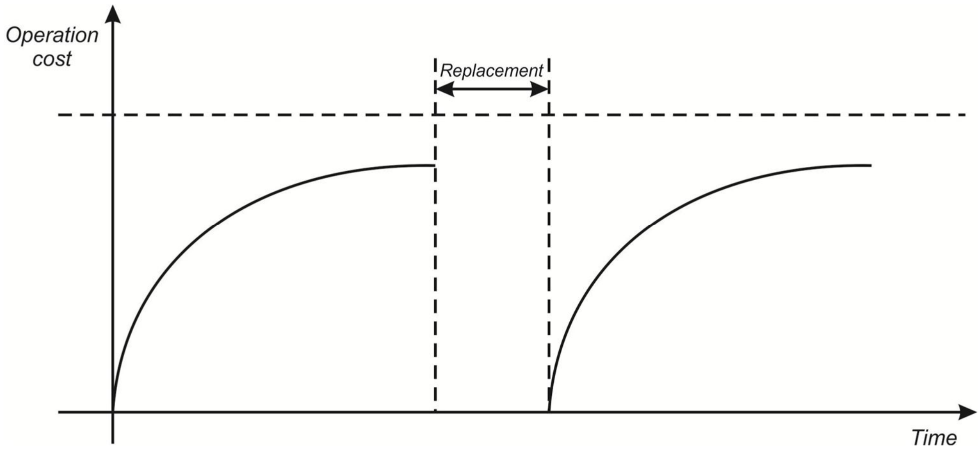

Figure 17. Operating Cost – Time Relation

Probabilistic situations are those when the time and implications of the replacement action cannot be exactly determined. Let us consider that the machine has two states: proper operating state (*F*) and non-operating state (*N*). The probabilistic law, describing the transition from state *F* to state *N* may be described by the distribution of time between the end of the replacement action and the fall of the equipment.

The decisions to replace machines in case the fall of machines follows a probabilistic law are those decisions where the risk is given by the impossibility to exactly determine the moment when such machine falls or the transition moment from state *F* to state *N*. Another source of risk is given by the impossibility to determine the state of the equipment when no inspection or other maintenance activity occurs. We consider that there are only two states of the equipment *F* and *N*, which are always known. We have to determine the times when the action of replacement of machines should occur. This is called *machine replacement policy.* In this case, we are interested in the optimal replacement policy, i.e. the one maximising or minimising certain economic criteria, such as: profit, total cost, non-operating time.

Let us consider that the activity of replacement of the equipment results in the further production, at the same quality level, of the same products and services previously produced by the replaced machine. Hence, fall distributions and related costs are the same for all models (except for the model which considers the technological improvement of the machine).

Preventive replacement for fixed assets implies two conditions:

- *the total replacement cost shall be higher after the fall itself at the moment when the preventive replacement is made;*
- *the fall rate of the equipment increases instead of remaining constant. In order to prove this, let us consider than an equipment has a constant fall rate and follows a negative exponential law. In this case, the replacement of the machine before the*

fall itself does not affect the chance that the equipment may fall at the following moment. In the case of negative exponential distribution, preventive replacement represents a loss of money and other resources.

Therefore, preventive replacement is only justified when the rate of replacement grows. In case the machine is damaged, the specialist in the department should increase the preventive replacement activity. This may be a mistake, as the preventive replacement of machines (or machine components) is not always justified.

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METODY ORAZ MODELE EKONOMETRYCZNE WYKORZYSTYWANE DO ANALIZY INNOWACJI TECHNOLOGICZNYCH W WYTWÓRNIACH I DZIAŁACH PRODUKCYJNYCH WYPOSAŻONYCH W ELASTYCZNE SYSTEMY PRODUKCYJNE

Streszczenie: Na podstawie analizy metod oceny struktury procesu produkcyjnego, w konstrukcji maszyn, okazuje się, że ze względu na wymogi dywersyfikacji asortymentu i cechy produktów, kryteria poziomu jakości i wydajności pracy, obniżenie kosztów produkcji, struktura procesu produkcji rozwija się w sposób ciągły. Począwszy od wytwórni wyspecjalizowanych w procedurach technologicznych, z rozwiniętą strukturą na liniach produkcyjnych w przepływie pojedynczego obiektu do linii produkcyjnych z przepływem wielu obiektów, a obecnie do elastycznych form produkcji. W tym celu rozwijają się komórki elastycznego wytwarzania. Ostatnia forma rozwija się w sposób ciągły, zwłaszcza po wykonaniu obrabiarek z poleceniem numerycznym. W ten sposób przechodzimy od struktury produkcji w automatycznych sztywnych liniach przepływu, wydajnych dla masowej i szerokiej zakresowo produkcji, do struktur elastycznych, szczególnie skutecznych w produkcji niskiego i średniego zasięgu.

车间内技术创新和装备柔性生产系统生产部门的分析的经济模式和方法应用

摘要：根据对生产进程结构评价方法的分析，以及机器的机构，我们不难发现品种多样性产品特点的要求，质量等级标准，生产成本的削减，生产方式结构再持续的发展。从车间中专门的工艺流程开始，这种结构在单一产品生产线上发展，继而发展到多产品生产线上，目前已经发展到了灵活生产模式上。
出于此种目的，柔性生产模式产生了。而后的模式在持续发展中，但是特别在机械工具数字化完成是后发展尤为迅猛。因此，我们通过自动化严格流水线吗，提高质量和中等规模的产品生产效率，对于柔性结构来讲，特别能提高中低规模产品生产效率。