PLANNING AND SCHEDULE OF MAINTENANCE WORKS FOR INJECTION MACHINES

Ramona-Iuliana Popa[1], Maria Catana[1], Gabriel Cimpoesu[1],
Lucian Burlea[2], Constantin Cărăușu[1]

[1]"Gheorghe Asachi" Technical University of Iasi-Romania, Department of Machine Manufacturing Technology, Blvd. Mangeron 59A, 700050, Iasi, Romania
[2]"Grigore T. Popa" University of Medicine and Pharmacy of Iasi, Universitatii Street, 16, 700115, Iasi, Romania

Corresponding author: Constantin Cărăușu, constantin.carausu@academic.tuiasi.ro

Abstract: Keeping the equipment and machinery in working order is a very important activity in the field of industrial production, being specific to the maintenance department within an enterprise. Ensuring an optimal in operation of the manufacturing systems is closely related to the prevention of defects, an action that must be found in a planning and scheduling of preventive-planned maintenance works. In the paper, in addition to the introductory part on the main objectives and implementation of the maintenance system and maintenance-specific operations, a case study is conducted for the planning and organization of maintenance in a company equipped with plastic injection machines. The main stages developed consisted in elaborating the maintenance plan, establishing the optimal moment for replacing the machine tools, choosing the optimal type of machine tool and establishing the elements of random wear of the machine tools. It is concluded that the optimal type of injection molding machine that will be chosen to replace the T_{10} injection molding machine is T_{14}, because it has a minimum average cost of acquisition, maintenance and repair, respectively 42.286 UV.

Keywords: maintenance, injection moulding machine, planning

1. INTRODUCTION

The introduction of a plastic material in a molten state under pressure in the mold where its cooling and solidification takes place, in order to obtain a product, is called injection. Injection is a highly productive process by which products, generally of high complexity, can be obtained from both plastics and biodegradable materials. Globally, there are many research results based on the plastic injection process and, to a much lesser extent, results for the injection of biodegradable materials. The main advantage of obtaining landmarks by injection from biodegradable material is a low energy consumption, given the melting temperature for these biodegradable materials, [1,2]. Taking into account all these mentioned aspects, even more so the periodic functional maintenance of preventive-planned type is of vital importance in the machine building industry, and the planning and scheduling of these activities must be done rigorously. Sometimes, this activity is interposed between the system of recurrent functional maintenance and that of technical revisions.

Preventive-planned maintenance has as main purpose the knowledge with a certain time before the parts or subassemblies that need to be replaced, knowledge that leads to a substantiation of the necessary stocks with spare parts, based on some calculations and economic indicators. Maintenance operations can be corrective or preventive. The main objectives of preventive-planned maintenance are presented in Figure 1.

The preventive-planned maintenance system has distinct specific operations, as follows:

-periodic verification of fixed assets, operation with the definite purpose of detecting in due time the occurrence of accidental defects or malfunctions of the equipment, and is performed on groups of machine tools or on technological lines. This operation takes place without stopping the equipment or with a very short stop, depending on the complexity of the possible defect to be detected. Adjustments, vibrations, and accuracy in operation are remedied by this operation;
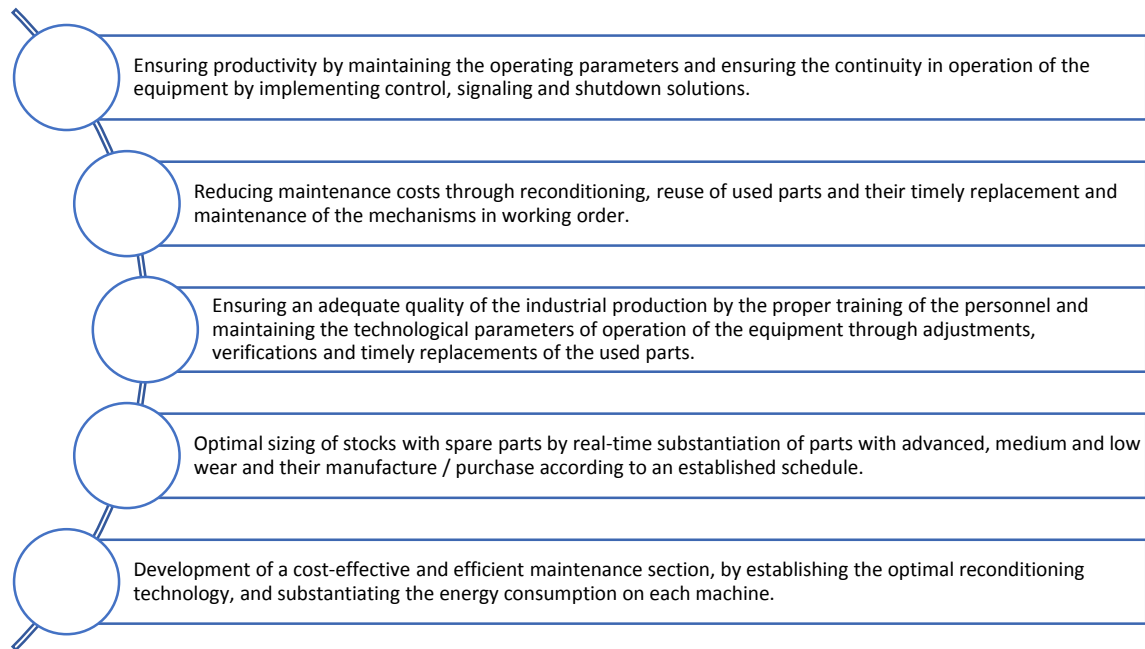
Fig.1. Main objectives and implementation methods of preventive-planned maintenance

-partial revision, consists in a careful examination of the operation of the parts, subassemblies and assemblies regarding the degree of assurance of the processing precision and of the safety in operation. The operation is performed on subassemblies and assemblies by disassembly, adjustment, replacement of worn parts and reconditioning, in order to reduce abnormal noise in operation or other deficiencies. This overhaul will be planned only during the technological breaks without the production being affected;

- the general revision aims at the verification in detail of the functional assemblies in order to ensure a safety in operation and an appropriate precision. The operation aims to check the entire machine tool, machinery or equipment in order to remedy any defects by reconditioning or replacing used parts. The operation is performed by disassembly, cleaning, measurement and verification, after which the replacements or repairs take place and, finally, the current adjustments are made;

- the technical quality control is necessary to be performed after the partial and general revisions, with the clearly defined purpose of ascertaining or not the precision and safety in operation of the equipment, maintaining the adjustments in time and the deviations from the quality of the parts.

The preventive-planned maintenance system, in addition to increasing productivity due to the normal operation of machine tools, production lines, etc., reduces repair costs and makes the human operator responsible for the importance of this activity.

The efficiency of the organization of the maintenance system of the equipment and installations can be influenced by a series of technical, economic and organizational factors. From a technical point of view, the operation of the equipment is the main factor, the technologies chosen for repairs, the costs of overhauls can be factors of economic nature and the way of organizing production, organizing the work process can be constituted as factors of organizational nature. In terms of a direct influence on the organization of the maintenance system, the following factors can have a significant influence:

-observance of the technical norms in force regarding the operation and maintenance of the equipment;

-use of normal operating regimes;

- the use of additional accessories on machine tools in order to reduce the physical effort made by the operators and to increase the labor productivity;

-existence of a plan to ensure the rhythmicity of maintenance activities.

Maintenance systems can be preventive and corrective. Preventive maintenance systems can be systemic and conditioned, and corrective ones can be curative and palliative. [4]

The main strategies of maintenance systems are:

-organizing own maintenance activities involves a certain orientation of investments, restriction or concentration of certain activities;

- the subcontracting of the maintenance activity must be based on a technical-economic substantiation in order to justify the economic efficiency in the situation of adopting such a strategy;

- the acquisition of new technical systems means big reductions in terms of maintenance costs and the possibility of directing investments to other directions.

2. INJECTION MOULDING MACHINE MAINTENANCE SYSTEM

Plastics injection machines are machines that include mechanical, electrical and hydraulic equipment, which means that the maintenance of these machines is a complex process. Ensuring a properly planned preventive maintenance system leads to an increase in the lifespan and availability of machines and to an increase in productivity.

In order to implement the maintenance system in the field of plastics injection, it is necessary to go through the operations presented in Figure 2, [3]. In addition to the eight operations presented, it is important to periodically check the noise sources, which may come from blocked hydraulic components or from an inadequate amount of oil in the machine tool.

Choosing quality oils	• Quality oils allow superior lubrication; • Quality oils reduce the risk of malfunctions and wear of injection molding machines.
Periodically clean or change the oil filters	• Oil filters ensure the proper operation of injection machines; • It is recommended to change once every three months.
Cleaning fans and cooling systems	• Fans and cooling systems ensure the proper functioning of the machines; • It is recommended to change them every two years.
Periodic inspection of the electrical system	• It is recommended to check the engine, the heating tube and the thermocouple; • This check is recommended once a year.
Carrying out a daily verification plan	• Checking the operating system manually, semi-automatically and automatically; • Checking the operation of all functions in the control panel.
Periodic check of the oil level in the hydraulic tank	• Check the tank to avoid accidental leaks; • Checking the correct lubrication of the equipment.
Checking the pressure in the hydraulic system	• Periodic pressure check; • Remedy situations in which the pressure is low or too high.
Checking the oil and cooling system	• Checking for changes in oil pressure and viscosity; • Remedying situations so as not to affect productivity.

Fig.2. Operations of the preventive-planned maintenance system for plastics injection moulding machines, [3]

3. CASE STUDY REGARDING THE ORGANIZATION OF THE MAINTENANCE SECTION

In order to organize the maintenance section at a unit producing plastic products by injection, the following steps are necessary:
-analysis of the existing situation;
-elaboration of the maintenance plan;
-establishing the optimal moment to replace the machine tools;
-choosing the optimal type of machine tool;
-establishing the wear elements of the machine tools.

The management of the company producing plastic parts by injection according to the interruptions registered in the operation of the injection machines, has as main objective the increase of the productivity by increasing the number of injection machines to be involved in the production process. Thus, the management of the unit also requests the maintenance department to elaborate a maintenance strategy in order to achieve, together with the other sections of the enterprise, this objective.

The situation existing at time t in the enterprise regarding the stationary period due to the failure on each injection machine is presented in Table 1.

Naturally, after setting the goal, we move on to establishing / adopting the maintenance method that will be used. The team in the maintenance department, taking into account the experience gained, proposed the rational method of maintenance, for the implementation of which the following rules must be observed: to be available and sufficient the necessary information; to make a quantitative and qualitative selection and to rationally adapt the means to the existing requirements.

The ABC method, also known as Law 80-20, is frequently assimilated to Paretto's law and consists of dividing an ensemble into three classes, A (elements with a weight of 80%), B (elements with a weight of 15%), and C (5% share), [5].

Table 1. The situation existing at time *t* in the enterprise

No.crt.	Injection molding machine type	Interruption period, [h]	Number of interruptions
1	T_1	105	2
2	T_2	5	3
3	T_3	15	5
4	T_4	20	4
5	T_5	13	2
6	T_6	8	3
7	T_7	150	7
8	T_8	41	6
9	T_9	9	6
10	T_{10}	185	5
11	T_{11}	25	4
12	T_{12}	7	7
13	T_{13}	3	4
14	T_{14}	95	5
15	T_{15}	4	2

In order to apply the ABC method, a classification of all faults is made in descending order according to the parking time, each fault being related to a certain injection machine, the data being presented systematically in Table 2. Figure 3 showed the share of stationary on each machine tool of the total parking times per unit. The zones A, B, C and the cars grouped on each zone are highlighted.

Table 2. Centralizing data required for the application of the ABC method

Injection molding machine type	Interruption period, [h]	Cumulative interruption period, [h]	%	Number of interruptions	Number of cumulative interruptions	%	Zone
T_{10}	185	185	27	4	4	6.15	A
T_7	150	335	48.90	8	12	18.46	A
T_1	105	440	64.23	2	14	21.53	A
T_{14}	95	535	78.10	5	19	29.23	A
T_8	41	576	84.08	6	25	38.46	B
T_{11}	25	601	87.73	4	29	44.61	B
T_4	20	621	90.66	4	33	50.77	B
T_3	15	636	92.84	5	38	58.46	B
T_5	13	649	94.74	2	40	61.54	B
T_9	9	658	95.05	6	46	70.77	C
T_6	8	666	97.22	3	49	75.38	C
T_{12}	7	673	98.24	7	56	86.15	C
T_2	5	678	98.97	3	59	90.77	C
T_{15}	4	682	99.56	2	61	93.84	C
T_{13}	3	685	100	4	65	100	C

Using the data in Table 2, the ABC curve can be drawn, Figure 3, which highlights the connection between the cumulative downtime and the cumulative failures.
As you can see, the curve has three areas:
- zone A: 29.23% of failures represent 78.10% of the total downtime of the injection machines;
-zone B: 32.31% of the defects found represent only 16.64% of the total downtime of the injection machines;
-zone C: 38.46% of the faults found represent only 5.26% of the downtime of the injection machines.
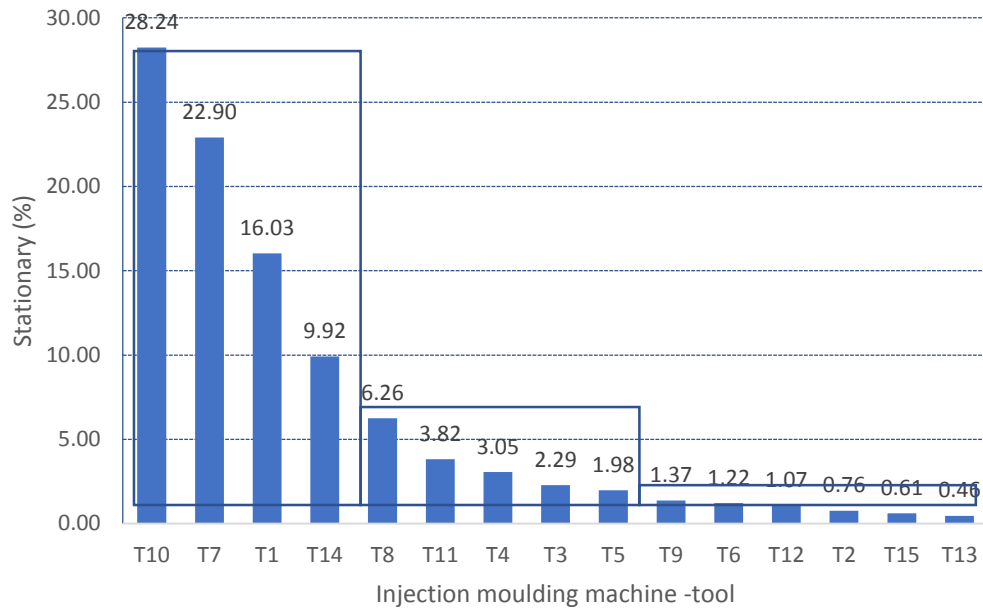
Fig. 3. Share of parking times per machine tool out of total parking times per unit
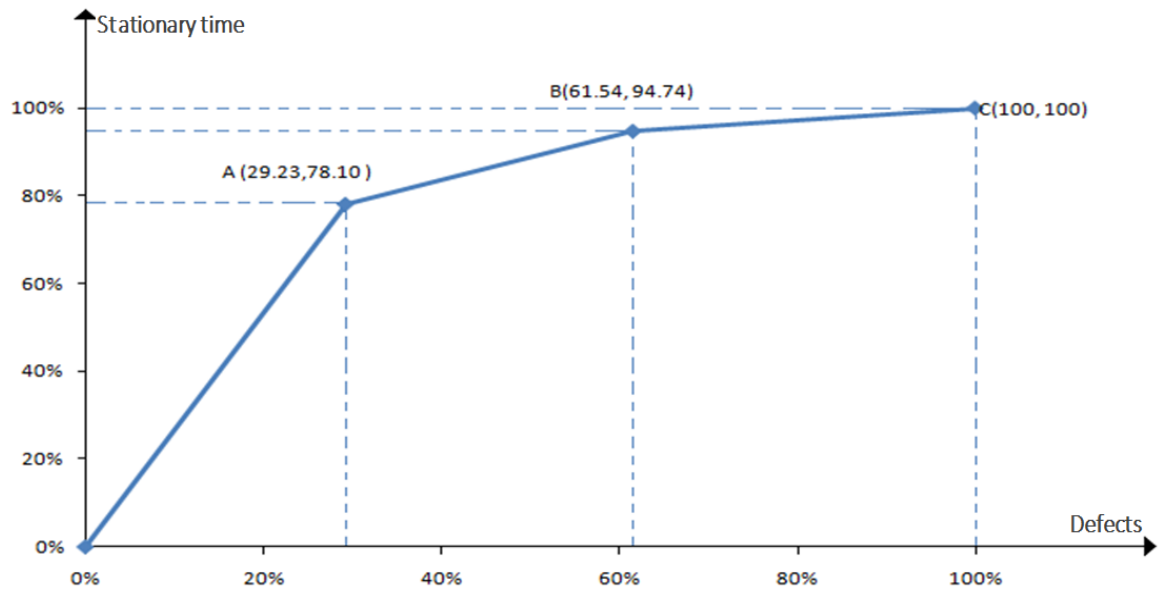

Fig. 4. Stationary time variation curve by applying the ABC method

According to the results obtained, some decisions can be made regarding the maintenance activity, as follows:

-injection machines T_{10}, T_7, T_1 şi T_{14}, belong to A *zone*, have fundamental priority; for these machines a preventive-planned maintenance policy will be implemented, with a rigorous supervision of the "critical points";

-in case of injection machines from B *zone* (T_8, T_{11}, T_4 ,T_3, T_5,) no high level requirements will be imposed in terms of prevention methods;

- for injection molding machines from C *zone* (T_9, T_6, T_{12}, T_2, T_{15}, T_{13}) no preventive maintenance method will be applied, but only maintenance actions according to needs.

Implementation of a method of preventive-planned maintenance of equipment T_{10}, T_7, T_1 and T_{14}, with direct effects on reducing or even eliminating accidental malfunctions, it will help increase the availability of injection molding machines by up to 78.10%.

3.1. Elaboration of the maintenance plan of the injection machines

In order to elaborate the maintenance plan for the injection machine T_{10}, taking into account the technical regulations for maintenance, the data in Table 3 are required for a three-shift operating regime.

Table 3. Data necessary for the implementation of the maintenance plan

Category number of intervention	The interval between two category interventions i	Standing time in repairs (working days)	Planned costs, (% of total)	Completion date type and number, in the general structure of the repair cycle, of the last repair in the current year	Planned operating mode of the injection molding machine
1	-for R_t – 1150 hours;	-for R_t – 1 day;	-for R_t– 1.5%,		
2	-for R_{C1} – 2300 hours;	-for R_{C1}– 5 days;	-for R_{C1} – 12.5%,	October 20 - Fourth Technical Review	-2 work shifts; -the duration of the shift is eight hours.
3	-for R_{C2}– 9200 hours;	-for R_{C2} – 11 days;	-for R_{C2}– 26%,		
4	-for R_K – 27600 hours;	-for R_K–20 days;	-for R_K – 60%;		

The stages of elaboration of the maintenance plan are as follows:
a) Determining the number of technical interventions (by categories) to be performed within a repair cycle, using relation (1), with the values presented in Table 4.

$$N_i = \frac{D_{CR}}{d_i} - N_i^S \tag{1}$$

where: N_i represents the number of category i interventions; D_{CR} is the duration of the repair cycle, [h]; d_i is the interval between two category i interventions, and N_i^S represents the number of higher degree interventions.

Table 4. Calculated values of technical interventions

No.crt.	Name of technical intervention	Value obtained
1	N_{RK}	1
2	N_{RC2}	2
3	N_{RC1}	9
4	N_{Rt}	12

b) Graphic representation of the structure of the repair cycle based on the number of interventions previously determined and the duration between two interventions of the same kind, according to Figure 5.
c) Establishing the time interval (T1) in the calendar days, from the date of the last intervention performed on the T10 injection machine in the base year until each of the following interventions in the structure of the repair cycle, using relation (2).

$$T_i = \left[\frac{D_{RC} \cdot n}{d_s \cdot n_s} + \sum_{i=1}^{n-1} t_{si} \right] \cdot K_t, \tag{2}$$

where: D_{RC} is the operating interval between two consecutive interventions (interval between two technical revisions), [h]; d_s represents the planned duration of the exchange; n_s is the number of shifts; n is the number of the intervention for which the total downtime of the injection machine is calculated in the previous planned interventions, in working days, according to the norm, T_i, given by the relation (3).

$$T_i = \sum_{i=1}^{n-1} t_{si} \tag{3}$$

where t_{si} it is the stationary time for the i intervention and K_t coefficient of transformation from actual operating days into calendar days given by the relation (4).

$$K_t = \frac{\text{Calendar days}}{\text{Nominal time}} = \frac{365}{255} = 1.43 \qquad (4)$$
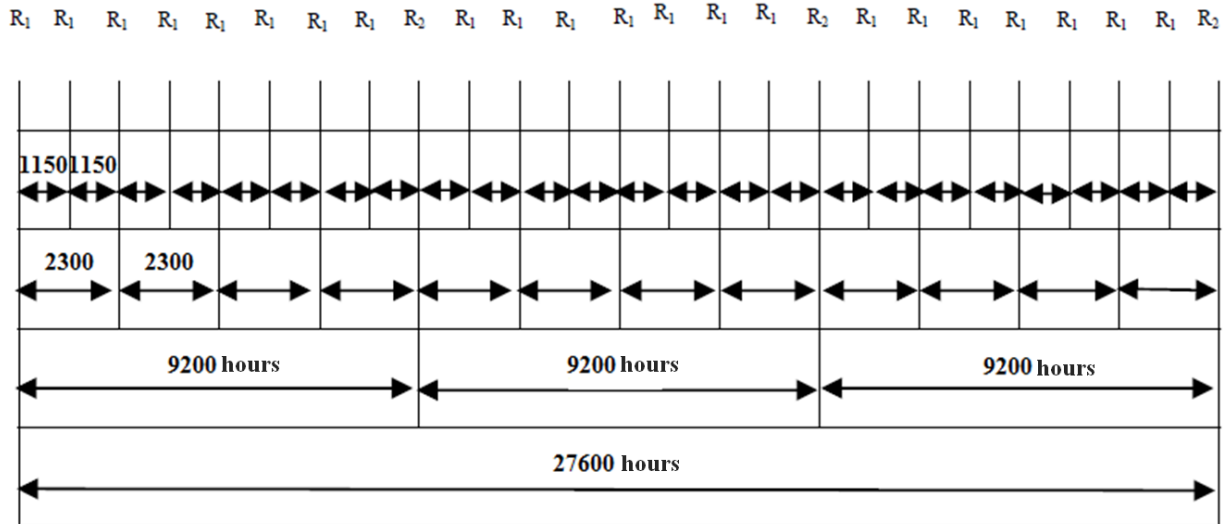

Fig. 5. The structure of the repair cycle

In case of T_{10} injection moulding machine the following interventions are: R_{C2}, R_t, R_{C1}, R_k.

$$T_1 = \left[\frac{1150 \cdot 1}{8 \cdot 2} + 0\right] \cdot 1.43 = \mathbf{103\ days}$$

$$T_2 = \left[\frac{1150 \cdot 2}{8 \cdot 2} + 11\right] \cdot 1.43 = \mathbf{221\ days}$$

$$T_3 = \left[\frac{1150 \cdot 3}{8 \cdot 2} + (11 + 1)\right] \cdot 1.43 = \mathbf{326\ days}$$

$$T_4 = \left[\frac{1150 \cdot 4}{8 \cdot 2} + (11 + 1 + 5)\right] \cdot 1.43 = \mathbf{435\ days}$$

d) The calendar schedule of the planned technical interventions is presented in Table 5. So, for the T_{10} injection machine in the plan year, the following technical interventions will be performed: two technical revisions (R_t); a current grade I repair (R_{C1}) and a current grade II repair (R_{C2}).

e) Determining the expenditure budget for carrying out the planned technical interventions.

In the case of the T_{10} injection machine, whose inventory value is 150.000 UV (value units), the repair costs, by type of technical intervention, will be:
- for a technical overhaul (R_t): $150000 \cdot 1.5\% = 2250$ UV;
- for a current grade I repair (R_{C1}): $150000 \cdot 9\% = 13500$ UV;
- for a current grade II repair (R_{C2}): $150000 \cdot 26\% = 39000$ UV;
- for a major overhaul (R_K): $150000 \cdot 60\% = 90000$ UV.

Considering the technical interventions planned for the plan year, it results that this year the expenses with the repairs of the T_{10} machine will be $2 \cdot 2250 + 13500 + 39000 = 57000$ UV.

Table 5. Scheduling of planned technical interventions

Year	Basic				Plan											
Indicator	IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Number of calendar days	10	31	30	31	31	28	31	30	31	30	31	31	30	31	30	31
Cumulated number of days	10	41	71	102	133	161	192	222	253	283	314	345	375	406	436	467
Planned technical interventions					R_{C2}			R_t				R_{C1}			R_t	

3.2. Determining the optimal time to replace machine tools

In order to determine the optimal time to replace an injection machine, the A model. Kaufman can be used, [6] a model that takes into account the maintenance and repair costs, the purchase value of the machine, considering as the optimal time to replace the year in which the maintenance and repair costs exceed the discounted cost of acquisition, maintenance and repair, respectively the year in which the relationship is satisfied (5).

$$Ch_{n+1} > \frac{A + \sum_{j=1}^{n} Ch^{j-1}j}{\sum_{j=1}^{n} y_{j-1}} \tag{5}$$

where: A is the expenses of machine purchase; Ch_j are the expenses for the maintenance and repair of the machine in year j, and $y = \frac{1}{1+d}$, is the updating factor, woth „d" percentage of interest and taxes.

Analyzing the "history" of the T_{10} injection machine, existing in the company, it turns out that it was put into operation seven years ago, the normal duration of operation being 10 years, and the maintenance and repair costs were: year 1 - 4000 UV, year 2 - 8500 UV, year 3 - 14000 UV, year 4 - 21500 UV, year 5 - 27000 UV, year 6 - 36000 UV and year 7 - 41000 UV.

Considering the maintenance and repair plan developed, the level of these expenses is 57000 UV, the expenses occasioned by the purchase of the T_{10} machine are 150000 UV, and the interests and taxes represent 8%.

Thus, in order to determine the time of replacement of the T_{10} injection machine, according to relation (5), the systematization of the results is presented in Table 6. It results that the T_{10} injection machine will be replaced in the plan year, because the planned repair costs are higher than purchase plus up-to-date maintenance and repairs.

Table 6. Injection machine maintenance and repair costs T_{10}

Year	Ch_j	α^{j-1}	$\sum_{j=1}^{n} y^{j-1}$	$\sum_{j=1}^{n} Ch_j^{y^{j-1}}$	$A + \sum_{j=1}^{n} Ch_j^{y^{j-1}}$	$\dfrac{A + \sum_{j=1}^{n} Ch_j^{y^{j-1}}}{\sum_{j=1}^{n} y^{j-1}}$
1	4.500	1	1	4.500	150.000	150.000
2	9.000	0.91	1.91	12.690	162.690	85.178
3	14.500	0.83	2.74	24.725	174.725	63.768
4	22.000	0.75	3.49	41.225	191.225	54.792
5	27.500	0.69	4.18	60.200	210.200	50.287
6	36.500	0.64	4.82	83.560	233.560	48.456
7	42.000	0.57	5.39	107.500	257.500	47.773
8	**57.000**	0.52	5.91	137.140	287.140	**48.503**

3.3. Choosing the optimal type of injection molding machine

To replace the T_{10} machine it is possible to choose a new machine from four types of machines (T_{t1}, T_{t2}, T_{t3}, and T_{t4}), with the same performance from a technical point of view, but with different purchase prices and maintenance and repair costs, according to the Table 7.

The choice of the optimal type of injection machine will be made based on the economic criterion (relation 6), considering as the optimal type that injection machine for which the purchase, maintenance and repair for a certain period is minimal.

$$C_m = \frac{1}{n \cdot m} \cdot \sum_{i=1}^{n} \left(A_i + \sum_{j=1}^{m} Ch_{ij} \right) \tag{6}$$

where: C_m is the average cost of purchasing, maintaining and repairing the injection molding machine, [UV]; These are the costs of purchasing the machine; Ch_{ij} represents the maintenance and repair costs of the purchased equipment and related to the maintenance and repair cycles j; n is the number of machine purchases during the period considered, and m is the number of maintenance and repair cycles between two replacements.

The values obtained for the average C_m costs for each type of injection molding machine are summarized in Table 8.

The optimal type of injection machine that will be chosen to replace the T_{10} injection machine is T_{t4}, because it has a minimum average cost of purchase, maintenance and repair, respectively 42.286 UV.

Table 7. Expenses for the purchase of new injection machines

Injection machine type	Purchase expenses, [UV]	Maintenance and repair costs							
		1 cycle	2 cycle	3 cycle	4 cycle	5 cycle	6 cycle	7 cycle	8 cycle
T_{t1}	105.000	6.500	8.500	11.500	-	-	-	-	-
	120.000	-	-	-	8.500	11.000	14.000	-	-
T_{t2}	175.000	8.500	10.000	13.000	15.000	17.500	20.000	-	-
T_{t3}	145.000	7.000	8.500	13.000	15.500	-	-	-	-
	160.000	-	-	-	-	8.000	10.500	13.000	16.500
T_{t4}	185.000	9.000	11.000	13.500	16.500	18.500	20.500	22.000	-

Table 8. Average C_m costs of acquisition, maintenance and repair

No.crt.	Average cost per type of injection molding machine	Value, [UV]
1	$CmT_{t1} = \frac{1}{2 \cdot 3}[\,105000 + (6500 + 8500 + 11500) + 120000 + (8500 + 11000 + 14000)]$	47500
2	$CmT_{t2} = \frac{1}{1 \cdot 6}[\,175000 + (8500 + 10000 + 13000 + 15000 + 17500 + 20000)]$	43167
3	$CmT_{t3} = \frac{1}{2 \cdot 4}[\,145000 + (7000 + 8500 + 13000 + 15500) + 160000 + (8000 + 10500 + 13000 + 16500)]$	49625
4	$CmT_{t4} = \frac{1}{1 \cdot 7}[\,185000 + (9000 + 11000 + 13500 + 16500 + 18500 + 20500 + 22000)]$	42286

3.4. Determining the random wear elements of the injection molding machine

For T_7 and T_1 injection machines, whose interruptions represent 53.1% of the total time of enterprises in the section, in order to increase the availability of machines in the production section, the management of the maintenance section aims to study the behavior of a part of great importance for the operation of these injection machines, using the theory of random wear of industrial equipment.

Considering the "history" of these injection machines for a period of 10 years, existing in the enterprise, the situation of the remaining parts in operation is presented systematized in Table 9.

In order to make decisions about the supply and stock size for this part, it is necessary to calculate: survival function, probability of failure, conditional probability of failure, probability of having a replacement, respectively two replacements from 0 to 5 years and the average life of the piece. The values obtained are centralized in Table 10.

Table 9. History of injection molding machines in the enterprise

t Year	0 (Number of parts remaining in operation)	1	2	3	4	5	6	7	8	9	10
Number of parts remaining in operation [n (t)]	1100	1080	1040	980	910	640	320	270	210	140	0

Table 10. Data for determining supply requirements and stock size

Year	Number parts in function [n (t)]	Average life n (t−1) − n (t)	Survival function $V(t)=\frac{n(t)}{n(0)}$	Probability of failure $p(t)=\frac{n(t-1)-n(t)}{n(0)}$	Conditional probability of failure $P_c(t)=\frac{n(t-1)-n(t)}{n(t-1)}$
0	1000	-	1	0	0
1	990	10	0.99	0.01	0.01
2	930	60	0.93	0.06	0.06
3	870	60	0.87	0.06	0.064
4	820	50	0.82	0.05	0.057
5	550	270	0.55	0.27	0.329
6	210	340	0.21	0.34	0.618
7	160	50	0.16	0.05	0.238
8	120	40	0.12	0.04	0.25
9	50	70	0.05	0.07	0.583
10	0	50	0	0.05	1

The probability of having a termination in the first "t" years is determined by the relation (7).

$$P_1(t)= \sum_{u=1}^{t} v(t-u) \cdot f(u) \tag{7}$$

where: v (t-u) is the survival function, and f (u) is the probability of failure.

Based on the relation (7) and the data from Table 9, the probability of having a decommissioning in the first 5 years of operation is presented in Table 11.

Table 11. Probability of failure in the first 5 years of operation

No.year	Probability every year	Value
1	$P_1(1)= \sum_{u=1}^{1} v(1-u) \cdot f(u)= v(0) \cdot f(1)= 1\cdot 0.01$	0.01
2	$P_1(2) = \sum_{u=1}^{2} v(2-u) \cdot f(u) = v(1) \cdot f(1) + v(0) \cdot f(2) = 0.99\cdot$ 0.01+ 1· 0.06	0.069
3	$P_1(3) = \sum_{u=1}^{3} v(3-u) \cdot f(u)= v(2) \cdot f(1)+ v(1)\cdot f(2) +v(0) \cdot f(3)=$ 0.93· 0.01+ 0.99· 0.06+ 1· 0.06	0.1287
4	$P_1(4) = \sum_{u=1}^{4} v(4-u) \cdot f(u)= v(3) \cdot f(1)+ v(2)\cdot f(2) + v(1)\cdot f(3) +$ v(0)· f (4) = 0.87· 0.01+ 0.93· 0.06+ 0.99· 0.06+ 1·0.05	0.1739
5	$P_1(5) = \sum_{u=1}^{5} v(5-u) \cdot f(u)= v(4) \cdot f(1) + v(3)\cdot f(2) + v(2)\cdot f(3) +$ v(1)· f (4) +v(0)· f (5) = 0.82·0.01+0.87·0.06+0.93·0.06+0.99·0.05+1·0.27	0.4357

In order to determine the probability of having "m" outputs in the first "t" years of operation, the recurrence relation is used (8).

$$P_m(t)= \sum_{u=1}^{1} P_{m-1}(t-1)\cdot f(u), \text{ with condition: } P_m(0) = 0 \tag{8}$$

Applying the relation (8), also based on the data from Table 11 and those obtained for the calculation of the probability of having a replacement in the range from 0 to 5 years, it will result :

$P_2(5) = \sum_{u=1}^{1} P_{2-1}\cdot(5-1) \cdot f(2) = P_1(4) \cdot f(1) + P_1(3) \cdot f(2) + P_1(2) \cdot f(3) + P_1(1) \cdot f(4) = 0.1739\cdot0.01+$ 0.1287·0.06+0.069·0.06+0.01·0.05 = 0.01410

For the calculation of the average life of the part (Dm), the relation (9) is applied, obtaining the value of 5.7 years.

$$D_m = \sum_{t=1}^{10} t \cdot p(t) \qquad\qquad (9)$$

4. CONCLUSIONS

The main stages specific to the preventive-planned maintenance developed in the paper consisted in elaborating the maintenance plan, establishing the optimal time to replace the machine tools, choosing the optimal type of machine tool and establishing the random wear elements of the machine tools. A. Kaufman's model was used to determine the optimal time to replace an injection machine, a model that takes into account the cost of maintenance and repairs, the purchase value of the machine, considering as the optimal time to replace the year in which the costs of injection. maintenance and repairs exceed the updated cost of acquisition, maintenance and repair. The optimal type of injection molding machine that will be chosen to replace the T_{10} injection molding machine is T_{14}, as it has a minimum average cost of purchase, maintenance and repair, respectively 42.286 UV.

REFERENCES

1. Mazurchevici S-N., Quadrini F., Nedelcu D., (2018), *The liquid wood heat flow and material properties as a function of temperature*, Materials Research Express 5 (3), 035303
2. Broitman E., Nedelcu D., Mazurchevici S-N., Glenat H., Grillo S., *Tribological and nanomechanical behavior of liquid wood*, Journal of Tribology 141 (2), 022001
3. https://www.starlubricants.ro/despre-noi/stiri/2016/07/28/9-pasi-pentru-intretinerea-masinilor-de-injectie-mase-plastice, accessed on 12.05.2021
4. https://www.afahc.ro/ro/facultate/cursuri/luculescu/6.%20Mentenanta%20si%20mentenabilitate.pdf, accessed on 29.03.2021
5. https://www.creeaza.com/referate/management/Metoda-ABC387.php, accessed on 12.05.2021
6. https://kodosurvey.com/blog/kaufmans-model-learning-evaluation-key-concepts-and-tutorial, accessed on 12.05.2021
7. Fradinho J., Nedelcu D., Gabriel-Santos A., Gonçalves-Coelho A., Mourão A., (2015), *Some trends and proposals for the inclusion of sustainability in the design of manufacturing process*, IOP conference series: Materials science and engineering 95 (1), 012142.