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IMPLEMENTATION OF TOTAL PRODUCTIVE MAINTENANCE PROGRAM FOR AN ELECTRONIC COMPONENT PRODUCTION PROCESS IN HUNGARY

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Abstract

By demonstrating the example of a multinational company in Hungary, this paper presents some parts of the introduction of a TPM program. Since the Hungarian company conditions show a significant difference compared with characteristics of the Western European company environment, it was necessary to amplify the usual phases of the TPM introduction. It seems that this presentation of our recommendations for different approaches to the local situation in Hungary will be useful and practical for future use.

Keywords: TPM, reliability engineering.

1. Introduction

The process of substantial changes of the Hungarian economy had begun about a decade ago, and about two years before the extensive political changes occurred in the country. From the very beginning, the obvious goal has been to catch up with world class standards on the level of individual companies. What is sad about this process of change several years until companies realized that the only possible way to catch up was the implementation of the most state-of-the-art management models. Because of this time lag, it is only now, after about a decade, that the evaluation these models that based on sufficient experience is possible. In the productive sector, it is probably – the World Class Manufacturing (WCM) models give form to the most widespread world class standards. Even though individualized packages of WCM technologies have to be designed for the different industries and types of companies, the modern maintenance management methods always represent one of the most important parts of the WCM. This paper is about the implementation process of these methods in Hungary.

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First of all, it is important to point out that companies in Hungary have taken two general routes to the implementation of these maintenance management methods. One route was the natural one, where companies had realized on their own the necessity to implement these methods. However, the most typical way of the implementation of new methods has been by foreign or multinational companies that they have purchased Hungarian companies and implemented these methods right away. These somewhat too rapid implementations have revealed the weak points of these methods, or at least the weak points of the specific applications of these methods used in Hungary. It soon became obvious that without corrections and modifications these 'imported' methods cannot be effectively applied in the current economic environment of Hungary.

2. Special Features of the Hungarian Company Environment

First, we will briefly summarize the most important characteristics of the Hungarian company environment. Although these characteristics are specific to Hungary, they are very typical of all the previous communist countries, as well.

2.1. General Characteristics of Hungarian Companies

- Relatively well-trained workers
- Equipment of different technical levels in one and the same plant (causing many bottle-necks and capacity surplus)
- Low level information systems
- Teamwork is not typical
- Lack of suitable coordination among departments and units within a company
- Lack of cross-functional teams
- No day-to-day continuous improvement
- No continuous logging and data tracking, in terms of manufacturing process, causes of machine failures, and so on
- General lack of organization on plants, offices, and so on
- Mismanagement of time, money, equipment, and man-power

2.2. Some Characteristics of the Culture of Management in Hungary (VÖLGYES, 1997)

Excellent ability of problem recognition and capacity for information reception. However:

- Lack of prompt decision making abilities
- There is a lack of clearly defined bodies or committees of decision making and of accountability
- Workers or managers in lower level positions are rarely involved in decision making processes
- Lack of prompt follow-up and of continuous improvement
- Weak practices of customer focus

2.3. Some Characteristics of the Culture of the Foreign Owners

- Foreign, usually multinational, owners of Hungarian companies had over-invested at the time of purchasing the companies, and later ran out of money.

Therefore:

- Too little investment in resources. Therefore the results have to be achieved with what they have got, and they have to be achieved as quickly as possible.
- Blind belief in methods established in other countries.
- Especially great emphasis placed on the improvement of maintenance because management practices are relatively weak in companies purchased by foreign investors and because even small investments made by these investors tend to bring about firm results.

2.4. Some Characteristics of Maintenance Management

- Operation and maintenance are formally separated.
- Machine operators basically do not perform maintenance of their equipment
- No small-group improvement
- Lack of organized data collection, resulting in insufficient data
- Lack of data analysis
- Practically no planned preventive maintenance
- Breakdown maintenance
- Lack of reliability analyses
- Lack of business-mindedness

2.5. ISO 9000 Quality System

Being a special case, it is important to mention the ISO 9000 Quality System, which is widely spread in Hungary. The implementation of this quality system is often a question of life and death for Hungarian companies because the ISO 9000 is not only the basic requirement for exporting to Western Europe, but it is more and more becoming a requirement of orders placed by the Hungarian government. Therefore, the implementation of this system is often necessity, as opposed to the result of the companies' faith in the methods. Consequently, the development of quality or management systems that would be based on internal needs are almost always preceded by the implementation of the ISO 9000 Quality System. As we know, the development of a thorough documentation system is a requirement of the ISO certificate, the basis of which is a several hundred page long manufacturing and quality assurance manual. Due to the lack of well-developed and useable documentation systems or existing production manuals, companies almost always have to start this process from scratch. Therefore, the development of such new documentation systems is extremely difficult and lengthy task. Unfortunately, it is to be noted that these difficulties often result in viewing the passing of the 'ISO exam' as the sole goal, instead of the development of an effectively working quality assurance system.

3. Specifications of the To-Be-Implemented Maintenance System in Hungary

The first task is to choose and describe the maintenance system that is found the most suitable one for implementation in the existing environment in Hungary. On the other hand, the situation in the country is unique, and unfortunate, in that due to outdated management practices currently in use, the implementation of less modern methods is often warranted. On the other hand, it is extremely helpful that Hungarian professionals now have the opportunity to familiarize themselves with the operations of modern Western companies. This helps them conceptualize the future of Hungarian companies and the plan for the next level to reach. Taking all this into consideration, the maintenance system to be developed has to be one that:

- encourages the modification of management systems, enables the development of better work ethics,
- prepares the company for the potential new investments in equipment and plants,
- is capable of supplying the rapidly developing information systems of companies with data,
- establishes the now widely spread implementation of condition-based or condition-monitoring technologies.

The two most important maintenance system frameworks to be considered are the Reliability-Centred Maintenance (RCM) and the Total Productive Maintenance (TPM).

3.1. Reliability-Centred Maintenance

The RCM purports to determine what must be done to ensure that any physical asset continues to fulfill its intended functions in its present operating context (MOUBRAY, 1992). Its best features are the involvement of the operators and maintainers in the reassessment of the maintenance needs, and the vital importance of the availability of reliability data and operating experience. Its most dramatic successes have been in cases when a plant has previously been grossly over-maintained (e.g. area aviation, defense and nuclear power plants) (SMITH, 1992). This framework is also quite effective at recognizing when a plant frequently fails because of over-stress or abuse (SHERWIN and JONSSON, 1995). However, RCM does not fully recognize that maintenance is an economic problem at the machine or plant level (AL-NAJJAR, 1996; SHERWIN and JONSSON, 1995). Actually, RCM has been developed with the emphasis on safety, without any built-in mechanism for determining optimal maintenance intervals (HORTAN, 1993). To date, the quantitative approach to RCM has taken a back seat to the qualitative approach (KOWALSKI, 1993). This is because of the unavailability of plant-specific historical data and appropriate statistical methods to interpret such data (SRIKRISHNA, YADAVA and RAO, 1996). Furthermore, it concentrates on improving an existing plant rather than establishing a future plant in the right way from the beginning, which can be achieved only by data feedback to designers. (SHERWIN and JONSSON, 1995)

Another shortcoming of RCM is that it does not make full provision for the use of condition-based techniques, and therefore the development of potential failures are not followed until just before failure. (HOLLICK and NELSON, 1995).

Even though RCM can be very effective in many special cases, on the basis of its above outlined characteristics, we do not think that RCM is the best general approach in the existing company environment in Hungary.

3.2. Total Productive Maintenance

In contrast to the RCM approach, the implementation of the Total Productive Maintenance (TPM) seems to be more practical and suitable in our country. TPM consists of a range of methods which are known from maintenance management experience to be effective in improving reliability, quality, and production (AL-NAJJAR, 1996). It aims to reduce failures, set-ups, and other causes of poor or reduced production by involving the operators in the maintenance of their machines, as an integral part of the TQM philosophy. This framework requires operators to take over some of the maintenance staff tasks (e.g., clean, lubricate, tighten bolts, adjust and report their observations about changes in the machine condition) (NAKAJIMA, 1989). Condition-monitoring (CM) (e.g., vibration analysis) also has an important role in TPM for supporting the operator maintenance and to assist the operators in searching for abnormalities in the equipment (AL-NAJJAR, 1996).

To summarize, because its basic philosophy seems to best fit the necessary process of changing the company culture in Hungary, the implementation of the TPM is recommended in most of the Hungarian companies.

4. TPM Implementation in Western Companies

In Western countries TPM is normally implemented in four phases, with each phase including some substeps (SUZUKI, 1994). These four phases can be further broken down into a more detailed list of phases.

1. Preparation Phase: a. Top Management Announces Its Decision to Introduce TPM; b. TPM Introductory Education; c. Create a TPM Promotion Organization; d. Establish Basic TPM Policy and Goals; e. Draft a TPM Master Plan

2. Introduction Phase: a. Kick Off TPM Initiatives

3. Implementation Phase: a. Build a corporate constitution designed to maximize production effectiveness (a-1. Focused Improvement, a-2 Autonomous Maintenance, a-3 Planned Maintenance, a-4 Training); b. Early Management; c. Quality Maintenance; d. TPM in Administrative and Support Departments; e. Safety and Environmental Management

4. Consolidation Phase: a. Sustaining TPM Implementation and Raising Levels

Obviously, step 3.a is the most critical stage of the TPM development. Even if one step of this stage fails, the implementation of the whole TPM will not succeed. This could have a whole range of different consequences, ranging from the whole management losing credibility to the general disappointment in other programs with the same philosophy. Therefore, it is very irresponsible to use a TPM program when a company does not have the background that is feasible for the implementation of TPM, an important fact companies often seem to forget about. With the above listed characteristics of the Hungarian company environment in mind, we can understand that a typical Hungarian company does not have the adequate background to implement a TPM program in the above outlined form.

In our view, a Pre-preparation, or Introductory Program should precede the Preparation Phase of the TPM when a company is not yet prepared for its implementation.

5. A Proposed Pre-Preparation Program Preceding the Implementation of the TPM Program in Hungarian Companies

First, let us review some of the aspects of the ISO 9000 quality system again. As mentioned above, we can assume that this system either exists or it is in the process of implementation at these companies. In spite of its various weaknesses, several points of the ISO can be considered appropriate introductory steps to the TPM. Therefore, it is definitely worthwhile to combine the common features of the ISO implementation and the Pre-preparation Phase of the TPM program. One example would be the inclusion of cross-functional teams that are trained for the implementation and/or application of TPM, in the development of ISO documentation. However, it is important to remember that the ISO 9000 quality system in itself does not equal to the preparation for the implementation of a TPM program. Rather, one of the goals of such a Pre-preparation Program is to use those basic TPM details that are not sufficiently emphasized in the ISO 9000. In essence, this TPM Pre-preparation Phase is a specialized training program for production engineers, maintenance personnel, and operators. It prepares these professionals for:

- solving maintenance related problems on an individual or team basis,
- working in cross-functional teams, and
- for understanding and embracing of the TPM concept.

Our plan is to start out with formal lectures and presentations, and later use consultations. Eventually, we would analyze and solve increasingly more complicated, real life, maintenance related problems in form of small group exercises.

This training program will be characterized by the parallel teaching of the field of Reliability and Maintenance Engineering and the field of Engineering Economy, in such a way that the different reliability and maintenance problems will be solved by considering their economic aspects. This teaching approach is crucial also because it will improve trainees' business-mindedness, which is not a focus of the ISO.

One of our other goals is to find teaching methods that will help to solve mathematically difficult problems and at the same time will assist with the deeper understanding of the problems. This can be excellently achieved by using graphic representations and explanations, and by the simultaneous application of computer simulations. A further essential feature of our approach is that our exercises will include data collection and analysis, an important practice that a typical Hungarian company does not effectively employ today.

5.1. *Some Characteristics of the Pre-Preparation Program*

Perhaps a good example of the above mentioned graphics aid is the following (MARSTON, WINFREY and HEMPSTEAD, 1953) (*Fig. 1*).

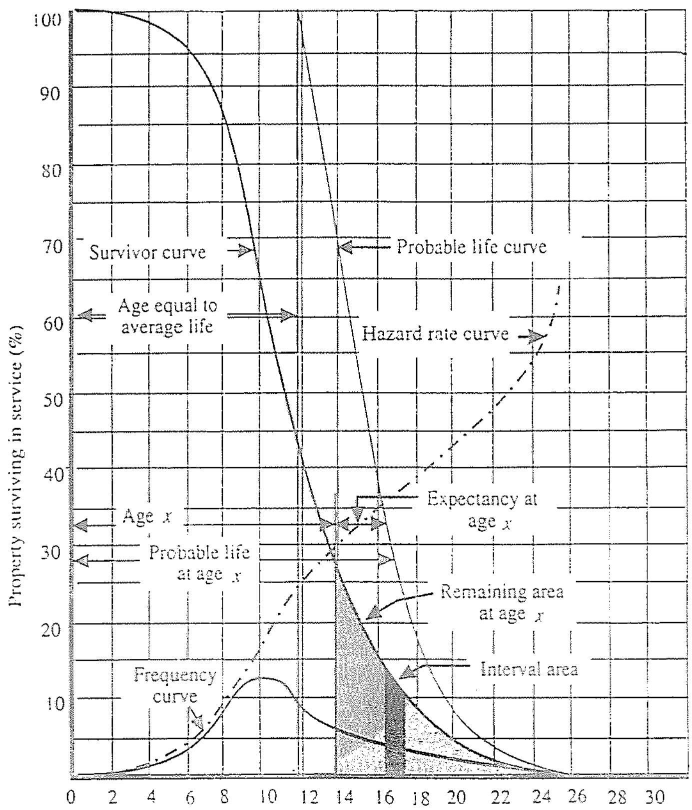


Fig. 1.

Participants may use this aid to understand the characteristics of the more important reliability functions, and their derivatives and integrates, and in addition, this figure helps them understand the relationships among these curves.

A special characteristic of the teaching of Engineering Economy is that it uses continuous cash flows instead of discrete cash flows, that is

Table 1.

Density function	Laplace Transform
Generalized normal: $\frac{1}{\sigma\sqrt{2\pi}}e^{-(x-\mu)^2/2\sigma}$	$e^{-r\mu+\frac{r^2\sigma^2}{2}}$
Standard normal: $\frac{1}{\sqrt{2\pi}}e^{-x^2/2}$	$e^{r^2/2}$
Uniform: $\frac{1}{b-a}, a \leq x \leq b$	$\frac{e^{-ra}-e^{-rb}}{r(b-a)}$
Gamma: $\frac{a^b}{(b-1)!}x^{b-1}e^{-ax}, 0 < x < \infty$	$(1+\frac{r}{a})^{-b}$
Exponential: $ae^{-ax}\ 0 < x < \infty$	$(1+\frac{r}{a})^{-1}$

$$P(i) = \sum_{n=0}^{\infty} \frac{F_n}{(1+i)^n} \longrightarrow P(r) = \int_0^{\infty} f(t)e^{-rt}\,dt.$$

The reason for using the continuous forms is the better and easier treating of the economic problems of uncertain timing, which problems are the most frequent in the field of maintenance. Since we base on

$$L\{f(t)\} = F(s) = \int_0^{\infty} f(t)e^{-st}\,dt \longrightarrow P(r) = L\{f(t)\}|_{s=r} = L(r)$$

and (PARK and SHARPE-BETTE, 1990), that the Laplace-transform of the most important probability density functions have relatively simple form (PARK and SHARPE-BETTE, 1990) do we the economic problems of uncertain timing are relatively simple solvable. For example see *Fig. 2.*

When analyzing different basic reliability problems, team members usually recognize on their own the advantages of the preventive maintenance. Their thinking could be characterized this way: 'Why do we wait until the very expensive unexpected failures happen?' On the other hand, too frequent preventive maintenance is not economical either because in many cases the item or the equipment would go on working without any problem. Consequently there must be an optimum frequency of preventive maintenance.

The solution of this problem is one of the tasks of the teams. Of course, assistance is available, if necessary. First team members have to determine the cost-function, and then find the frequency where the minimum cost is. The use of diagrams is recommended in such cases, as well. Allowing team members to make mistakes is a good practice because they can learn a lot

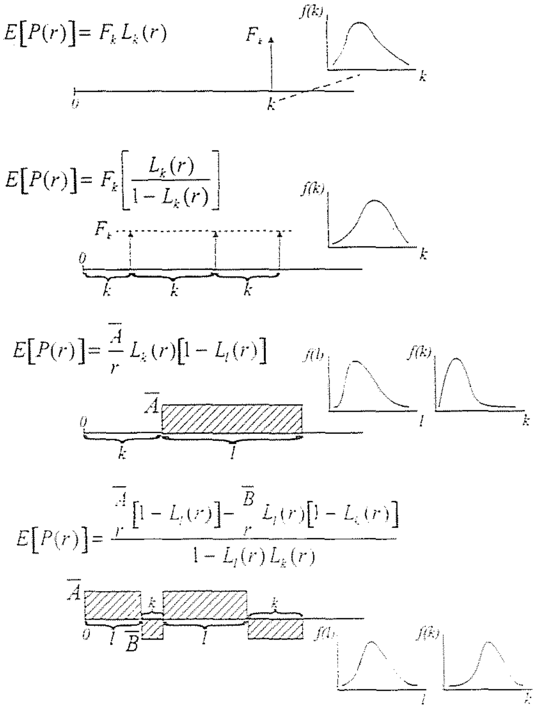


Fig. 2.

from the process of working through these mistakes (e.g., they often try to calculate an NPV instead of cost per unit time, or they have problems with giving the expected cycle length).

If they manage to determine the

$$C(T) = \frac{C_f F(T) + C_p R(T)}{\int_0^T t f(t) dt + T R(T)}$$

function, then the next step is the calculation of the preventive maintenance frequency, where the cost per unit time is minimum. Though this problem is difficult to solve analytically, it is simple to solve by using computer simulation. A good example of such a simulation program is the following MINITAB macro (*Fig. 3*).

The thorough understanding of this problem is extremely useful. On the one hand, it shows the economic aspects of the maintenance problems very well, on the other hand, a lot of important points of Reliability Engineering and Engineering Economy are easier to understand and/or repeat by going through this problem.

It can also be very useful to consider the weak points of this approach.

```
macro
preve c1 c2 c3 c4 c5 c6 c11 c12 k1 k2
mconstant k1 k2
mcolumn c1 c2 c3 c4 c5 c6 c11 c12
random 100 c11;
  weibul 2 0.5.
random 100 c12;
  normal 0.5 0.1.
do k1=1:99/2
do k2=2:100/2
let c2(k1)=c11(k1)
let c3(k2)=c11(k2)
let c1(k2)=c12(k2)
let c4(k1+2)=c12(k1)
let c4(1)=0
let c5(1)=c2(1)
if c1(k2)<c3(k2)
let c5(k2)=c5(k2-1)+c3(k2)
elseif c1(k2)>c3(k2)
let c5(k2)=c5(k2-1)+c1(k2)
let c6(k2)=c1(k2)-c3(k2)
endif
if c4(k1)<c2(k1)
let c5(k1)=c5(k1-1)+c2(k1)
elseif c4(k1)>c2(k1)
let c5(k1)=c5(k1-1)+c4(k1)
let c6(k1)=c4(k1)-c2(k1)
endif
enddo
enddo
endmacro
```

Fig. 3.

- Again, team members are faced with the problem that the density functions of the normal distribution processes are characterized by two parameters (mean and variance). Because of this fact the normal distribution allows for negative times (which physically cannot occur); therefore, it is only applicable in cases where the MTTF (mean time to failure, which is equal to the number of failures/number of trials) is fairly large and variances are relatively small.
- It is also important to consider by the teams that it is reasonable to apply preventive maintenance only if the new parts or equipment are better than the old ones in terms of likelihood of imminent failure or other measures of usefulness (MANN, SAXENA and KNAPP, 1995). Team members can realize that, although the exponential distribution is used extensively in reliability modelling because of its memoryless property (constant failure rate) and resulting analytical tractability, the preventive maintenance is of no benefit in this situation, because it does not improve the condition of components. By all means, it is

worth drawing team members' attention to this fact when the system consists of a lot of items with high MTTF (MTBF). In this case the failure process of the system is given as the sum of the failure process of items. It is easy to recognize that the failure process of the system will be approximate by a Poisson-process, therefore the preventive maintenance has no advantage.

- It is relatively simple to see that the application of the preventive maintenance method is reasonable only if the cost of a preventive repair is appreciably less than the cost of a failure and its associated repair. If the availability of the equipment also has to be taken into consideration, the problem becomes more complex. We can see in the following figure (*Fig. 4*) that the cost minimum and the availability maximum *are usually not come* at the same T. Consequently, in such cases we have to find the T preventive maintenance frequency, where the difference between the expected added-value per unit time produced by the given equipment and the expected cost per unit time is maximum. Of course the teams have to solve all these problems by computer simulation. It is also of great importance that these exercises force team members to qualify the added-value produced by the given equipment.

- Teams usually also recognize the disadvantages of the preventive maintenance on their own, that the results of the calculation are based on the use of the mean value as the measure of central tendency. If the standard deviations of these means are large, then the probability of ascertaining the maintenance interval with accuracy is small. In many of these cases the plant is over-maintained and the failures are also relatively frequent. At this point the application of the condition-monitoring technology can emerge. Again, we can interpret the case as an economic problem. If each failure can be signalled before it happens by introducing such a condition-monitoring technology, then the maintenance cost could be reduced.
- A further argument that could be brought up against the statistical-based (and beside the condition-based) preventive maintenance, is that the maintenance manager must usually assume that all operating conditions will remain the same. This assumption is seldom correct in practice, and, as a result, the 'optimal' maintenance interval may, in fact be quite inappropriate, given the current plant-operating conditions (MANN, SAXENA and KNAPP, 1995).

6. Case Study

The experiences of practical application of the pre-preparation program for the introduction of TPM are introduced by the example of a production line

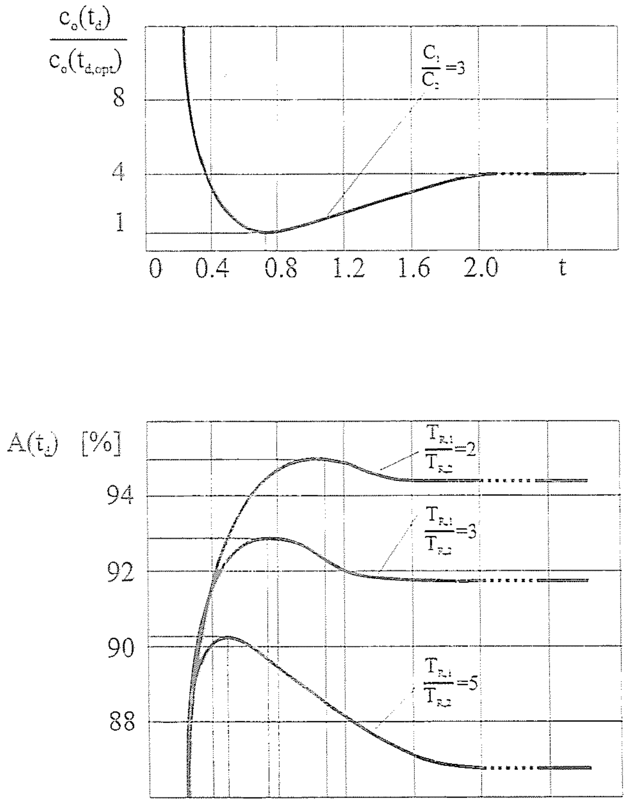


Fig. 4.

making automotive electronic components. The task of the team commissioned to carry out the program was to suggest measures which increase the reliability of the production line.

6.1. Plotting the Ishikawa Diagram

The team mapped the reliability structure of the production line and the factors influencing reliability as a first step. Due to the heterogeneous composition of the team all the significant technical, economic and organisational criteria have been taken into account. The main causality parameters of the Ishikawa diagram plotted by the team were as follows:

- Construction
- Set-up

Table 2.

Source of waste	Downtime (hour)	downtime/Total downtime(%)
Machine 1	145.4	26.1
Machine 2	6.8	1.2
Machine 3	11.8	2.1
Machine 4	52.8	9.5
Machine 5	92.8	16.7
Machine 6	39.7	7.1
Machine 7	36.3	6.5
Machine 8	64.5	11.6
Machine 9	13.8	2.5
Set-up and adjustment	11.7	2.1
Idling and minor stoppage	0.7	0.1
Reduced speed	39.6	7.1
Reduced yield	1.0	0.2
Quality defect	40	7.2
Total	556.9	100

- Technical condition
- Operational parameters
- Standard of maintenance
- Technical and safety regulations
- Level of organisation
- Human factors

The team taking part in the preparatory program tested altogether 72 factors relating to the above ones.

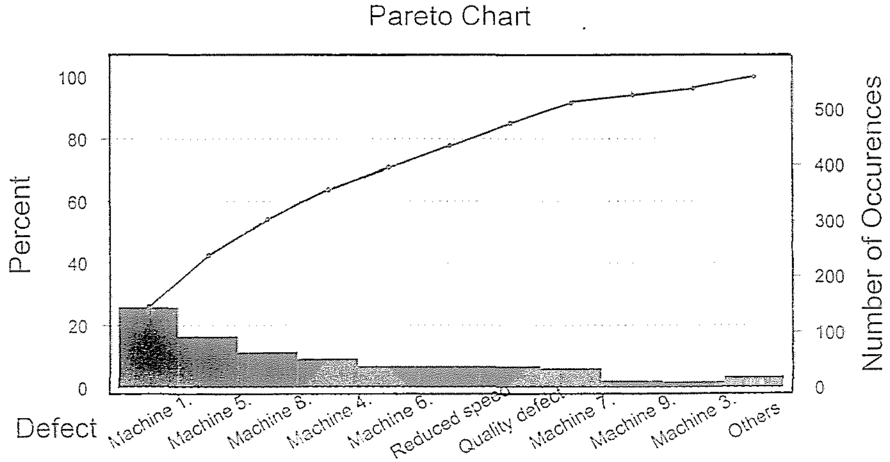
6.2. Pareto Analysis

As a next step the team carried out the Pareto analysis of the production line divided into 14 system elements on the basis of the operation data from the previous 1500 hours (causes of failures, period of idling, failure-free operation, periods between two unexpected failures, repair periods).

This breakdown strictly followed the basic principles of TPM that the reliability of the systems has to be tested as a function of the 'six big sources of loss' (equipment failure, set-up and adjustment, idling and minor stoppage, reduced speed, reduced yield, quality defects).

In this way the team carried out the analysis on the basis of the technical failure of the 9 machines constituting the system and on the additional five sources of loss (*Table 2*).

The table clearly shows that the distribution of the total 557 hour idle time follows the Pareto principle since 28.6% of all the possible sources of loss cause 63.9% of all idle time.



Defect	Machine 1.	Machine 5.	Machine 8.	Machine 4.	Machine 6.	Reduced speed	Quality defect	Machine 7.	Machine 9.	Machine 3.	Others
Count	145	93	65	53	40	40	40	36	14	12	21
Percent	25.9	16.6	11.6	9.5	7.2	7.2	7.2	6.4	2.5	2.1	3.8
Cum %	25.9	42.6	54.2	63.7	70.8	78.0	85.2	91.6	94.1	96.2	100.0

Fig. 5.

6.3. Determination of the Overall Equipment Effectiveness (OEE)

In the next step of the program the team determined the OEE factor characterising the whole system on the basis of the data in the table used for the Pareto analysis. Following the interpretation in accordance with the practice of TPM the following results are given:

$$OEE = A \times P \times Q = 0.66 \times 0.96 \times 0.96 = 0.61,$$

where

A = Availability = (Loading – Downtime) / Loading time

P = Performance efficiency = (Theoretical cycle time – Amount processed) / Operating time

Q = Quality rate = (Amount processed – Defective amount) / Amount processed.

The team analysing sources of loss concluded that OEE can be increased economically by increasing availability.

Table 3.

	Distribution of time to failure	Mean time to failure (hour)	Distribution of time to repair	Mean time to repair (hour)	Deviation of time to repair (hour)
Mach. 1	exponential	21.28	normal	3.2	0.95
Mach. 4	exponential	47.62	normal	2.61	0.87

6.4. *Increasing Reliability by Duplication*

The team with their operation experiences analysed the duplication effect of machines 1 and 4 when they draft mapped the investment possibilities. These two machines are among the critical sources of loss since in the period of tests these equipment caused 35.6% (=198.2 h) of all idling.
The team determined the reliability parameters of the machines (*Table 3*).

Then assuming cold reservation the team simulated the reliability of the duplicated elements (in parallel) by MINITAB (*Fig. 6*).

```
rem machine 1
macro
preve c1 c2 c3 c4 c5 c6 c11 c12 k1 k2
mconstant k1 k2
mcolumn c1 c2 c3 c4 c5 c6 c11 c12
random 100 c11;
  exponential 21.28.
random 100 c12;
  normal 3.2 0.95.
do k1=1:99/2
do k2=2:100/2
let c2(k1)=c11(k1)
let c3(k2)=c11(k2)
let c1(k2)=c12(k2)
let c4(k1+2)=c12(k1)
let c4(1)=0
let c5(1)=c2(1)
if c1(k2)<c3(k2)
let c5(k2)=c5(k2-1)+c3(k2)
elseif c1(k2)>c3(k2)
let c5(k2)=c5(k2-1)+c1(k2)
let c6(k2)=c1(k2)-c3(k2)
endif
if c4(k1)<c2(k1)
let c5(k1)=c5(k1-1)+c2(k1)
elseif c4(k1)>c2(k1)
let c5(k1)=c5(k1-1)+c4(k1)
let c6(k1)=c4(k1)-c2(k1)
endif
enddo
enddo
endmacro
```

```
rem machine 4
macro
preve c1 c2 c3 c4 c5 c6 c11 c12 k1 k2
mconstant k1 k2
mcolumn c1 c2 c3 c4 c5 c6 c11 c12
random 100 c11;
  exponential 47.62.
random 100 c12;
  normal 2.62 0.78.
do k1=1:99/2
do k2=2:100/2
let c2(k1)=c11(k1)
let c3(k2)=c11(k2)
let c1(k2)=c12(k2)
let c4(k1+2)=c12(k1)
let c4(1)=0
let c5(1)=c2(1)
if c1(k2)<c3(k2)
let c5(k2)=c5(k2-1)+c3(k2)
elseif c1(k2)>c3(k2)
let c5(k2)=c5(k2-1)+c1(k2)
let c6(k2)=c1(k2)-c3(k2)
endif
if c4(k1)<c2(k1)
let c5(k1)=c5(k1-1)+c2(k1)
elseif c4(k1)>c2(k1)
let c5(k1)=c5(k1-1)+c4(k1)
let c6(k1)=c4(k1)-c2(k1)
endif
enddo
enddo
endmacro
```

Fig. 6.

The running results (*Fig. 7*).

"1A" down	"1A" load	"1B" load	"1B" down	Total time	Both down
*	16.8546	*	0.00000	16.85	*
4.12122	*	7.7005	*	24.56	*
*	3.8701	*	3.62875	28.43	*
2.53857	*	28.6853	*	57.11	*
*	23.4354	*	2.72324	80.55	*
1.90592	*	2.1257	*	82.67	*
*	25.3189	*	3.01109	107.99	*
1.24038	*	33.2747	*	141.27	*
*	2.0966	*	2.84177	144.11	0.7452
4.12190	*	11.8152	*	155.92	*
*	1.3356	*	3.50374	159.43	2.1682
2.03160	*	13.3708	*	172.80	*
*	10.8580	*	1.58441	183.65	*
4.64586	*	2.0445	*	188.30	2.6013
*	13.0702	*	2.25842	201.37	*
4.05692	*	4.5786	*	205.95	*
...	...		...		...
	...	...	...	...	...
...		...	...		...
2.81978	*	5.3049	*	2064.43	*
*	60.2557	*	2.56012	2124.68	*
3.33286		20.6997	*	2145.38	*
					25.7860 (Total)

"4A" down	"4A" load	"4B" load	"4B" down	Total time	Both down
*	33.823	*	0.00000	33.82	*
2.70476	*	23.195	*	57.02	*
*	16.712	*	1.79931	73.73	*
2.30793	*	7.877	*	81.61	*
*	78.940	*	1.63572	160.55	*
2.64878	*	35.080	*	195.63	*
*	128.115	*	2.89325	323.74	*
2.96823	*	27.127	*	350.87	*
*	92.318	*	2.75391	443.19	*
2.81084	*	24.380	*	467.57	*
*	0.810	*	3.77332	471.34	2.9634
4.92510	*	79.706	*	551.05	*
*	57.106	*	3.16945	608.15	*
2.62859	*	132.329	*	740.48	*
*	22.532	*	1.74457	763.01	*
3.15542	*	0.093	*	766.17	3.0628
...	...	...	...	...	...
...	...	...	...	...	...
...	...	...	...	...	...
3.13465	*	57.668	*	4355.52	*
*	73.829	*	1.57572	4429.35	*
2.86331		28.943	*	4458.30	*
					12.9600 (Total)

Fig. 7.

On the basis of the running results we can see that the downtimes caused by the two machines can be almost totally eliminated by duplication

$$A_{duplicated\ machine\ 1.} \cong (2145.38 - 25.79)/2145.38 = 0.988,$$

$$A_{duplicated\ machine\ 4.} \cong (4458.30 - 12.96)/4458.30 = 0.997.$$

and in this way original $A = 66\%$ availability can be increased to $A = 76\%$. This reliability growth also increases the OEE factor of the system:

$$OEE_{new} = A \times P \times Q = 0.76 \times 0.96 \times 0.96 = 0.7.$$

6.5. *Economic Analysis*

The team also provided engineering economic analysis to support the suggested idea. When preparing the analysis, the following assumptions and data were considered as a basis by the team:

- An annual 5.6 million products have been sold by 0.95 USD so far.
- More products originating from increasing productivity can also be sold by the above price.

- The direct cost of the product(including the maintenance costs as well) is 0.51 USD.
- The duplication of the two elements needs a 500,000 USD investment. (It is not possible to invest into only one of the two machines, therefore the duplications should be regarded as one investment.)
- Indirect costs of production remain fixed. The economic life of the two elements is 5 years.
- By considering the averages of industrial branches and companies, as well as the market risk of the product, a 12% discount rate was settled.

The calculation of NPV can be seen below.

$$NPV(12\%) = -500,000 + [\frac{A_{new}}{A_{prev}} - 1]5,600,000(0.95 - 0.51)\frac{1}{r}(1 - e^{-5\cdot 0.12})$$

$$= -500,000 + [\frac{0.76}{0.66} - 1]2,464,000\frac{1}{0.12}0.4512 = \$903,696$$

One can see that the Net Present Value of the investment is positive, therefore the duplication project should be completed.

7. Conclusions

We know that the implementation of TPM is rather difficult everywhere in the world. Taken the uniqueness of the Easter-European cultural and economic heritage, this task seems to be even more difficult to accomplish in this part of the world. Based on our experiences of the last decade, it is evident that the only way to improve the effectiveness and profitability of companies in Hungary is through the changing of their corporate culture. It is our view that with the TPM, perhaps as a part of a TQM program, this goal is attainable.

Even though the TPM seems to be a feasible solution, we have to be aware that numerous companies in Hungary are not ready for the implementation of methods that are well-established in Western countries. Today we see that even though our country had successfully converted from one political system to another in less than two years and that its economic structure has transformed in about a decade, a more thorough cultural change that will prepare our country for the adoption of more advanced Western methods will take considerably longer.

While a general cultural change will probably take a long time, the transformation of the corporate culture does not only seem to be a faster process, but it is a more easily controllable one, as well. Therefore, instead of sitting back and waiting for the changes to occur in their natural course of development and instead of importing unfit methods from other countries, our aim is to search for solutions that will enable the changes in our corporate culture to occur in the smoothest and fastest fashion. We hope that our proposal of the implementation of a form of the TPM that is adopted to our local environment is an example of such a solution.

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