PREDICTIVE MAINTENANCE IN SMALL AND MEDIUM ENTERPRISES

María del Carmen Carnero Moya

Universidad de Castilla-la Mancha, Escuela Técnica Superior de Ingenieros Industriales, Av. Camilo José Cela s/n, 13071 Ciudad real, 926295262, carmen.carnero@uclm.es

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ABSTRACT:
Despite the significant benefits that a company can achieve by the implementation of a Predictive Maintenance Program (PMP), these are not widely applied in industry, especially in the case of small and medium enterprises (SME), aspect that can affect its competitiveness. This paper presents the results of a survey of 35 SME's in the Castilla-La Mancha Autonomous Region in Spain. In companies that do not have a PMP implemented, this study assesses their level of knowledge and possible future application of the predictive program and in those who already have a PMP, it analyzes their characteristics. A statistical analysis was performed on the most influential variables with the greatest effect on the decision to establish a PMP.

Keywords: → Predictive Maintenance, Survey, Small and Medium Enterprises

1.- INTRODUCTION

Predictive Maintenance is a maintenance policy in which certain physical parameters associated with a working machine are measured and recorded intermittently or continuously to obtain data and information through which failures can be detected and the future state of the machine can be determined as a function of the load to be applied to the equipment or process, that is, a prediction of the remaining life of the machine [1].
There exist a number of predictive diagnostic techniques, the best known being [2]:

- Vibration analysis. This consists in recording the vibration level of the machine, as it increases when there are anomalies such as misalignment, disequilibrium, defective bearings, etc. Alert and alarm levels are set which require the frequency of the vibration checks to be increased. The overall vibration level can be used as an indicator of the seriousness of a failure and spectral analysis can diagnose the specific type of fault. A full description of the general procedures of measurement and evaluation of mechanical vibrations by machine type can be seen in standard ISO 18016.
- Lubricant analysis. This technique controls the loss of protective function of lubricants due to use, by performing physical and chemical analysis of the lubricant in use such as viscosity, acid content, flash point, etc.; this gives information about the need to change the lubricant. Contamination of the lubricant through the presence of chemical substances of particles that were not in the original composition of the lubricant and which alter its characteristics and efficient working can also be identified. Atomic emission spectrometry, particle counting or ferrography identify the presence of wearing particles, produced by an anomaly and which can be detected from the first stages of production.
- Thermography. This consists in obtaining, remotely and without contact, an infrared image of a machine, to measure and record surface temperature accurately; this technique detects anomalous heat sources in high and low tension electric cables and installations, control panels, connections, spark plugs, fuses, transformers, electric motors, generators, etc.
- Ultrasound. An apparatus produces a wave of ultrasound (with a frequency greater than 20 kHz), which propagates between the emitter/sensor and the material to be inspected. From the difference between the emitted and received, or echo, waves, it is possible to determine the presence and size of defects and at what distance they are to be found. It allows the detection and characterization of discontinuities, the measurement of the width, breadth and degree of corrosion, the identification of physical and characteristics and characteristics of the linkage between materials.
- Penetrating liquids. A special staining fluid is applied to the clean surface to be analysed so that it penetrates into the possible flaws. After a period of time to allow the liquid to penetrate into surface openings, the stainer is cleaned and

an absorbent or revealing liquid is used that absorbs the liquid that has penetrated into the cracks or surface flaws. The areas where there is absorbent liquid are those with surface discontinuities such as cracks.

- Current spectrum. This consists in taking the intensity spectrum of the phases of the motor. It allows the effects of damaged rods, cracks in short circuit rings, poorly soldered joints, gaps caused by melting, static and/or dynamic irregularities of the air gap, etc., to be detected.
- X-rays. The surface to be analysed is placed between a radioactive source and a screen sensitive to radiation, and can detect cracks, bubbles or internal impurities, or defectively soldered joints.

Each predictive diagnostic technique is applied to one or more machines with which its usefulness has been clearly proven (see Table I).

Method of analysis	Main areas of application
Visual inspection	All industrial equipment
Analysis of process parameters	All industrial equipment
Vibration analysis	Rotary machines, planes, helicopters
Analysis of lubricants in use	Transport pools, electrical installations, rotary machines
Thermography	Electrical installations, refractory materials, building insulation, power lines
Ultrasound	Control of fluid and gas flow
Penetrating liquids	Equipment connected by soldered joints, steel structures, boilers, plastic structures, axles
Current spectrum	Motors
X-Rays	Equipment connected by soldered joints, steel structures, plastic structures, rotary machines
Acoustic emissions	Pressurized or vacuum-filled systems
Corrosion control	Metallic conduits, industrial equipment

Table I. Predictive diagnostic techniques and their area of application [3]

The benefits obtainable through the introduction of a Predictive Maintenance Program (PMP) are these ([3], [4], [5], [6]):

- It gives a diagnosis of anomalies and faults.
- Action only in machines which show signs of developing a fault. The number of breakdowns caused by the preventive actions themselves is, therefore, reduced, as are the clear opportunity costs avoided. These breakdowns cause a failure rate similar to the early failure stage of the bathtub curve.
- Failures are detected in their early stages of development and so there is enough time to plan the corrective actions via programmed stops under controlled conditions which minimize downtime and the negative effect on production.
- Increase in the availability of the plant, by increasing the Mean Time Between Failures (MTBF), and reducing the Mean Time To Repair (MTTR).
- Capacity to carry out checks on the quality of the maintenance actions, both in-house and outsourced.
- It increases safety in the factory, including the safety of the staff, the equipment and the environment.
- It facilitates optimum programming of maintenance actions.
- It allows effective programming of spare parts and labour.
- The quality of the product is increased as machines operate without the consequences of faults, such as excessive vibration.
- It is used in the design of machines via modal analysis.
- It reduces the number of hours dedicated to maintenance activities and the consumption of parts, since, as it eliminates catastrophic failures, fixing industrial equipment is cheaper than when they cease to function completely.
- It improves the image of the company by meeting delivery dates.
- Reduction in the cost of spare parts and labour.
- Machines may remain operative while predictive techniques are applied, and so the measuring process does not directly influence the availability of the equipment.
- Reduction in the costs associated with insurance policies, by increasing safety in the factory.
- A complete record of the history of the machines, which allows the reliability parameters to be more easily determined.

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- Significant reductions in energy use.
- It encourages the development of maintenance policies in the plant, as it replaces the time interval with the condition of the machines.
- It contributes to gaining and keeping certificates ISO 9000, QS 9000, etc.

The economic benefits brought about by the above can, then, justify the introduction of a PMP. Nevertheless, this decision is strategic since there are considerable introduction costs, medium and long term time horizons, and it is essential to have global vision of the organization in order to evaluate it. Introducing a PMP requires a major change in the application of traditional maintenance policies. To keep the usual preventive maintenance alongside the PMP causes an increase in maintenance costs. The PMP should thus act to reduce and change rationally the application of preventive and corrective maintenance.

Among the disadvantages of a PMP are:

- High cost, as it requires a considerable investment in instruments, software, consultancy, training, etc.
- The need for highly qualified personnel to carry out the data gathering and the fault diagnosis.
- The support of the Management since a PMP is a project with long-term benefits.

However, as well as introducing a PMP in-house within a company it is also possible to outsource it.
The state of the art of maintenance has been analysed in countries such as the United States [7] and [8], Norway [9], Sweden [10] and in Spain via the Spanish Maintenance Association (SMA) [11], [12], [13] and Goti-Elordi et al. (2009) [14]. The previous research papers, however, do not analyse the specific situation of Predictive Maintenance in these countries and, in most cases, there is no section devoted to the subject. This may be due to the fact that PMP's are not widely applied in industry, and so there is a great difference between the literature and industrial practice [15]. Other aspects of maintenance, also with a high technological level, such as Computerized Maintenance Management Systems (CMMS) have, however, been analysed extensively in the literature or in many specialized surveys (see for example [16], [17], [18], [19] and [20]).

Among the contributions which make a comparative study in companies related exclusively to predictive maintenance the survey carried out by the Technology for Energy Corporation in 1988 in 500 factories in America, Europe and Australia, is worthy of note. It shows the benefits achieved following the introduction, at least three years previously, of a PMP [1]. [21] performs an internet survey of 70 companies from different countries; it makes a comparative study of different predictive techniques. [22] shows the results of a survey carried out through three web pages dedicated exclusively to maintenance. The study analyses different industrial sectors and companies from 15 countries. Fumagalli and Macchi (2009) [15] perform an analysis of the state of the art of predictive maintenance in Italian industry, in which 59 companies from different sectors and of different sizes took part. The survey in [23] analyses, together with other general maintenance questions, some specific aspects related to predictive maintenance, showing that the use of predictive data for prediction or the use of analytic models is low in industry.

The majority of comparative analyses of the state of maintenance are, then, general, and do not look at the characteristics of PMPs in companies; furthermore, most of the PMPs are applied in large companies, and so small and medium companies do not benefit from the increase in competitiveness (via the benefits described above) which the efficient introduction of a PMP can bring. It is necessary only to adapt the characteristics of the PMP to the specific needs of this type of company and choose cheaper predictive technologies or subcontract the service.

This paper shows the results obtained from a survey of 35 small and medium enterprises in Castilla-La Mancha. The aim of the study is to discover the level of application of predictive maintenance in SME's in the region. In the case of companies which have a PMP, the intention is to learn the characteristics, degree to which objectives are met and in particular, if the benefits that may be achieved by its application are being controlled. In companies that have not introduced a PMP, the aim is to get information about the level of knowledge and the intentions with regard to its future introduction. A statistical analysis has been performed on the variables which most influence the decision to introduce a PMP. The intention is to encourage the introduction of the maintenance policy in SME's in Spain.

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This paper is structured as follows; Section 2 sets out the characteristics of the survey and of the companies covered by it. Section 3.1 shows the most relevant results for the general state of maintenance in these companies and the variables which most influence the decision to introduce a PMP. Section 3.2 describes the characteristics of the companies that have a PMP. Section 3.3 gives the results of the survey into the knowledge of PMP's and the intentions for future introduction in companies without a PMP. Finally, Section 4 gives the conclusions.

2.- MATERIALS AND METHODS

A questionnaire was produced for the survey with a total of 101 questions. This questionnaire was organized into several sections:

- General data of the company.
- General maintenance data.
- Data of critical machines.
- Knowledge of and future intention to introduce a PMP (for those companies which do not have one).
- Data of PMP already introduced and future extension.

The survey was carried out in companies in Castilla-La Mancha, classified by the European Union as an Objective 1 Region, which permits the highest level of public subsidy to business investment. Companies in Castilla-La Mancha are characterized by a preponderance of small businesses.

A total of 35 companies took part in the study, of which 17 are situated in the province of Ciudad Real, 2 in Toledo and 1 in Albacete; the remaining companies did not answer the question about their location. The study comprises companies with up to 250 employees, and so they are within the category of SME according to the EU definition; most, however, are in the category of small business (from 11-50 employees). Micro-businesses (up to 10 employees) make up 22.9% of the companies surveyed and the other 22.9% are medium companies.
34.3% of the companies surveyed were from the food sector, 17.1% alcoholic drinks, 8.6% the chemical and machine sector and 2.9% the dairy, meat, porcelain, furniture, energy and water treatment sectors; the remaining 11.4% did not know or did not answer.

The surveys were filled out by the heads of management of the companies and the results were collected over a period of three years.

3.- RESULTS

3.1.- RESULTS OF THE STATE OF MAINTENANCE

Figure 1 shows the results for the training of the head of the maintenance departments. It can be seen that high school level or a form of vocational training is most common in the companies assessed. University level education is only found in 20% of the companies answering. These results are very different from those of [24] for the chemical and processing industry where 75% of department heads have either university education or a diploma as an industrial craftsman; [25] states that 96% of heads of maintenance in Spanish manufacturing industry have a university degree, and 79% in SME's [13].

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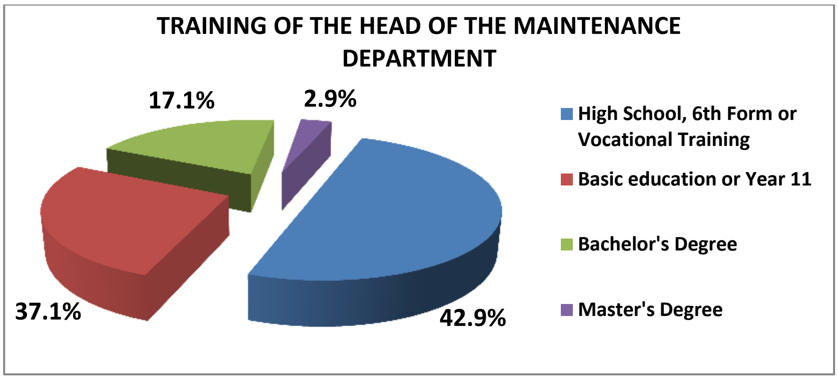

Fig. 1. Training of the head of the maintenance department

All the companies surveyed allocate more than 15% of hours to corrective or reactive maintenance; this is the highest value permitted by the best practice benchmark [26]. In fact 45.71% of the companies have a percentage of corrective activity equal to or above 75%. These values are higher than the 63% of hours dedicated to corrective maintenance in the research of Goti-Elordi et al. (2009) [14]. Given that planned maintenance work is four to twelve time more efficient than unplanned work [8], the low efficiency of the maintenance activity of these companies is clear, and this will directly affect their competitiveness. In the survey carried out for the European Federation of National Maintenance Societies (EFNMS) in eight companies in the food industry (which are more frequent in the survey performed for this paper) in Slovenia, Croatia, Ireland and Denmark, 23.6% of time is found to be given over to corrective maintenance [28]. In the results given in this article only 28.6% of those surveyed are close to this value. Comparing these results with the best practice shown by the EFNMS, where only 3.2% of hours are given over to corrective maintenance, it can be seen that these companies have a great deal of room for improvement.

Figure 2 shows the percentage of hours allotted to preventive maintenance. It is seen that the results are very similar for percentages of 0%, 25%, 50% and 75%. In the survey carried out by [28] in the food sector, 59% of hours are given to planned maintenance, while the results from seven companies of various industries show 73% of hours are dedicated to preventive maintenance. The best practice benchmark of the EFNMS establishes 96.7% of hours of planned maintenance as the optimum value.

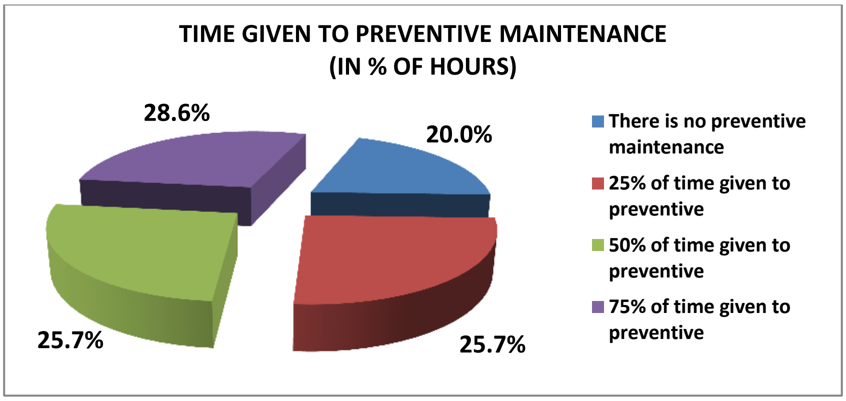

Fig. 2. Percentage of preventive maintenance applied in SME's

The time that the preventive maintenance policy has been applied in each company is shown in Figure 3; 54.3% of the companies have had this policy for 5 years or longer, that is, they are well-established policies.
Only 28.6% of the companies have a CMMS; this result is close to the 32.9% found by Vigoroso and Israel (2006) [29]; however, the results given by the SMA [13] for companies with up to 20 employees shows that 45% already have a CMMS and 23% will introduce one in the future. [14] shows that 55% of companies of all sizes have a CMMS, or 50% of companies in Galicia [30].

Figure 4 shows the results for annual maintenance costs. Figure 5 shows the annual results for accidents in the company.

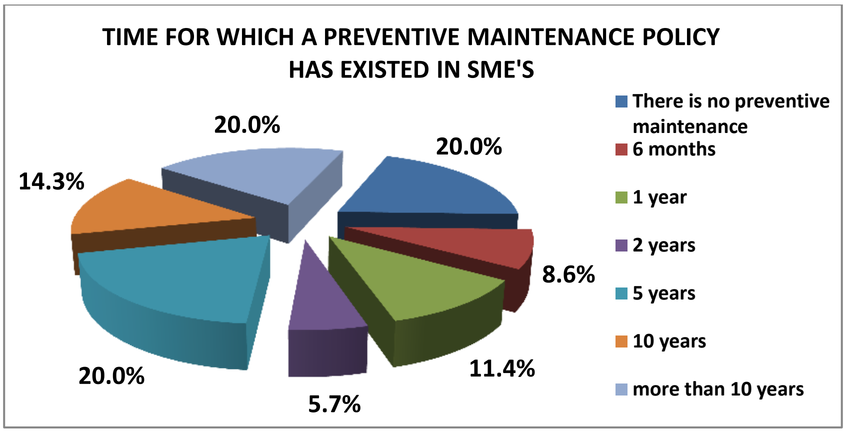

Fig. 3. Time for which a preventive maintenance policy has existed in SME's

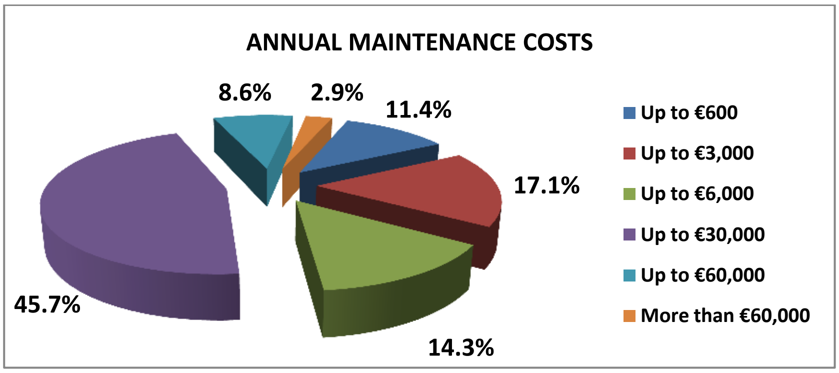

Fig. 4. Annual maintenance costs

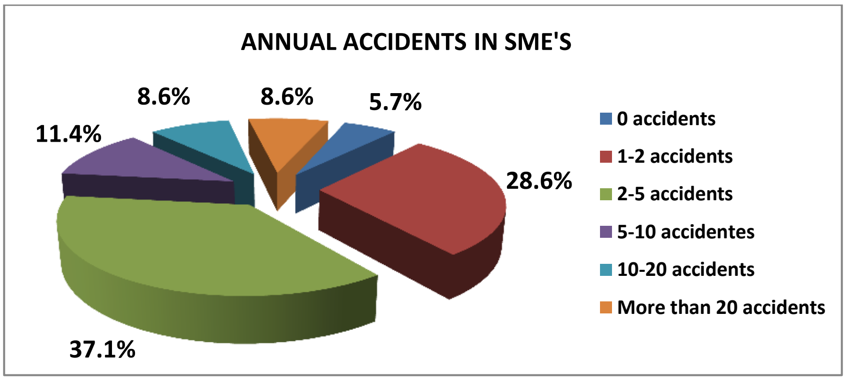

Fig. 5. Annual accidents in SME's

Only 22.9% of the companies surveyed have a PMP. This result is very different from the 43% and 77% obtained for the best and worst cases respectively in other surveys [29]. The activity sector is, however, a deciding factor in the introduction of a PMP, as they exist primarily in the chemical, machine and steel sectors [15] or petrochemical plants, the chemical and associated industries, manufacturing, energy production and gas extraction [21].

When the companies that have introduced a PMP are compared with those that have not, it is seen that the quantity of equipment in companies without PMP is generally lower than in companies with PMP (see Figure 6). The percentage of companies without a PMP which have up to 25 machines is 70.4%, while the figure for those with from 26-50 machines is 14.8%. Among companies with PMP, 37.5% had from 26 to 50 machines, and a similar percentage had from 51 to 75 machines; the percentage with 76 to 100 and 101 to 125 machines is 12.5% in each case. Also, if the number of critical machines is small (up to 25), the companies generally do not have a PMP (see Figure 7).

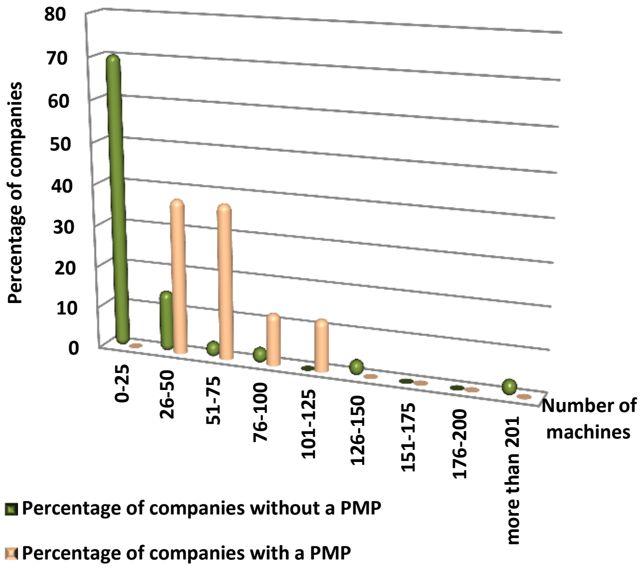

Fig. 6. Comparison between companies with and without PMP as a function of number of machines

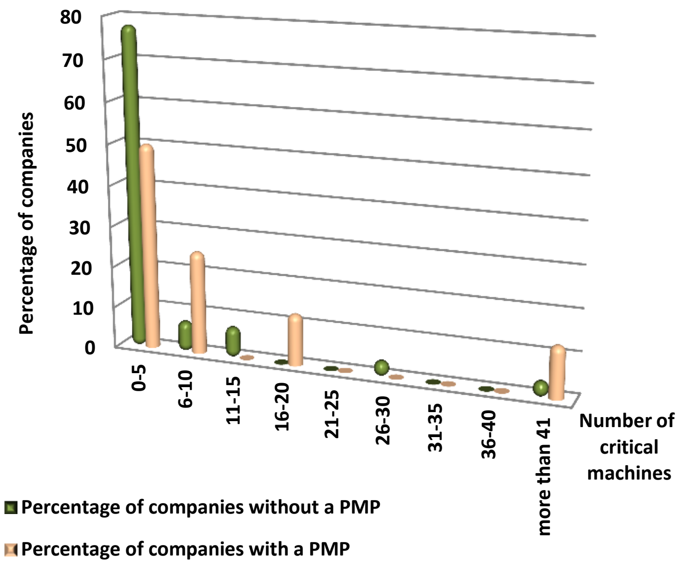

Fig. 7. Comparison between companies with and without PMP as a function of number of critical machines

Maintenance staff had IT knowledge in 87.5% of companies with a PMP and only in 44.4% of companies without. Computerization of records existed in 50% of companies with a PMP and only in 22.2% of those without. Coding of data is present in 50% of companies with PMP and in 33.3% of those without. References to maintenance in other company documents are found in 75% of companies with a PMP and in 40.7% of those without. Thus, the management of documents and computer records is more advanced in companies with PMP.

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Comparing the total number of workplace accidents, 40.7% of companies without a PMP have between 3 and 5 accidents, while 37.5% of those which have a PMP have from 1-2 accidents annually. The percentage of companies with PMP which have not had annual workplace accidents requiring time off work (25%), is higher than in companies without PMP (11.1%). It would seem, therefore, that the existence of a PMP is a contributory factor in the increase of safety.
A statistical analysis was performed with the results of the survey into the general state of maintenance to assess which variables have a most significant effect on the introduction of PMP. In order to do this 26 categorical variables were defined (see Table II); furthermore, there is a dependent variable that shows introduction or otherwise of PMP in a company.

Contingency tables were created to analyse the dependence or independence of the relations between pairs of nominal quantitative variables. Statistical contrast based on χ^2 (Chi-squared) was used. The null hypothesis H_0 to be contrasted is independence among the factors, and the alternative hypothesis is dependence.

Only four variables show significant influence on the introduction of PMP:

- Percentage of hours of preventive maintenance gives χ^2=4,333 (p-value 0.037<0.05). Thus, the null hypothesis of independence among the factors can be rejected, and so the percentage of maintenance activities performed affects the introduction of PMP.
- IT knowledge gives χ^2=4.610 (p-value 0.032<0.05).
- University education of maintenance staff gives χ^2=5.850 (p-value 0.016<0.05).
- Existence of maintenance procedures gives χ^2=5.402 (p-value 0.020<0.05).

Activity sector
Total number of employees
Number of production workers
Number of maintenance department workers
Total number of machines in the company
Number of critical machines
Percentage of hours of corrective maintenance
Percentage of hours of preventive maintenance
University education of maintenance staff
Normal production capacity
Maximum production capacity
Existence of a CAMMS
IT knowledge of maintenance staff
Existence of maintenance procedures
Time for which preventive maintenance policy has been established
Existence of equipment records
Existence of manufacturer's documents
Codification of maintenance information (equipment, components, etc.)
References to maintenance in other company documents
Computerization of maintenance records
Daily working hours
Number of working days per year
Number of accidents involving time off work per year
Total number of accidents per year
Annual cost of equipment repair
Annual cost of maintenance training

Table II . *Variables included in the statistical analysis*

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3.2.- RESULTS OF THE SURVEY INTO PREDICTIVE MAINTENANCE

Although a PMP can provide all the benefits set out in the introduction, it is true that to obtain them the program must be effectively implemented. It should be borne in mind that these are complex programs to implement, they require a high level of training and the benefits only accrue in the long term.

Of the companies which have introduced PMP, the predictive technique they use has been assessed (see Figure 8). It is important to understand that most of the companies use different techniques simultaneously; this result agrees with that found by the Plant Maintenance Resource Center (2002) [21]. Given that vibration analysis is recognised as the most widely used predictive technique [31], it is surprising that it is not found to be the most commonly introduced technique, as it is in other surveys (for example [15] and [21]).

The objectives set out at the introduction of a PMP are met in 62.5% of cases, while 25% of the companies consider that the objectives have not been met; the remaining 12.5% did not know or did not answer. This figure is slightly higher than that obtained in [21], where 53.50% of those surveyed stated that the PMP had achieved the intended objectives. In the survey by Fumagalli and Macchi (2009) [15], 50% of the companies assessed the PMP positively.

Figure 9 shows that the most widely used criterion for the inclusion of machines in a PMP is the quality of the product, followed by the criticity of the machine or the process and the cost of the machine.

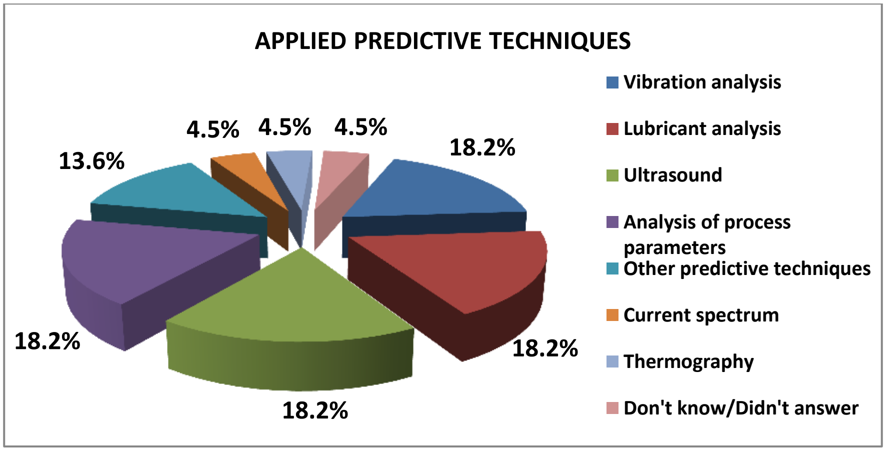

Fig. 8. Applied predictive techniques

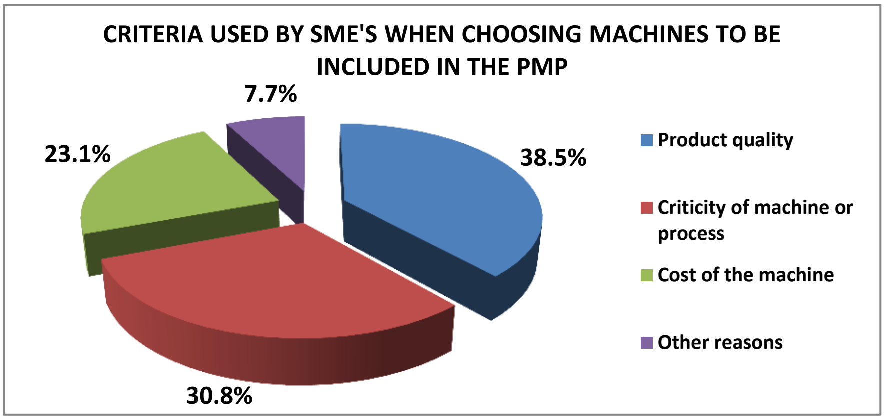

Fig. 9. Criteria used by SME's when choosing machines to be included in the PMP

Analysis of the hours given to preventive maintenance as against total maintenance hours shows that, in general, little time is dedicated to the PMP; 75% of the SME's surveyed give 25% of time to predictive maintenance, while the remaining 25% of companies give 75% of the time to predictive maintenance. These results are slightly better than those set out in [27], where the 14 companies surveyed allotted less than 20% of time to predictive maintenance. In any case, most (75%) of the companies are below the best practice benchmark, which is set at 50% of hours allotted to a PMP.

All the companies with a PMP acknowledge that production staff co-operate in carrying out some activities specific to the PMP, and they also acknowledge an improvement in cleanliness since introduction of the PMP. The reduction in costs of corrective and preventive maintenance as a result of introducing the PMP is shown in Figures 10 and 11. It can be seen that most companied have managed to reduce costs in both areas by around 10-20%. Only one of the companies has eliminated traditional preventive maintenance. The results of the assessment of the reduction in insurance premiums as a consequence of introducing a PMP are shown in Figure 12. 57.1% of the companies have succeeded in reducing their insurance premiums as a consequence of introducing a PMP.

50% of the companies which had a PMP broadened the program, and in all cases they achieved the targets set for that broadening.

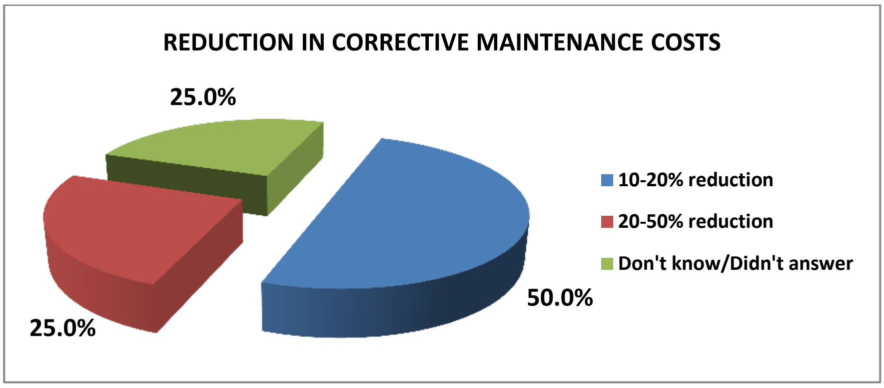

Fig. 10. Reduction in corrective maintenance costs after introducing a PMP

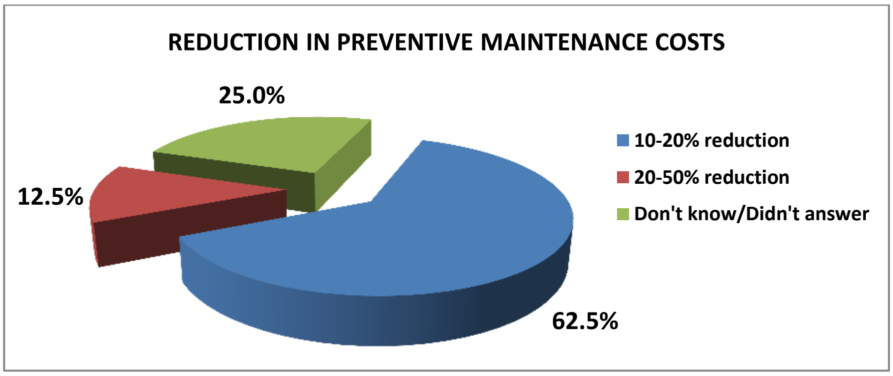

Fig. 11. Reduction in preventive maintenance costs after introducing a PMP

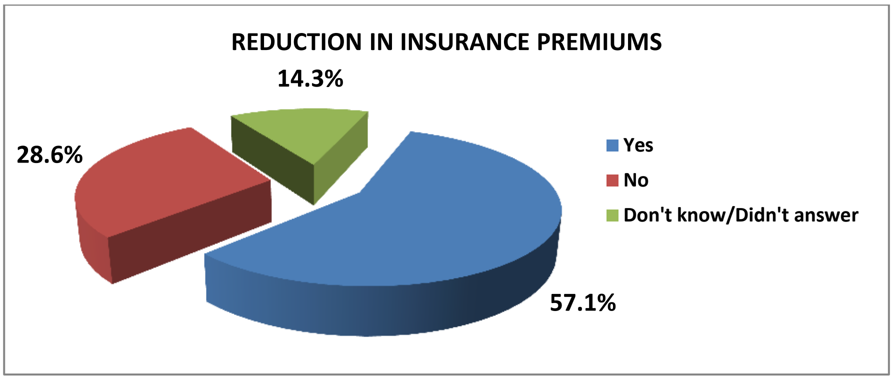

Fig. 12. Reduction in insurance premiums as a consequence of introducing a PMP

3.3.- RESULTS OF THE SURVEY IN COMPANIES THAT DO NOT HAVE A PREDICTIVE MAINTENANCE PROGRAM

This section sets out, in those companies that do not have a PMP, the degree of knowledge that existence about the PMP and the intention with regard to its future introduction.

Figure 13 shows the expected time for obtaining benefits, as estimated by the heads of maintenance. There is clearly little knowledge of the matter, as 28.6% do not know or do not answer the question, while another 28.5% believe that benefits can be achieved within 6 months of introducing the PMP, that is, short-term benefits.
60% of the companies see positively the idea of introducing an in-house PMP in the future, while only 24% would consider outsourcing.

The cost that the company could bear for the introduction of a PMP gives the results shown in Figure 14. It can be seen that most companies do not know or would not set aside any specific budget for the introduction of a PMP. If the companies provided funding, it would be very limited, which would only allow the use of a PMP based on low-technology portable equipment, and generally applying only one predictive technique. The companies without a PMP do not have frequent catastrophic breakdowns, although 68% state that a PMP would improve the availability of the company.

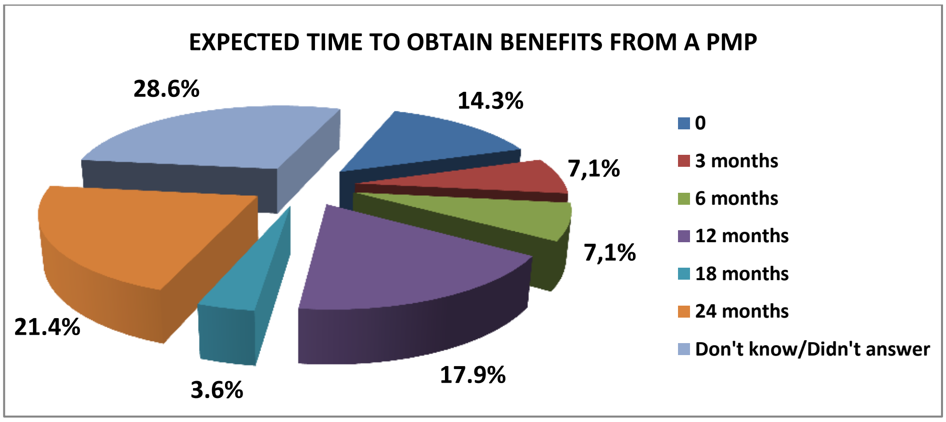

Fig. 13. Expected time to obtain benefits from a PMP

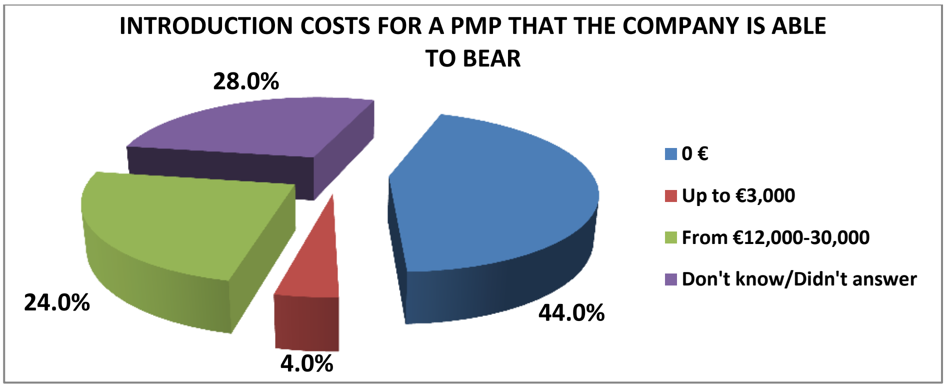

Fig. 14. Introduction costs for a PMP that the company is able to bear

4.- DISCUSSION

Comparing the results of the survey in SME's with best practice benchmarks given in the literature, there are low levels of university training in maintenance management, underuse of CMMS's, the amount of corrective maintenance is too high, and there is no accurate record of the time and costs associated with each maintenance policy.

Comparing the companies with a PMP with those that do not have such a program, the former behave far better in IT knowledge of maintenance staff, use of computerized equipment records, data coding, existence of maintenance procedures, and have a lower number of workplace accidents.

The PMP's introduced have received a very positive assessment, compared with the results of other surveys. This suggests that if a slightly higher budget were provided for the PMP, especially in training, the benefits would be much higher.

In those companies which have not yet introduced a PMP there is poor knowledge of the subject, and a great reluctance to provide funding for its introduction. Nevertheless, the benefits that could be obtained from a PMP are recognised.
The variables percentage of hours of preventive maintenance, IT knowledge in the maintenance department, university training of maintenance staff and the existence of maintenance procedures are the considerations which most heavily influence the decision to introduce a PMP.

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