MAINTAIN MAINTENANCE: A LOOK AT SOME THREATS IN THE SECTOR

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ABSTRACT

Industrial maintenance is a key factor in ensuring the availability of the production systems of companies. Furthermore, it also has a significant impact on energy efficiency and on safety.

The study of the status of the maintenance departments activity in the industrial sector in Spain (and probably in other European countries) shows negative aspects that indicate little innovation, lack of resources or personnel, poor planning and a downward trend in own staffing levels, while hiring with outside companies increases. Many companies perceive maintenance as an unavoidable cost.

To change these negative trends it is necessary to make visible to the management staff the cost-benefit analysis of the maintenance activity and justify the investments to improve their results.

This article highlights some of the threats that affect the activity of maintenance departments in industry, as perceived through statistics on industrial activity and sectorial surveys in Spain. Secondly, the article proposes the basis of a cost-benefit analysis, based on the avoided costs that maintenance department activity can generate. The authors propose this model as a simple tool to justify investments in the maintenance department in companies.

1. INTRODUCTION

Industrial maintenance is one of the key factors to ensure the availability of productive resources of companies. Its influence on productivity is very large. It also influences other aspects such as job security and energy savings.

Its worldwide importance is proved through the many theories that have been developed, which aim to improve the organization and the effective optimization of maintenance. Among these theories, Reliability Centred Maintenance (RCM) (Moubray 1991), (Smith 1992), Total Productive Maintenance (TPM), (Nakajima 1988, 1989), Proactive versus Reactive Maintenance (Muller et al. 2008), (Reeve 2012), World Class (WCM) (Willmott & McCarthy 2001), (Ashraf 1998) and Risk centred (Selvik & Aven 2011) are cited.

However, not all industrial companies assign to maintenance department work the importance that the research suggests it deserves. Maintenance is often perceived as an expense that must be undertaken and, in difficult situations for companies, it is one of the first departments where staff and budget cuts are applied.

In order to reduce costs, there are more and more companies that operate without maintenance department and commission this work to outside workers, although the benefits of this practice are questionable.

In this paper, a general analysis of the activity of maintenance in Spanish industry will be conducted so as to try to get some insights into the current status of activity in the industrial sector, and how it can be improved. Although the paper focuses on Spanish industry, most findings can be extrapolated to other countries, at least in the European context.

A brief outline of the industrial maintenance organization is presented in section 2. Some figures about industrial activities related to the maintenance work are presented and analysed in section 3. Section 4 shows the study of the maintenance activity in Spain. Section 5 shows a summarized analysis and a proposed methodology to evaluate the maintenance cost-benefit. After that, some conclusions are drawn in section 6.

2. THE INDUSTRIAL MAINTENANCE.

The goal of maintaining an industry is to ensure the availability of all assets that the company needs to remain competitive.

Although not mentioned in the above definition, the safety of many facilities and the control of power losses (and therefore the energy efficiency) directly depend on proper maintenance of them. In fact, the improvement of workplace safety with proper maintenance is mandatory from (Directive 89/654/EEC).

Maintenance tasks fall into two types of actions (Figure 1): Preventive and corrective.

The way these actions are organized gives rise to various maintenance strategies, Total Productive Maintenance (TPM) being the basic approach that is used in many industries (Nakajima 1989), although there are many subsequent proposals that try to improve some organizational and tactical aspects of maintenance (RCM, Condition Based Maintenance (Golmakani & Fattahipour 2011), (Tian et al. 2011), (Prajapati et al. 2012), etc).

TPM aims to achieve maximum efficiency in equipment and facilities with the following objectives:

- Actively involve all staff, from senior management to the workers of the plant.

- Involve all departments: planning, design, operation and maintenance.

- Promote TPM through motivation and autonomy of small groups. Remain receptive to suggestions for improvement from employees and stakeholders.

In TPM, one of the key factors is the knowledge the workers have about the facilities. If the maintenance of industrial facilities depends on external companies providing services in several factories, the employees of these factories tend to neglect the maintenance, thus the knowledge that they have about the facility is lost, leading to an opposite situation to the one that would have arisen with TPM.

The tendency to ignore the maintenance department and to entrust this task to external companies seems to be increasing. Therefore, in this paper we make a transversal study of the maintenance activity in the industrial sector, based on data published in recent reports on maintenance activity in Spain.

3. THE SPANISH INDUSTRY. SOME FACTORS AFFECTING PRODUCTION AND MAINTENANCE.

In 2007, Spain was ranked fifth in the European Union in its contribution to added value (Table 1) (Eurostat).

With respect to 1997, the decline in the contribution of the Spanish manufacturing industry (from 19.0% in 1997 to 15.2% in 2007) is offset by the increase experienced in construction in that period, resulting in an increase of total industry and construction from 29.3% in 1997 to 29.8% in 2007 (OECD 2009).

Table 2 (Eurostat) compares the contribution to added value by sectors of each country of the EU in 2007, showing that Spain has intermediate values. These values are a bit low in industry, but they are rather high in construction. This table only shows the countries with the highest and lowest percentages and those with the greatest contribution. Therefore, we consider that the subsequent data concerning the Spanish industry can be extrapolated to many neighbouring countries. Although it is beyond the scope of this article, the sharp increase that was experienced in Spain in the decade 1997-2007 in the construction sector, over the total industry, is one of the keys to understanding the serious effects of the current global crisis on the country (see appendix A).

The number of enterprises in every sector in Spain has evolved as shown in Figure 2 between 1997 and 2010. In manufacturing industry, the development has been from 158,430 companies in 1997 to 151,323 in 2007 (INE 2010) (in 2010 this number was 136,041).

As regards industry, Figure 3 shows the variation in employment in Spanish industry (INE 2010). The number of employees shows a slight trend to decrease from 2001 to 2007, following the trend of the output of the industrial sector.

Operating expenses in business during 2007 are summarized in Table 3 (INE 2010), which shows that the departure of in-house staff is almost equal to the external services. In external services, transportation items and advertising accounted for 27.3%, followed by repairs and maintenance (11.9%) and freelancer jobs (11.2%). While transport and advertising costs increase with the size of the company, repairs and independent jobs increase significantly in small companies.

Maintenance work involves significant outlays in staff costs and external services. While staff costs decreased between 1999 and 2007 (from 17.3% to 14.1% of operating costs), external services remained almost at the same level (from 14.6% in 1999 to 14.4% in 2007), like repairs and maintenance expenses, which remain throughout this period at about 1.7% of operating expenses.

The tendency to reduce staff costs has a direct effect on the maintenance departments of the companies, because, by its own nature, maintenance work is mainly based on staff.

Finally, Figure 4 shows the relationship between productivity per worker and number of workers. Small industries have less scope to have a maintenance department, but in Spain, small industries (up to 20 workers) account for 85% of industrial companies. The average productivity in Spain in 2007 was 58,815 Euros per employee, an intermediate value in the whole of the EU (between France and Italy).

4. SECTORIAL STUDY OF THE MAINTENANCE ACTIVITY IN SPAIN.

The following data come from a survey conducted with 152 employers by the Spanish Association of Maintenance (AEM 2010).

First, it emphasizes that the maintenance cost structure has remained almost stationary during the past 15 years, at 30% for cost of materials and 70% for manpower (in-house or external), which indicates little innovation in this activity. Figure 5 also shows the already mentioned trend to increase outsourcing and to reduce in-house staff.

Maintenance planning is usually done through working orders, but only 35% of companies have a planning office for this activity.

About 20% of the surveyed companies apply autonomous maintenance techniques, where preventive activities depend on their own facility or equipment operators, but only 10% of the industries have implemented the technique of TPM, with little significant use of other maintenance strategies.

The evolution of preventive versus corrective maintenance is shown in Figure 6. The increase in preventive maintenance actions results in fewer requests with utmost urgency (only 23% of the surveyed companies require urgent actions with a frequency greater than 30%). This better planning of preventive actions is related to the widespread use of any maintenance management software (Duran 2011): in 1995 only 20% of companies used a program for comprehensive maintenance management, while in 2007 that percentage had risen to 50%.

The deficiencies in the structure of the maintenance departments in many industries (understaffed or with insufficient resources) are reflected in the considerable workload lag that tends to be accumulated in this activity, as shown in Figure 7.

The average profile of the responsible person for managing maintenance department corresponds to a person with good technical training (in 70% of cases Engineer or Industrial Engineer;

Industrial Engineer in Spain applies to a masters in engineering with broad technical training) and, at least, 15 years of experience in maintenance activity. In many cases, the maintenance manager performs this function alongside a broader set of responsibilities, such as, production manager, so that, dedication to the maintenance department organization is slight and limited to short-term tasks.

The profile of operators of a maintenance department corresponds to people that are qualified in some technical field (electrical, mechanical, ...), whose effectiveness depends mainly on their experience. In many cases it is also unqualified personnel but with a long history in the business, whose knowledge of the factory facilities has been obtained in an empirical way, through the years. Currently, about 40% of the surveyed industries send maintenance crew for training courses (in 1990, this figure was only 20%).

5. SUMMARIZED ANALISYS AND PROPOSALS.

Maintenance activity in the industry has an important influence on many strategic and functional aspects, as summarized in Table 4.

Several key elements allow the maintenance department to successfully achieve its targets:

- A highly qualified chief with great organizational skills.
- Qualified and experienced staff.
- Suitable resources for the activity.
- A tactical organization of maintenance (e.g. TPM).
- Continuous staff-training.
- Adequate knowledge management (Cárcel & Roldán 2013).

However, in many companies, management staff considers the maintenance activity as an unavoidable expense and not as an opportunity. This is because:

- Maintenance activity is intensive in manpower use.
- Maintenance department requires skilled staff.
- The effectiveness of maintenance department operators heavily depends on their experience.
- The maintenance costs are obvious to the management, but the benefits obtained are not so apparent.
- Poor maintenance department organization may produce a non-uniform workload in its operators, with times of high activity (prominent to employees) and others of low activity (prominent to management).

As a result of this perception, outsourcing maintenance tasks to outside companies is already a common practice. The outsourcing trend is higher in small companies (up to 20 workers), but it also takes place in large companies, where they usually contract out the maintenance of some facilities. When economic problems increase, the companies try to reduce maintenance costs by reducing staff and resources. But this results in the need to rely more on external services for repairs.

To improve the status of the maintenance department activity in the industry, it is necessary to change the perception of management. To do that, some key priorities for increasing efficiency and improving the assessment of maintenance departments in the industry are:

- Proper organization of the activity. Integration of maintenance into the overall management structure of the company (Ahuja & Khama 2008). This requires that the maintenance manager has a good training, both technical and in management and organization tasks.

- In addition, the management staff must support the maintenance department, integrating it into the company's strategic decisions (investments in new equipment and facilities, product development and so on).

- Adequate knowledge management, efficient use of the experience (knowledge creation (Von Krogh et al. 2000)). This is a fundamental tool to facilitate the incorporation of new staff and to reduce the costs of their training.

- Provide the department with the adequate resources, including investments in elements and tools that facilitate routine operations, permanent training of operators, coaching, and so on (Ireland & Dale 2001).

- Staff motivation. Autonomy and promotion of initiatives aimed to improve the activity. Good results have been obtained in the area of energy efficiency and others (Cárcel 2012).

- Make the cost-benefit analysis of the activity visible to management. This is probably the main issue (and perhaps the most difficult) to change the negative trends. An example is shown in (Naikan & Rao 2005).

Given the importance of cost-benefit analysis on the perception of maintenance department activity we will develop this further.

For the objective that has been set out in this paper, what is needed is a simple method which provides an indication to management on whether to invest more in resources for maintenance, invest in staff or hire outside contractors. But this approach, seemingly simple, can be of great complexity.

A conceptual framework for evaluating the maintenance cost is proposed in (Muchiri et al. 2011). In this framework, several indicators are proposed to measure and compare the quality of maintenance activities. In this way, to facilitate the management decision making, we propose a conceptual framework for the assessment of the maintenance benefit that can be expressed through the avoided cost (AC).

The AC is the sum of three values:

$$AC = AC(\text{repair}) + AC(\text{efficiency}) + AC(\text{safety}) \quad (1)$$

In (1), AC(repair) represents the cost that the company avoids by the proper performance of maintenance department in breakdown repairs or preventing them from occurring. To calculate AC(repair) the benefit by improving breakdowns costs and the expense required to realize such improvement must be taken into account. To quantify this cost, it is assumed that the average cost (C_{avg}) due to failures that may occur in a process is:

$$C_{avg} = V_{add} \cdot UA \quad (2)$$

V_{add} being the annual added value of the process and UA the unavailability.

Under simplified but frequently admitted conditions in reliability studies (exponential failure distribution with constant failure rate (λ) and constant repair rate (μ)), the unavailability is

$$UA = \frac{\lambda}{\lambda + \mu} \tag{3}$$

Or, if the mean time to repair (MTTR) is small compared to the mean time between failures (MTBF) (3) can also be written:

$$UA = \frac{MTTR}{MTBF + MTTR} \tag{4}$$

Therefore, C_{avg} is a function of these two values (MTBF and MTTR) or the rates λ and μ. Analysing the influence that managers' decisions will have on these values is one of the keys to select the best strategy regarding investments in maintenance department. Under certain conditions, (Naikan & Rao 2005) analyses the cost-benefit ratio in an activity formed by N equal machines using queuing theory and the optimal number of maintenance crews is obtained.

If UA varies from UA_1 to UA_2, by means of an action with a certain cost C_{act}, the AC(repair) will be:

$$AC(repair) = (UA_1 - UA_2) \cdot V_{add} - C_{act} \tag{5}$$

AC (repair) generally represents the highest weight in (1). Table 5 shows typical values of reliability for some equipment (extracted from OREDA 2002). In this table, λ_a (failures/year) represents the average rate of critical failures (with equipment shutdown), λ_M (failures/year) indicates the maximum rate of such failures (5% probability of being exceeded), λ_{in} (faults/year) the average rate of incipient faults (no shutdown, but can evolve to critical faults if they are not attended soon), MTTR (man-hours) is the mean time to repair critical faults and $MTTR_{in}$ (man-hours) the same in incipient faults.

In a factory with a fault rate lower than λ_a , investment to reduce λ can be large and it would be only justified if V_{add} is high. In contrast, with λ values greater than λ_a , the improvement should not be expensive. In this case, one way to reduce λ will be focusing maintenance department resources in decreasing λ_{in} (improving preventive maintenance for example) as well as reducing MTTR.

Several actions can be considered to achieve these improvements:

- To hire maintenance with specialized companies.

- To improve training and specialization of in-house maintenance staff.

- Availability of spare parts.

- Acquire test equipment.

- To hire more staff, ...

The costs associated with these actions can vary in broad ranges, so they must be independently analysed in each case.

In (1), AC(efficiency) represents the profit that the company gets for keeping high energy efficiency. To keep high efficiency the following indications are useful:

- To avoid any leaks of heat (for instance, damaged insulation), fuel, compressed air, etc.

- To maintain equipment in optimal conditions in order to achieve the highest possible performance in thermal (e.g. boilers), mechanical (proper lubrication, replacement of parts with excessive wear...) or electrical elements (cleaning of luminaries, proper selection of motors, etc.)

- Correct utilization of facilities, avoiding misuse of lighting, air conditioning, etc.

- To consider replacing of old equipment with more efficient ones, installing variable speed drives, etc.

All these actions must be carried out by the maintenance staff. Our experience is that if the maintenance staffs are committed to energy saving, the results are very positive.

All of these actions represent quantifiable savings for the company, so the cost-benefit analysis is not difficult and, AC(efficiency) is evaluated from it.

Some examples are given below:

- Cleaning of luminaires represent improvements between 10% and 20% in light output, so you can reduce the installed power (lower installation cost) and energy consumption.

- The performance of a boiler drops from 88% to less than 80% if the combustion conditions are not optimal.

- An uninsulated steam pipe (50 mm diameter) at 160 ° C loses 530 W/m, 500 W/m more than a properly insulated one.

- A hole of 1.6 mm diameter in a compressed air system to 7 bar produces a leak of 3.1 l/s, equivalent to 1.42 kW. With a prize of 0,13 €/kWh, the loss is €1617/year.

- In a fluid pumping system, replacing a flow controller by a speed control on the pump motor reduces power consumption up to 40%, at flow rates of about 70% of maximum.

The calculation of AC(safety) in (1) is more complex. As a starting point, it is proposed to compare frequency of accidents in the company with the statistical values for the activity. Since the company's own data may be too sparse to obtain reliable statistics, we propose to use as a reference the values in the sector that fits the activity, which can be obtained from accidents prevention companies.

The average number of industrial work accidents for each branch of activity can be computed from the incidence rate (Ii): number of injures (with absence from work for more than one day) per 100,000 workers. The incidence rate in Spain in 2012 in the industrial sector was 4652 (the incidence rate of fatal accidents that year was 3.2). The average duration of absence from work due to accidents was 29 days. Table 6 shows the incidence rate of some industrial activities in 2012 in Spain.

Some accidents can be prevented through better maintenance (some caused by breakdowns). Corrective actions, which may depend on the maintenance department, should be implemented to avoid this type of accidents. Involving the maintenance department to improve safety may achieve good results.

In a factory with N workers, if the number of accidents (injures) is I_n and the incidence index of the sector is I_i, we can write:

$$AC(safety) = \left(\frac{N \cdot I_i}{100000} - I_n \right) \cdot C_{Inj} \qquad (6)$$

The average number of accidents on each activity is taken as a reference in (6). This allows us to consider a benefit if there are fewer injures than average and a cost (negative value) if the number of injuries is higher than the average.

Because of the risk posed by accidents (permanent injury or death), every company should be focused on reducing them as much as possible. If the frequency of accidents in a company is higher than the average in its activity, the immediate target should be to avoid exceeding this average value, so that (6) indicates the current extra cost due to lack of security and with positive value it would represent the avoided cost if the goal is reached. If a company is already below average values of workplace accidents, the target of reducing their accidents will provide the avoided cost calculated with (6). If a company has sufficient own statistical data (at least 10 years) the analysis can be done by setting the number of accidents to reduce by year (based on those accidents whose causes could be avoided with corrective actions) and multiplying this number by the average cost per accident, which may be also estimated from their own data.

In (6), C_{Inj} is the average cost assigned to each accident. This value should be used with caution, because some accidents may pose risk of death and economic quantification is always controversial.

The average cost of accidents must include:

Direct costs: loss of working hours (the injured and other fellows), travel expenses, medical expenses, allowances for the duration of absence from work, increased taxes to pay for social services prevention, compensation, penalties, expenses due to investigation and report of the accident, ...

Indirect costs: loss of productivity (demoralization), increase of labour conflict, loss of reputation, missed deadlines with clients, ...

Although the calculation is complex, many countries have statistical data that allow getting an indicative value for C_{Inj}. In Spain, considering only the part supported by the employer, this cost ranges from almost €1,000 for minor accidents to more than €20,000 in case of serious accidents and more than €50,000 in fatal cases. An average value can be between €3,000 and €5,000.

With the analysis of the expected AC that can be obtained with an investment and its cost, the manager may have a good basis for making the right decision. The maintenance manager should be fully involved in the decision making, as he must advise on the need for more staff, resources, etc., besides providing adequate information to perform the AC analysis.

Later, after making the right decision, the maintenance manager must justify, with subsequent results, that the objectives have been met. This is, in our opinion, the key to a proper cost-benefit analysis to strengthen the confidence of management in the maintenance department.

To illustrate the procedure, we will apply it to two cases.

Case 1: A small company of less than 5 workers, with an added value of € 400,000 and a unique production process. There are no maintenance department. The workers perform basic maintenance work (cleaning and lubrication). In case of failure they call an external company for repair.

λ = 4 / year = 0.00227 / hour (based on 1,760 hours of work per year).

μ = 0.0625 /hour

UA = 0.035, using (3)

C_{avg} = € 14,000, from (2)

The expected workload and the C_{avg} value do not justify the hiring of maintenance personnel. The possibility of a maintenance contract with an outside company (6,000 € / year) is studied. It guarantees a monthly review (preventive) and assistance in 2 hours in case of failure. This can achieve a 10% improvement in the failure rate and a reduction of 50% in MTTR. The influence on energy efficiency and safety is considered negligible.

The new values are:

$\lambda = 0.002$ /h

$\mu = 0.125$ /h

UA = 0.0157, using (3)

AC(repair) = (0.035 – 0.0157) · 400,000 – 6,000 = € 1,720, calculated using (5), resulting in a positive net benefit.

Case 2: A medium enterprise (furniture production, 45 workers) with an added value of € 5 million. It is assumed that the company performs five different processes and, for simplicity, the same added value (1 million) is assumed in each process. Each fault can affect a process. The company has two maintenance workers dealing with prevention and repair. The MTBF is 176 h and MTTR 10 h (on 3520 h of work per year). Energy consumption is 300,000 €/y. In recent years there have been 3 accidents (injures) per year, with an assigned cost of € 4,000 per accident.

A maintenance head's report raises the need for a new operator, with which the following objectives could be achieved:

Improve by 10% failure rate and 20% repair time.

Better control of energy expenditure, with a saving of at least 3%.

Avoid at least one accident per year (that is, placing on an average according to this activity).

Then, the UA (of a process) calculated with (4) would decrease from 0.0538 to 0.0397. If the cost of the new worker is € 25,000, from (1), AC is derived:

AC = (0.0538 – 0.0397)·1,000,000 – 25,000 + 0.03·300,000 + 4,000 = € 2,100

So hiring is beneficial and has a profit margin of 8.4%.

6. CONCLUSIONS

In many cases, the maintenance department is seen as an unavoidable expense. Most studies to optimize maintenance aim to minimize the cost. In this regard, significant improvements have been the widespread preventive maintenance (and some variants such as predictive maintenance), the use of software for maintenance management and modern tactics on the organization of maintenance (TPM, RCM and others). But some figures shown in the paper indicate little innovation, lack of resources and, ultimately, little investment in improving maintenance.

When the economic situation worsens, many companies try to cut costs by reducing the staff or resources for maintenance and others. There is an increasing tendency to replace its own staff with outside services.

To improve the perception of maintenance department in industries it is necessary to quantify the benefits obtained with it, give positive value to its activity and demonstrate the return on investment.

Among the activities of the maintenance department with high profit to the company we highlight the preservation and repair of equipment and facilities and the improvement of energy efficiency and safety. In this paper a conceptual basic model to quantify these benefits is proposed. A target for the maintenance manager should be to show the profitability of his department.

APPENDIX A

From 1995 to 2007 industrial production in Europe had a positive evolution, with significant growth, except for the years 2000-2002, in which there were minor setbacks with little impact (figure A.1). In 2008, a period of heavy losses starts, as a result of the global crisis affecting many countries. Spain is still suffering from these setbacks (OECD Economic data).

As a result of this negative situation for the industry, the number of industrial enterprises in Spain fell from 151,300 to 136,040 between 2008 and 2010 (it had remained between 151,000 and 163,000 for more than 10 years). The drop was even greater in other sectors, such as construction and services. The number of employees in industrial enterprises declined in recent years, as shown in figure 3, and operating expenses and investments have followed the same trend.

To prevent the bad economic situation from influencing the results, most of the analysed data are limited to 2007.

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TABLES

Country	Agriculture	Industry	Building	Services
Germany	10	26	13	19
U. Kingdom	7	14	17	18
Italy	14	13	12	12
France	19	11	15	17
Spain	13	7	16	8

Table 1. The 5 countries with higher added value in EU-27 in 2007 (%).

Country	Industry	Agriculture	Building	Services
Czech Rep.	32.6 [a]	2.4	6.3	58.7
Romania	27	6.4 [a]	10.1	56.6 [b]
Germany	26.4	0.9	4 [b]	68.7
Italy	21.4	2.1	6.1	70.4
Spain	17.5	2.9	12.3 [a]	67.4
United Kingdom	16.7	0.6	6.4	76.3
France	14.1	2.2	6.3	77.4
Luxembourg	9.8 [b]	0.4 [b]	5.8	84 [a]
EU-27 (2007)	**20.2**	**1.8**	**6.4**	**71.6**
[a] Highest value		[b] Lowest value		

Table 2. Sectorial contribution to added value (%) of several countries in EU-27 in 2007.

	Million Euros	%
Consumptions and activities of other enterprises	400,621	67.6
Employees	83,206	14.1
External services	84,628	14.3
Amortizations	22,999	3.9

Table 3. Operating costs of Spanish industries in 2007.

Strategic and functional aspect.	Operational influence of maintenance
Production	High influence, directly related with reliability and break downs.
Fixed assets amortization	Increases life.
Repair and conservation	Directly related.
Tangible fixed assets investment	Under its control when are bought. Maintenance should be consulted.
Staff	High qualification and expertise is required in maintenance.
Permanent training	Permanent training is needed in maintenance.
External services	All external services related with maintenance or repair should be under maintenance supervision.
Energy efficiency	Maintenance must control the energy efficiency.
R&D+i	New proposals on equipment, installations or process should be reviewed by maintenance.
Safety	Safety of equipment and installations depend on maintenance control.

Table 4. Some functional and strategic tasks related to the maintenance department.

Machine	λ_a	λ_M	*MTTR*	λ_{in}	$MTTR_{in}$
Centrifugal Compressor	0.64	1.83	79.8	2.12	15.3
Reciprocating Compressor	3.04	14.7	13	3.75	4.5
Screw Compressor	1.02	5.34	23.2	1.57	28.2
Centrifugal Pump	0.19	1.09	57.6	0.50	15.6
Reciprocating Pump	0.36	0.93	13.9	0.99	11.6
Electric motor	0.25	0.70	55.6	0.17	11.4

Table 5. Some reliability data for industrial machinery (obtained from OREDA 2002).

Activity	Incidence index	Activity	Incidence index
Food industry	5254.4	Chemical industry	2815
Plastic manufactures	4444.9	Machinery fabrication	4715.5
Automotive industry	3347.1	Furniture	4541.5
Electric material production	3143.5	Metal manufactures	7024.5

Table 6. Incidence index of labour injures by activity in Spain in the year 2012.

FIGURE CAPTIONS

Figure 1. Maintenance classes according to (EN 13306)

Figure 2. Distribution of enterprises (thousands) in sectors in Spain (1997-2007-2010).

Figure 3. Evolution of the number of employees in industry in Spain.

Figure 4. Productivity per employee in Spain in 2007.

Figure 5. Evolution of the maintenance costs.

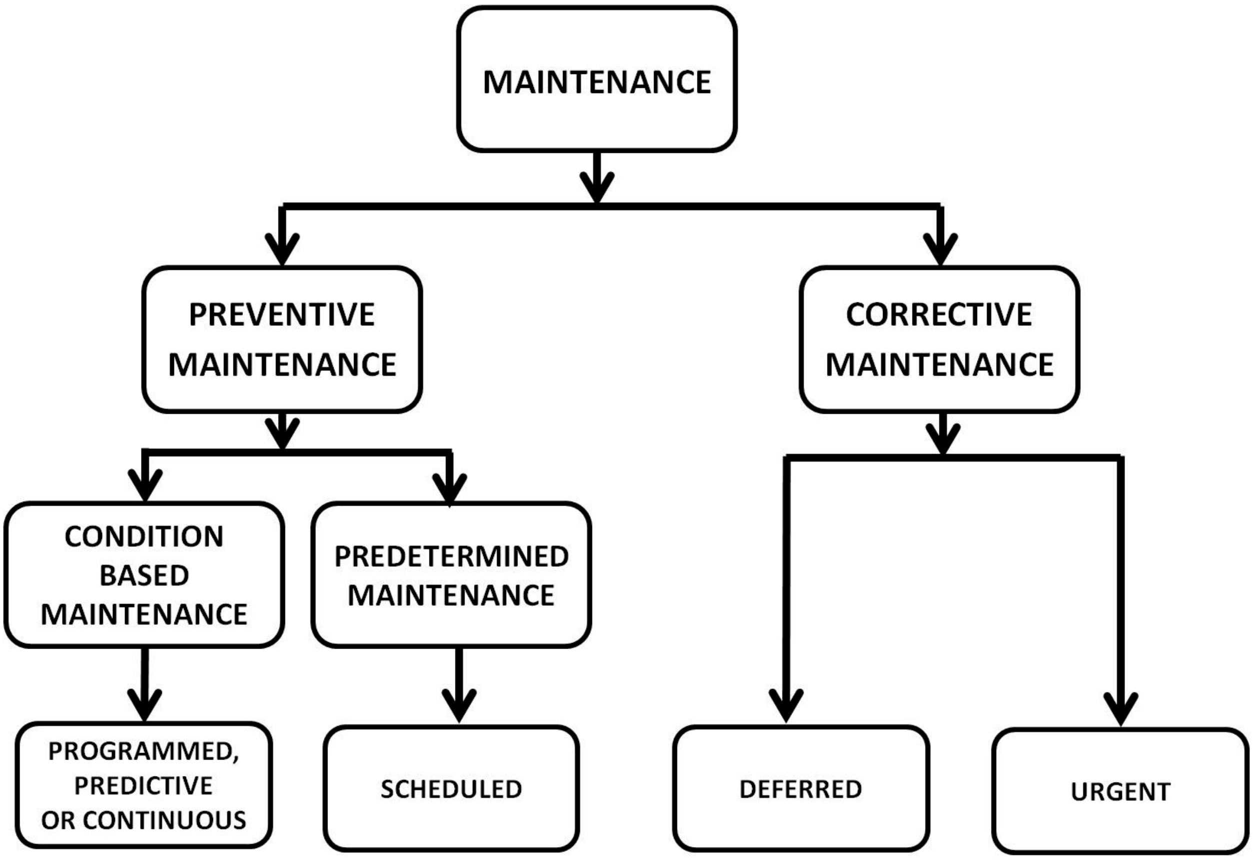
Figure 6. Trends in preventive and corrective maintenance.

Figure 7. Lagged maintenance works.

Figure A.1. Industrial production index in several countries (base 100 in 2005).

FIGURES

Figure 1:



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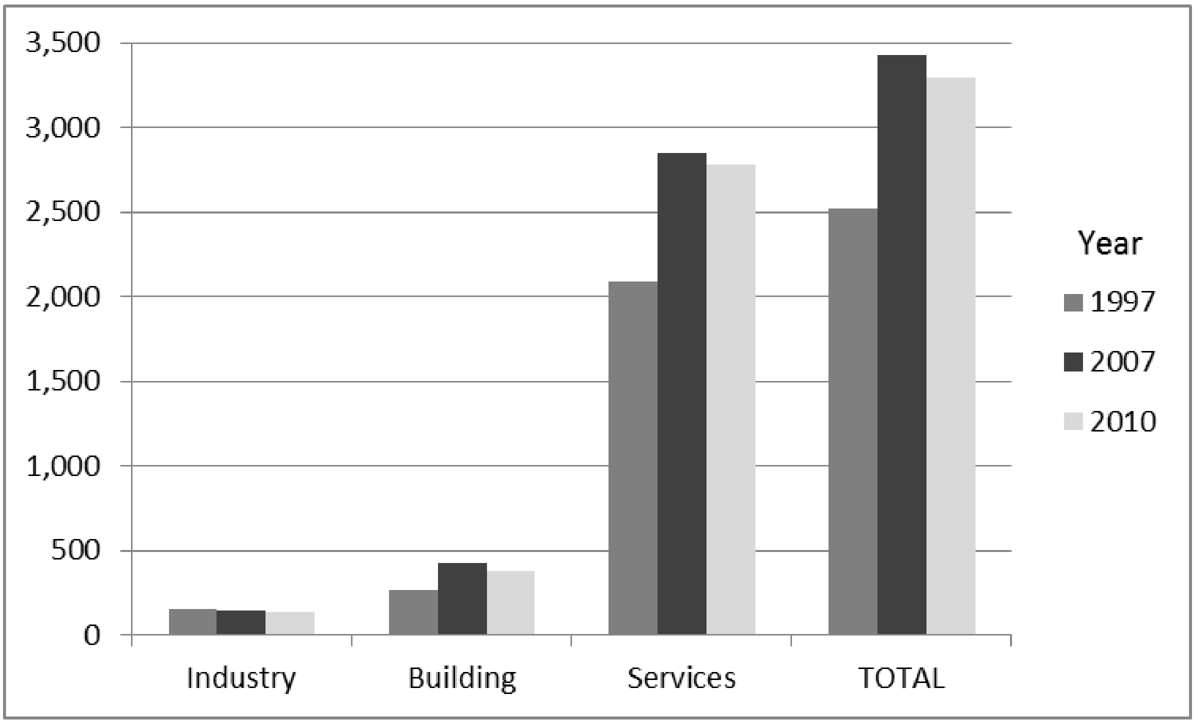

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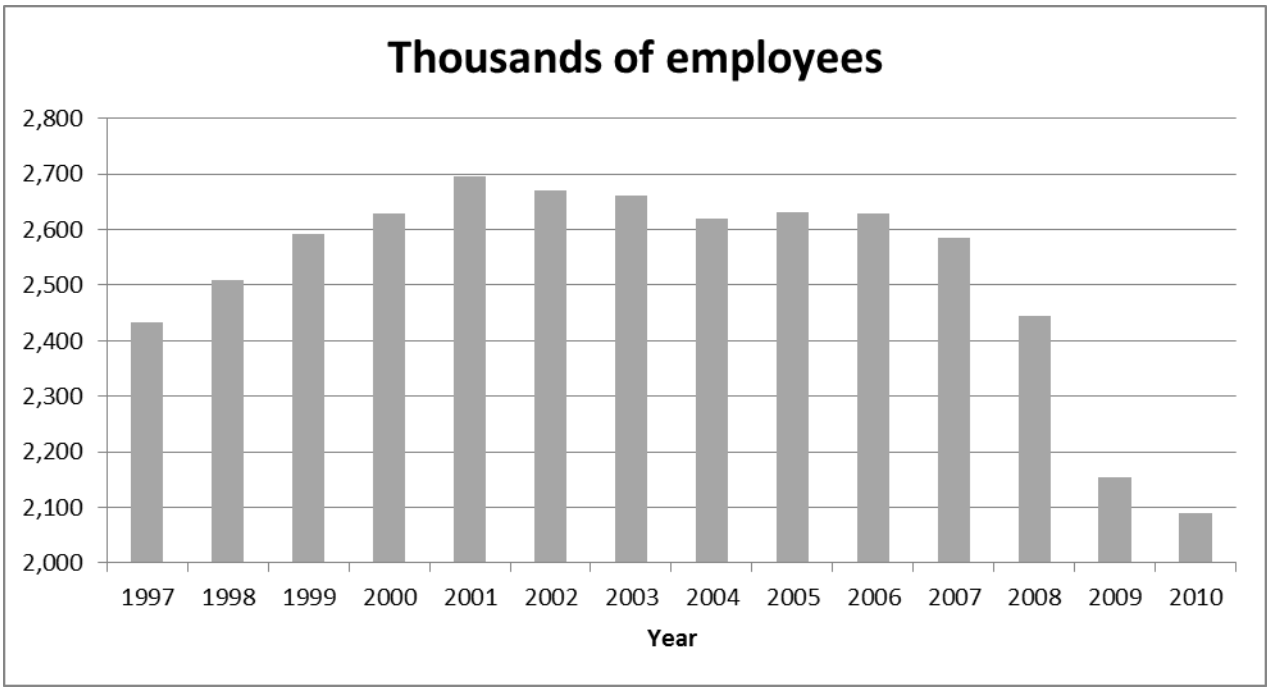

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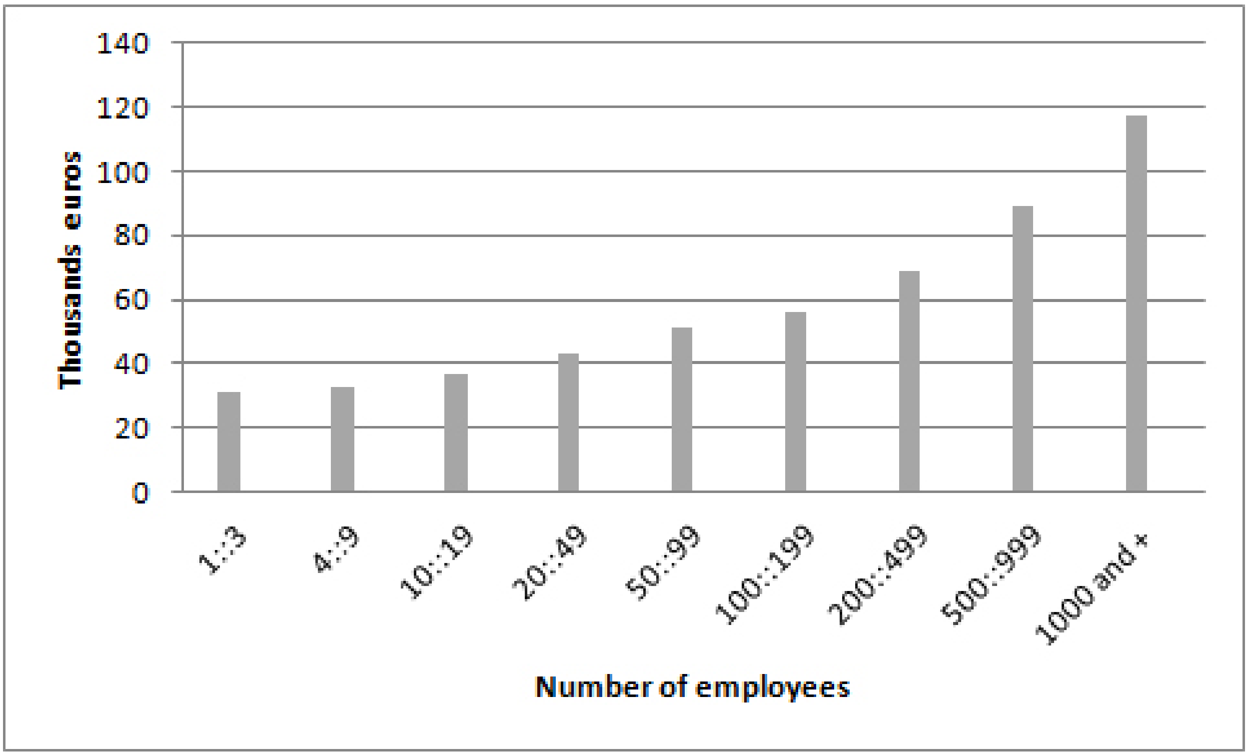

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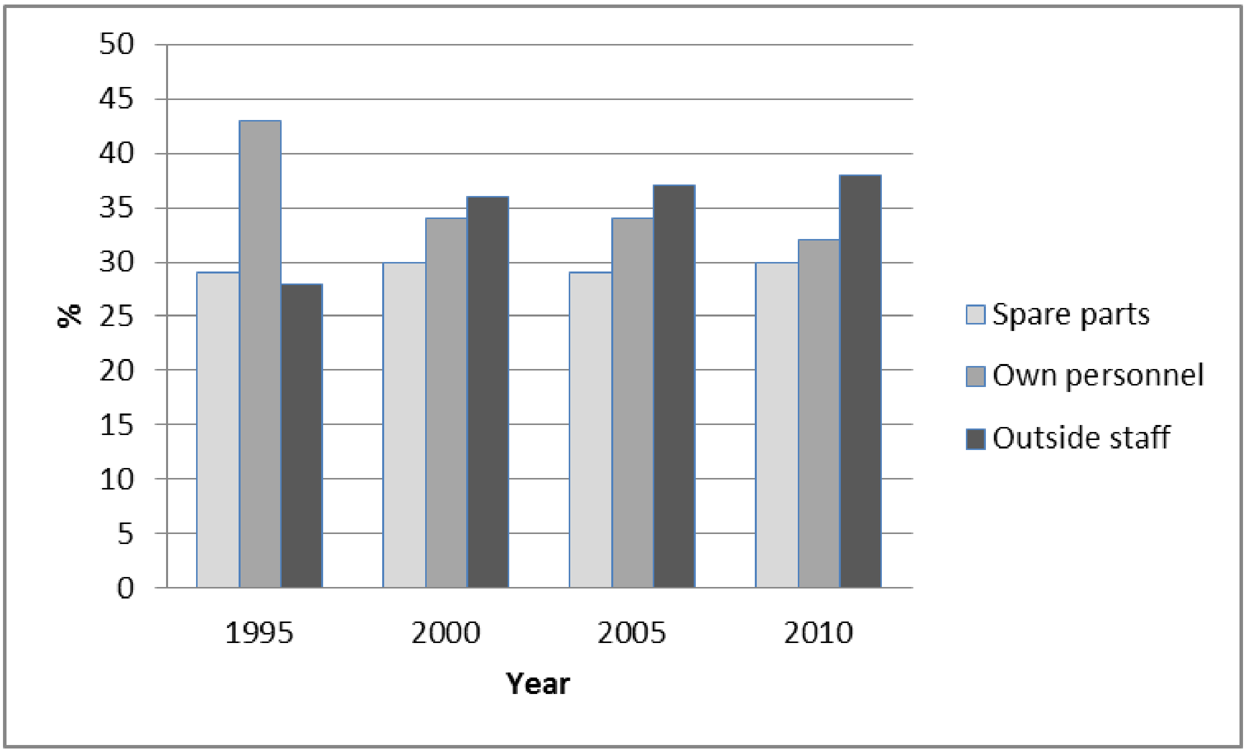

50
45
40
35
30
25
20
15
10
5
0
%
1995
2000
2005
2010
Year
Spare parts
Own personnel
Outside staff

Figure 6:

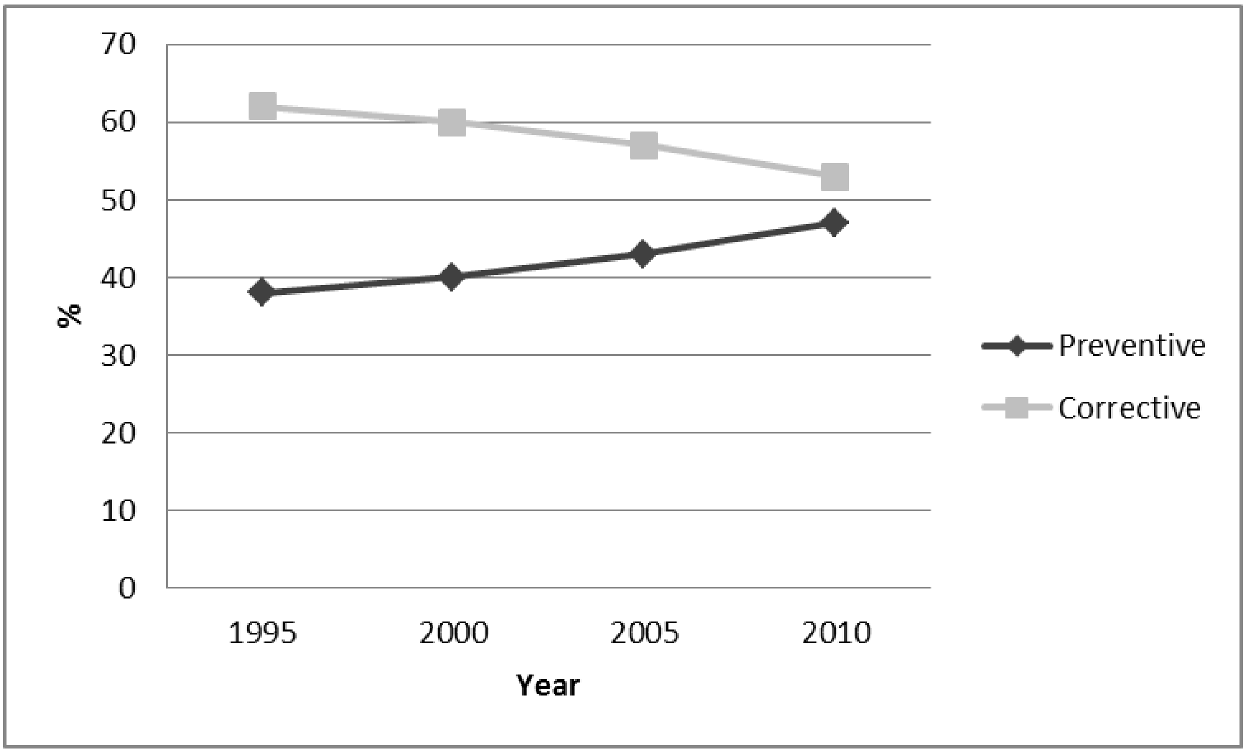

70
60
50
40
30
20
10
0
%
1995
2000
2005
2010
Year
Preventive
Corrective

Figure 7:

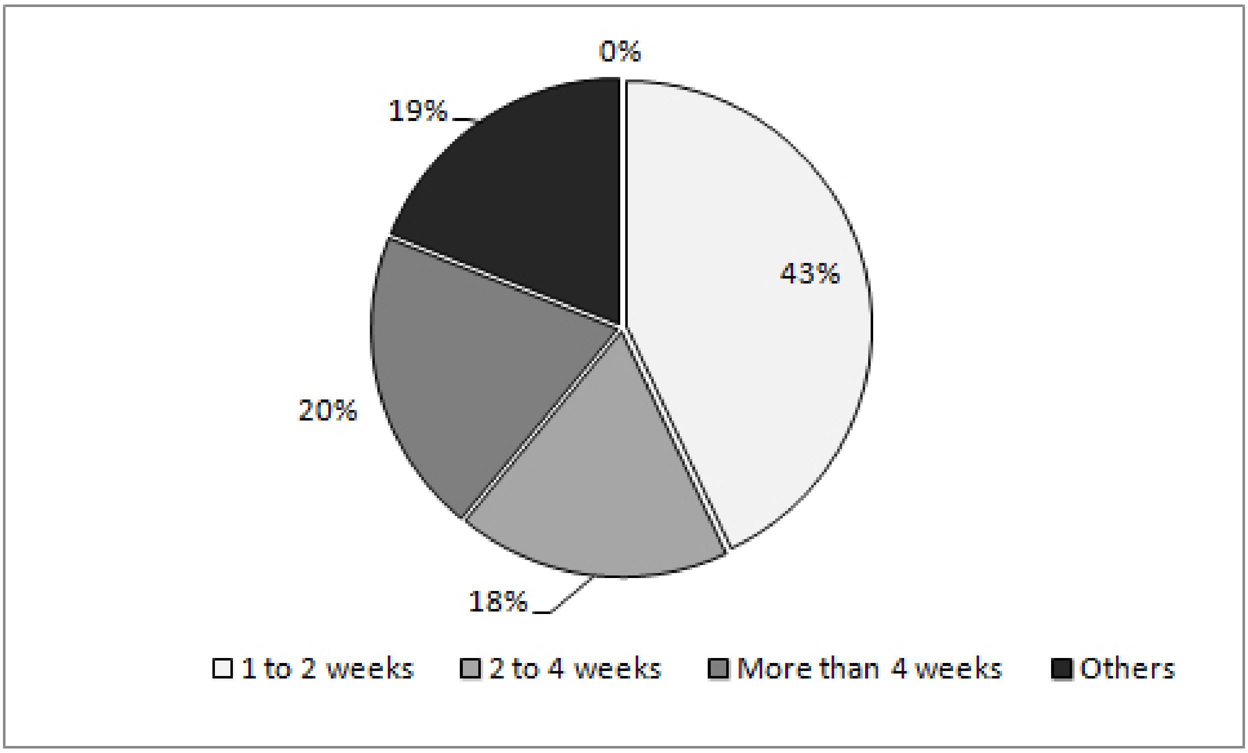
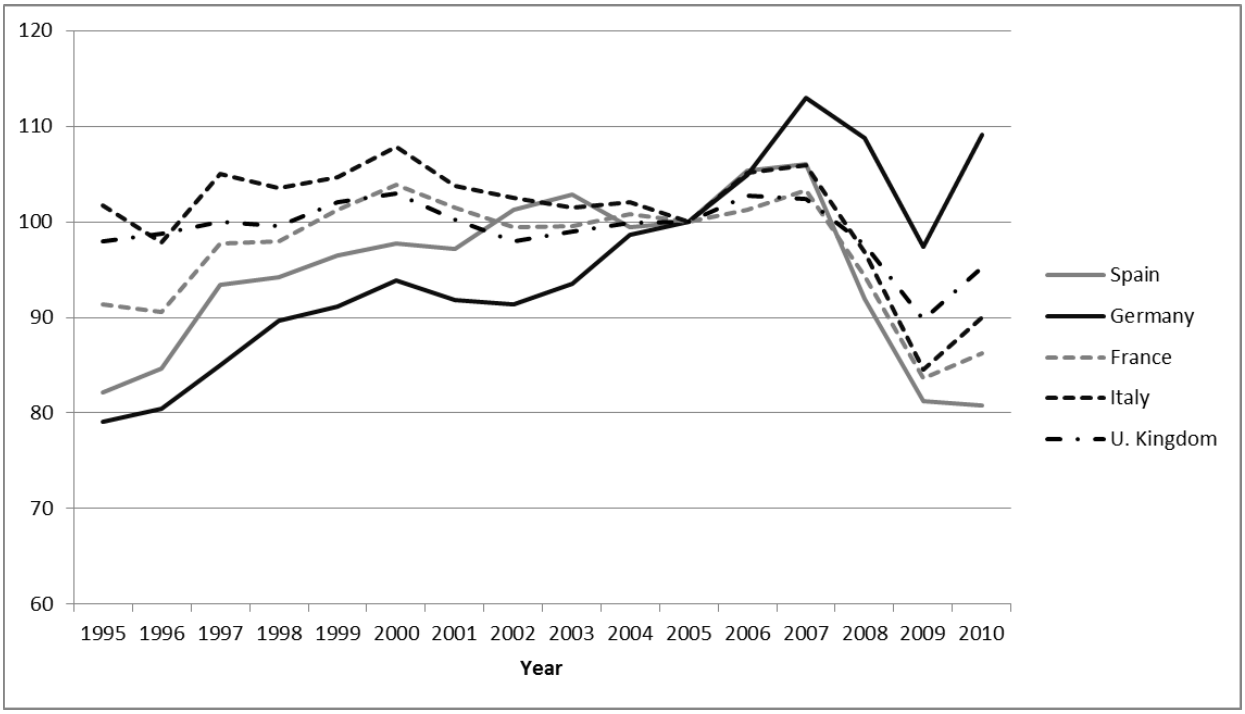


Figure A.1:



KEYWORDS

Maintenance organization, cost-effective maintenance, investments, external services, cost-benefit analysis.