A REVIEW OF PLANT MAINTENANCE METHODS AND ECONOMICS

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Abstract: This paper gives a brief review of the available techniques for plant maintenance and suggests that a mix of techniques is probably the optimum for any particular piece of plant, with different techniques being used for different components. Some approximate guidance is also give on maintenance expenditure and on industries in which improved maintenance is likely to give the greatest financial return.

Key Words: Component failure; Condition monitoring; Maintenance costs; Predictive maintenance Preventative maintenance

The maintenance of plant and equipment is an area of activity which, in recent decades, has received a lot of attention from management consultants, with the associated generation of many buzz words. It may therefore be useful to review plant maintenance methods to see how the various "types" fit together, where they are particularly appropriate to apply, and what the relative economics of them are likely to be.

Maintenance Techniques: The original plant maintenance technique was breakdown maintenance. In this case an item of plant would be repaired each time that it broke down. The problem however is that the process of failure often creates consequential damage, which calls for more extensive repairs. Also there may be delays in the repair process because spare parts and specialised skilled labour may not be immediately available.

An improvement can be obtained by moving to regular preventive maintenance where the plant is stopped at intervals, often annually, and partly stripped and inspected for faults. The problem then is that the components of machines do not fail at regular intervals, but more with a distribution as in Figure 1. To avoid all service failures the time between overhauls has, therefore, to be very short or some ongoing in service failures have to be accepted.

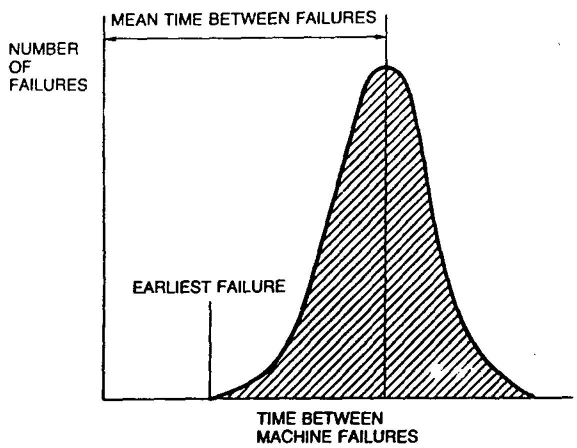


Fig. 1 The distribution of the time to failure for a typical component

The next step forward is to move to condition based maintenance where the critical components are monitored for deterioration and the maintenance is carried out just before the problem arises. The principle is to select an appropriate method of monitoring for deterioration from those listed in Table I and apply it to the machine in order to obtain a lead time of warning in advance of a failure as indicated in Figure 2.

Method	*Principle*	*Application examples*
Wear debris monitoring	The collection and analysis of wear debris derived from component surfaces, and carried away in the lubricating oil	Components such as bearings or other rubbing parts which wear, or suffer from surface pitting due to fatigue
Vibration monitoring	The detection of faults in moving components, from the change in the dynamic forces which they generate, and which affect vibration levels at externally accessible points	Rotating components such as gears and high speed rotors in turbines and pumps
Performance monitoring	Checking that the machine components and the complete machine system are performing their intended functions	The temperature of a bearing indicates whether it is operating with low friction. The pressure and flow rate of a pump indicate whether its internal components are in good condition.

Table I Monitoring methods and the components for which they are suitable

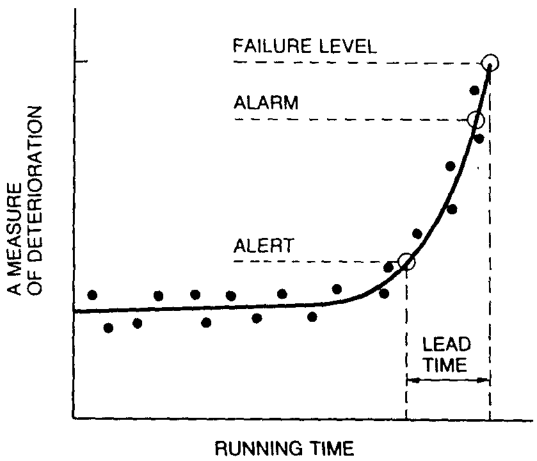
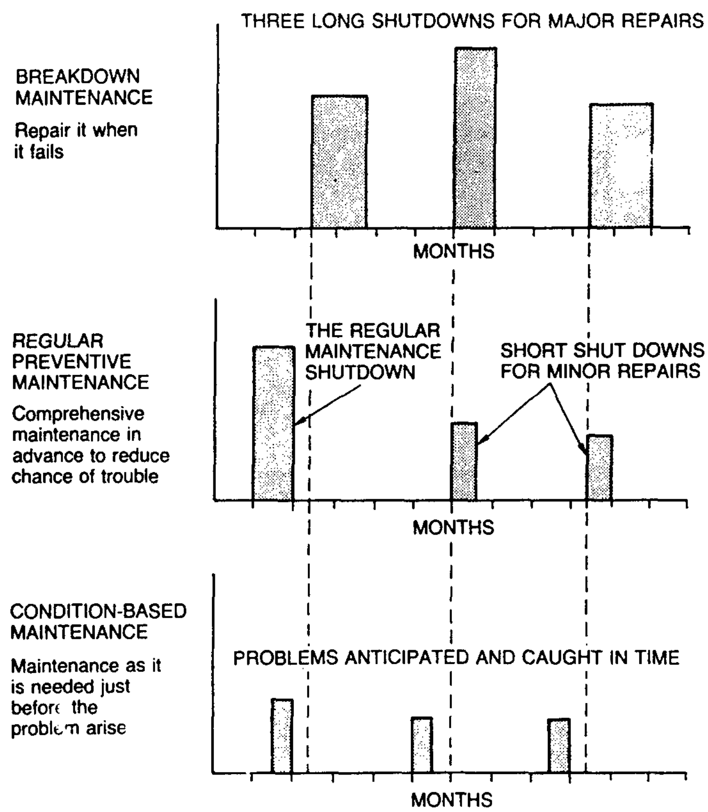


Fig. 2 The lead time before failure provided by condition monitoring

The expected effect of moving from breakdown maintenance through to condition based maintenance, for a plant which might have had three breakdowns in a year, is shown in Figure 3. The effect shown here is impressive and could stimulate all plant users to start monitoring all the components of their machines.

However in practice it is not as simple as this, because, not all failures can be detected by condition monitoring, and the economics of the situation limits the number of components that are worth monitoring, so a choice has to be made. Also there will be a number of components on any machine for which condition monitoring is not particularly appropriate.



The height of the bars indicates the amount of maintenance effort required.

<u>Fig 3</u> **<u>The results of maintaining the same industrial plant in different ways.</u>**

The optimum mix of techniques: The various components of a machine may optimally be maintained in different ways and Figure 4 shows this in a diagrammatic form. Also the starting point of this diagram is the selection of critical machines in a plant, because not all machines will be critical. For example if machines are duplicated and can be readily repaired after failure, carefully organised monitoring and maintenance procedures may not be necessary for them.

Figure 4 could be used to provide some broad guidance on the choice of suitable maintenance methods for a critical machine. Such a machine may have some non critical components which are in this category, either because they are extremely unlikely to fail, or because, if they fail, they do not require the machine to come out of service, and can be replaced on line. The critical components are those which, if they fail, make it necessary to stop the machine, and may also cause it to suffer consequential damage.

Many of these components may be optimally maintained on a basis of their condition, as assessed by condition monitoring. However for some of these components, if their operating conditions are relative consistent and monotonous, it may be more economical to maintain them on a regular timed replacement basis.

An essential feature of components that are suitable for condition monitoring, however, is that they must have a progressive failure mode. This is because it is essentially this progression which is detected by the monitoring technique in order to give a lead time prior to the final development of the failure.

Components which, in contrast, fail with a more sudden mode, need to be replaced on the basis of life expiry. This usually involves an assessment of possible fatigue and creep, and the results of testing and experience. Also since various machine operating conditions may produce increased rates of deterioration, it will usually be necessary to record these conditions, and use them as a basis for computing the maximum allowable operating hours for the component, before it must be changed.

The majority of the critical components of most machines will, however, generally be found suitable for condition monitoring by one method or another. If all of them were to be monitored and a variety of different methods used, the cost of doing this could be unacceptable. It is therefore necessary to have some means of priority assessment so that the most critical components can be selected. This is shown in the diagram in Figure 5 which suggests that a suitable method of assessment may be to judge the required priority by looking at an index derived from the product of indicators of the likelihood of failure and the effect of any failure, together with the expected repair time.

The next decision will be to decide how far down the priority list to go, or how many components is it essential to monitor. Safety requirements are an important factor, as well as the necessary minimum size of the maintenance budget. These issues are discussed in the final section of this paper.

The monitoring techniques to be used also require consideration because there are several different techniques available, commonly with two of three that may be applicable to any one component. For efficiency, training and familiarity, at a particular plant, it is desirable to use the minimum number of different techniques. However if a plant shutdown carries very high economic penalties, it is generally also desirable to have more than one technique, dependent on different physical measurements, in order to avoid false alarms, which can arise from a single monitoring alarm. For these reasons it is suggested in Figure 5 that it is desirable to list the possible monitoring technique for each high priority component so that one or two methods that are common to these components can be selected for use on the plant.

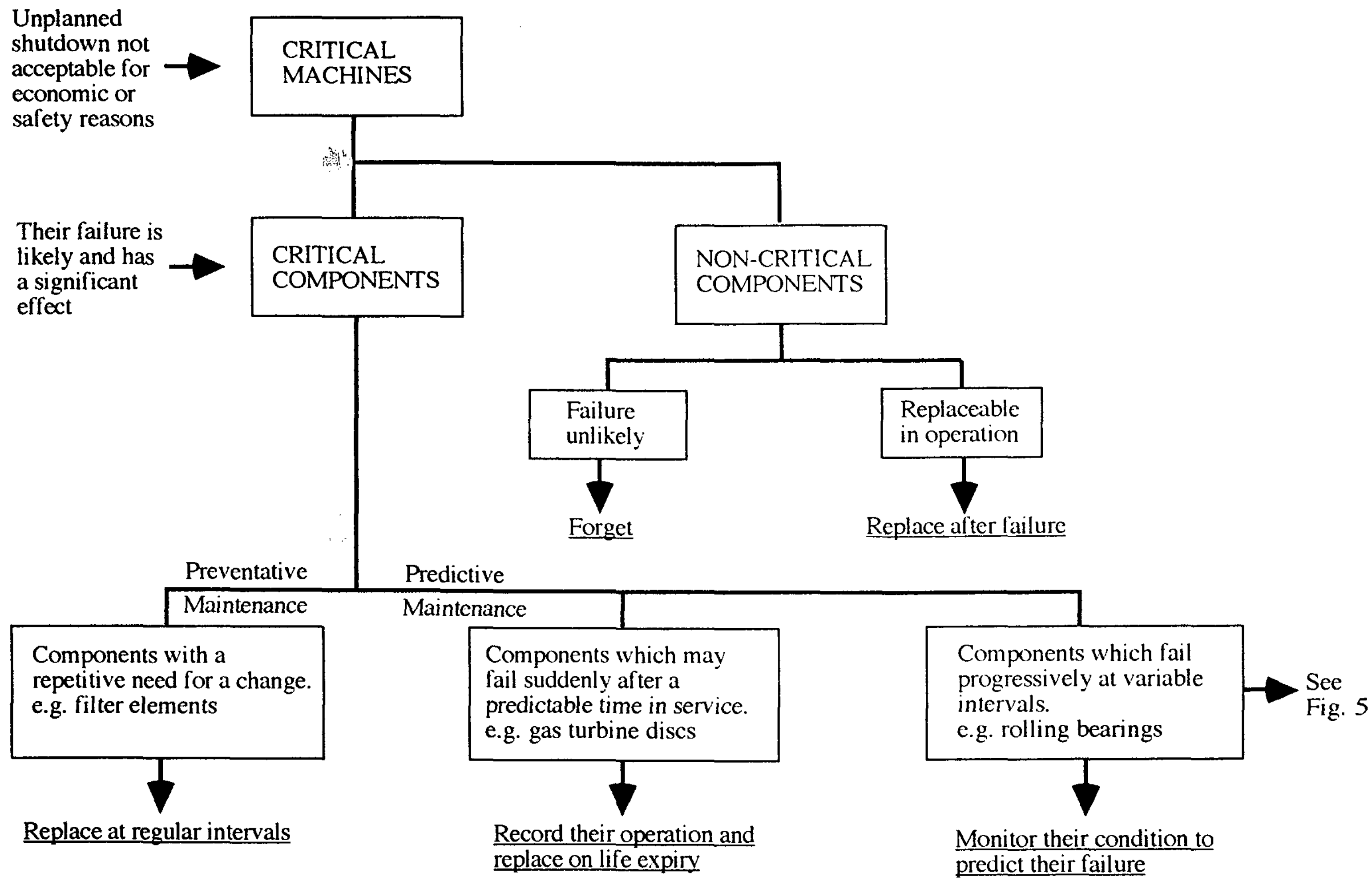


Fig. 4 Appropriate maintenance techniques for various machine components

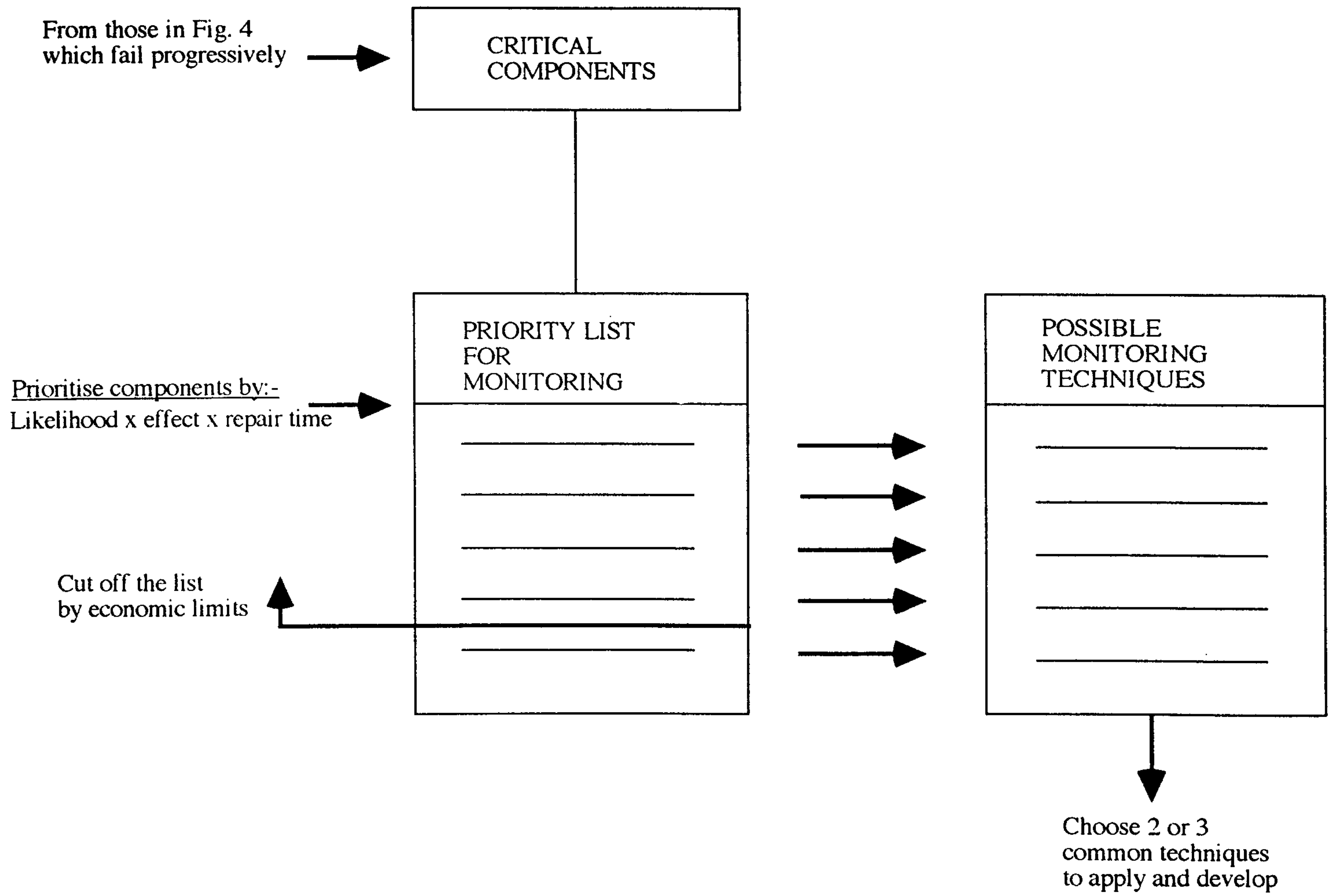


Fig. 5 The choice of components and techniques for component condition monitoring

Maintenance economics: The optimum budget is something that is very difficult to determine. One problem is that it is often difficult to persuade the financial management of a company that they should spend money in advance to avoid a problem that has not yet arisen. Expenditure on condition based maintenance may therefore be resisted, while expenditure to repair a disaster arising from a breakdown maintenance policy, will be agreed as obvious.

Another cause of problems is that very robust machinery can appear to be very tolerant of reduced and inadequate maintenance. Budgets are sometimes cut on a trial percentage basis to see if any problems arise, and robust machines often suffer as a result because it may take five years before disaster strikes. The cost of repair is then usually vastly more than the total savings achieved, from the reduced maintenance budgets. Clearly some economic guidance figures on optimum maintenance levels are required.

Some years ago a government funded study in the UK investigated the amounts that companies considered to be worth spending on setting up improved maintenance systems. This indicated that an expenditure corresponding to 1% of the capital value of the plant could achieve annual savings of the order of 1% of the added value of the company's activities, as indicated in Figure 6. Also if safety was a major consideration it was worth spending up to 5% of the capital value of the plant, which resulted in major improvements. While these figures do not give precise guidance on annual budgets, they do give some indication of the sensitivity of a system to improved standards of maintenance.

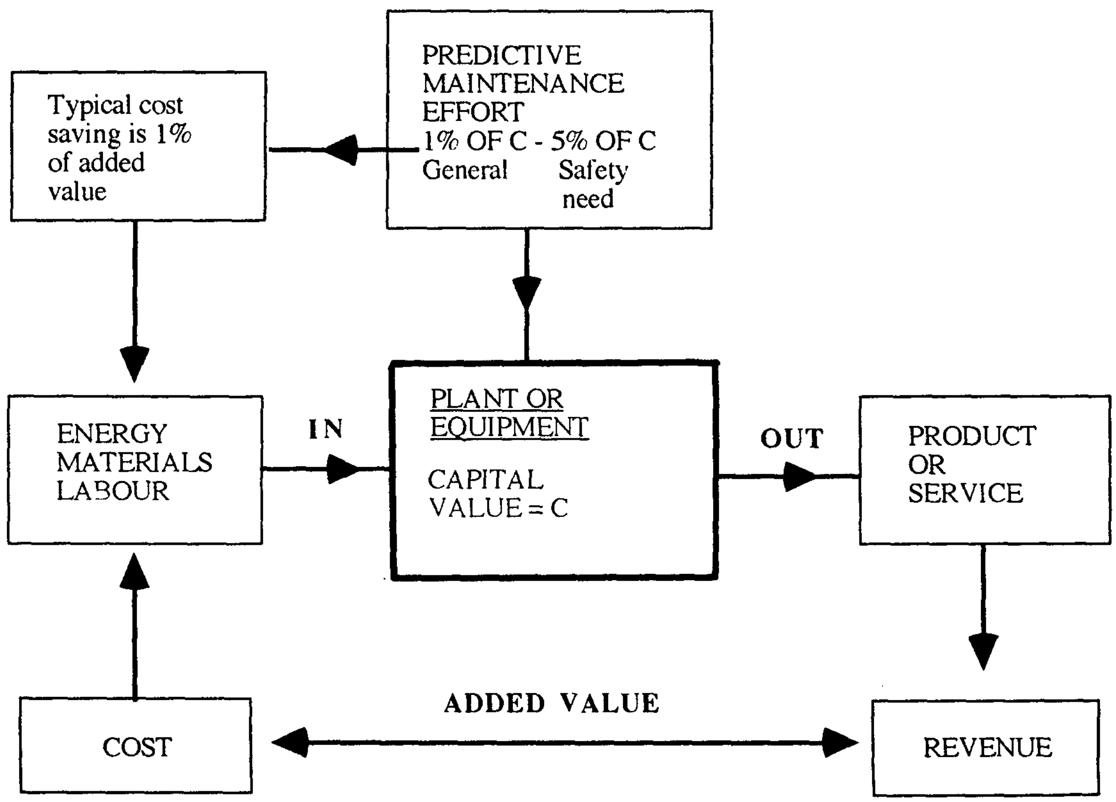


Fig. 6 An indication of the economics of predictive maintenance

In the same study an attempt was made to assess the industries that could achieve improved savings from better maintenance strategies. This was recognised as being those industries which were capital and machine intensive, and which had large enough plants for the process to be effectively organised. Figure 7 shows a range of industries plotted against these two indicators. It shows that industries towards the top right hand corner of this diagram should be able to maintain or increase their maintenance budgets with a higher level of confidence.

This paper is only an approximate overview of methods of plant maintenance. It is hoped however that it may provide some guidance and stimulation for those industrial companies who have not yet taken full advantage from some of the latest maintenance techniques.

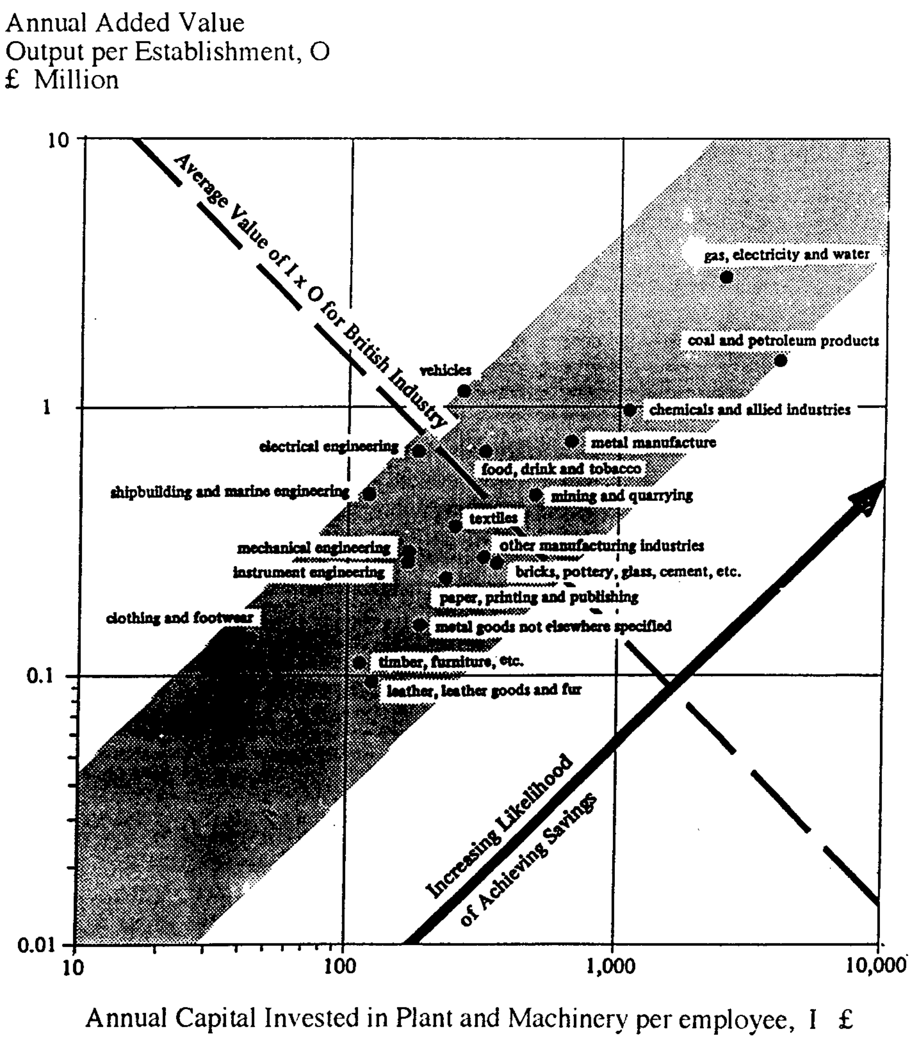


Fig. 7 The industries most likely to profit by the application of predictive maintenance