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# The status of maintenance management in Swedish manufacturing firms

The status of maintenance management

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## **Introduction**

Maintenance has become more important since firms have downsized their organizations, minimized inventory levels and changed to flexible and time-based manufacturing systems. Flexibility is no longer built into the system and reactive maintenance policies have to be exchanged for proactive policies integrated in production. The aim of maintenance is to support and maintain efficient production. It can no longer be considered a cost centre separated from the main business processes of firms, but an integrated function, linked to production and manufacturing strategy. The impact of maintenance on quality and unit costs has to be understood. Advantages could probably be gained by co-ordinating maintenance goal setting with manufacturing and corporate strategies, improving the status of maintenance and integrating it with the overall information system. The trends in maintenance are towards simple maintenance by operators, on-condition maintenance, outsourcing of heavy maintenance and decreasing plant assets. All these separate trends are towards more effective maintenance, but they are often not fully developed or implemented in most firms.

The main objectives of this paper are to present a framework for describing maintenance management and to analyse its status in Swedish manufacturing firms. The status of maintenance management is studied through a survey, designed with the developed framework as a comparative datum.

## **Methodology**

### *Sample*

The sample consists of companies in the food, timber, paper, chemical, mechanical engineering and iron industry, chosen to cover companies with different manufacturing environments and processes (see Table I). Most measures in the survey instrument had not been used in any previous study. The survey instrument was pretested and sent by mail to 747 maintenance managers or production managers of Swedish manufacturing firms, with more than 50 employees. The respondents were asked about their maintenance strategy, perceived status of maintenance in their organization, commitment to and participation in maintenance activities, the characteristics of their

**Table I.**  
Data about respondents

	Number sent	Total number of responses	50-100	Size 101-500	>500	Total response rate (%)
Food	74	31	11	14	6	42
Timber	48	24	15	9	0	50
Paper/print	121	46	11	25	10	38
Chemical	114	43	23	18	2	38
Mechanical engineering	366	131	63	53	15	36
Iron/steel	24	9	4	5	0	38
Total	747	284	127	124	33	38

maintenance management information systems, how they spend maintenance time, which are the most important maintenance techniques, and how they organize maintenance resources. Analyses of individual measures are presented in the sections discussing various maintenance components (goals and strategy, human aspects, support mechanisms, tools and techniques, organization). Other questions about maintenance, which will not be analysed in this paper, were also included in the questionnaire and it took the respondents about 15-20 minutes to fill in the questionnaire. The addresses were identified in the Sema Group database of Swedish organizations.

For this study, 284 relevant answers were received. There was a bias towards small and medium-sized mechanical engineering firms. More than 40 per cent of the responding firms belong to these two groups. However, this is a relevant proportion according to the proportion of such firms in the total population of Swedish manufacturing firms. The response rates of the various industries were almost the same. A comprehensive follow-up, in which 210 non-respondents were telephoned, indicated faults in the database of addresses – 39 (or 19 per cent) of the 210 questionnaires had been addressed to irrelevant companies (that had no manufacturing function) and 46 had been addressed to incorrect people (but had been forwarded correctly). Another 30 said they were not interested in answering. Forty telephone interviews were conducted. Chi-square tests indicated no significant difference between respondents and non-respondents or between early and late answers regarding industry sectors and plant size ( $p < 0.05$ ). If 19 per cent of the addresses are considered irrelevant, the total number of relevant companies would be 608 and the response rate 47 per cent. A response rate above 40 per cent is often considered necessary (Flynn *et al.*, 1990), even though much recent empirical research in manufacturing shows lower response rates (e.g. Miller and Roth, 1994; Vickery *et al.*, 1993)

#### *Instrument and data analysis*

The respondents from different industry sectors were grouped according to their size (number of employees). This resulted in a total of 18 groups of

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respondents (six industries and three sizes). However, most groups were too small to conduct statistical analysis. Therefore, statistical comparisons between small, medium and large firms (independent of industry sectors) and between the five largest industries (independent of size of firm) were carried out (see the Appendix). The level of measurement differed between nominal, ordinal and interval scales.

The scales that measured “formulated maintenance strategy”, “maintenance management information system” and “maintenance organization” were of a nominal type, and statistical comparisons were carried out through chi-square statistics. The overall values of chi-square were partitioned with the use of adjusted standardized residuals for each cell in the contingency tables. Proper application of the chi-square test requires that the expected frequencies in each cell are not too small. Cochran (1954) recommends that in tests for which the degrees of freedom are greater than 1, no more than 20 per cent of the cells have an expected frequency of less than 5, and no cell have an expected frequency of less than 1. To obtain most of these requirements the categories “special” and “standard” were combined when analysing the maintenance information systems in the industries.

The scales for “perceived status”, “commitment”, “participation” and “techniques” were of an ordinal type with underlying continuous distributions. Kruskal-Wallis one-way analysis of variance by ranks was used for identification of overall differences across industries and sizes of firms, while Mann-Whitney tests were used for pairwise comparisons between individual industries and sizes.

Finally, the section on “planning, prevention and corrective maintenance” was measured with interval scales. The analyses were carried out through one-way ANOVA tests, and pairwise Scheffe’s comparison. The results from the statistical tests are presented in the Appendix. The original 18 groups were visually compared without any statistical method.

### **A maintenance management framework**

The concepts of total productive maintenance (TPM), terotechnology, reliability-centred maintenance (RCM), asset management, integrated logistics support (ILS) and life cycle cost/profit (LCC/LCP) focus on various topics of maintenance management. The TPM concept has succeeded very well in making maintenance into an overall company-wide issue, by focusing on continuous improvement, autonomous small group activities, training, education, communication and flow of information. The crucial factors are operator participation and that TQM has to be applied first. TPM does not, however, pay attention to any specific tool or technique for preventive maintenance (Nakajima, 1988). Terotechnology is a British concept focusing on the link between maintenance costs and feedback of proper information to designers and constructors, relying on maintenance optimization and life cycle costing (Husband, 1978). RCM is a systematic approach that differs from the two philosophies above. Firms could benefit from combining the RCM method

with the TPM philosophy. RCM features a systematic road map for preventive maintenance in complex plants, like the airline industry. The fundamental principle of RCM is that scheduled maintenance has little effect on the overall reliability of a complex item, unless the item has a dominant wear out failure (Smith, 1993). RCM almost ignores cost. It does not recognize maintenance as a fundamentally economic problem, but tries to achieve the “inherent reliability” of the system. Asset management takes a company-wide life-cycle approach to equipment but, unlike TPM, it focuses on economic and financial issues, and not engineering (Pintelon and Gelders, 1992; Young, 1996). Terotechnology, on the other hand, tries to combine both issues. LCC/LCP focuses on external effectiveness and how maintenance can contribute to improved revenues (Ahlmann, 1984). ILS is the American counterpart to these life-cycle concepts, with a greater emphasis on logistics (Blanchard, 1991).

The differences and borderlines between these maintenance concepts are vague and vary between authors and users. The importance of viewing maintenance as a company-wide approach is obvious. A few integrated maintenance management approaches, besides the above-mentioned “concepts”, have been presented (e.g. Ben-Daya and Duffuaa, 1995; Geraerds, 1991; Kelly, 1989; Pintelon, 1990; Pintelon and Gelders, 1992; Raouf and Ben-Daya, 1995; Yamashina, 1995), but no uniform maintenance management model yet exists.

To describe the status of maintenance in various firms we felt it necessary to have a uniform maintenance management framework. The framework consists of five linked components;

- goals and strategy;
- human aspects;
- support mechanisms;
- tools and techniques;
- organization.

The first component is about goals and strategies that lead the organization to fulfil corporate objectives. Human aspects constitute the second factor which is the basis for company-wide commitment and continuous improvement. The third element is supporting mechanisms, such as information systems, that make the communication and spread of information easier. The fourth component is maintenance tools and techniques, and the fifth the organization structure that determines resources. The effectiveness of the maintenance management policy depends a lot on the strength of the links between these components as well as on their individual effectiveness.

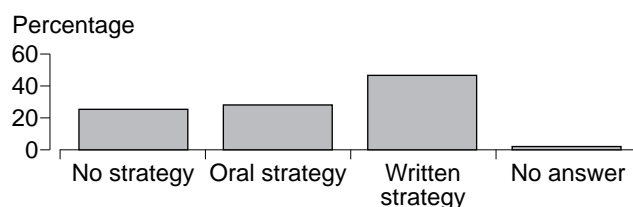
### **Goals and strategy**

Maintenance goals and strategies constitute one of the most important components of the maintenance management framework. They should be formulated to support the corporate strategy and business drivers that

constitute the critical success factors of the firm. Maintenance management will for example, support corporate strategies striving towards least-cost producers, reliability of supply or high product quality.

Strategies for maintenance act as co-ordinating and integrating mechanisms, if they are related to corporate and production strategies, maintenance knowledge, and committed to by the management as well as the personnel involved. Thirty years ago Skinner (1969) showed the necessity of integrating manufacturing into the corporate strategy, and that is still a problem in lots of firms. It is common that marketing and manufacturing groups decide on courses of action that are inconsistent with each other and the business strategy. Several authors (e.g. Buffa, 1984; Caron and Ernest, 1991) verify that manufacturing strategies have been left out in the past, which has led to strategies with production “out of sync” because of a mismatch between the demands of the marketplace and the capability of the production system. The benefits of fully linking long-term corporate, marketing and manufacturing strategies and making plans jointly in an holistic approach cannot be underestimated. Tunälv (1992), for example, showed in an empirical study that companies with a manufacturing strategy derived from the corporate strategy and marketing plan emphasize quality programmes and other preventive actions to a higher extent and are more profitable than companies without such a manufacturing strategy. Hayes and Pisano (1994) consider that one of the key factors behind Japan’s success is that Japanese companies have a clear, interlinked and holistic integration from marketing to manufacturing. The same should probably be true for maintenance strategies, given that manufacturing has already been successfully integrated. Clear goals should be expressed, at the equipment or system level, in operational and understandable terms – for example, “improve availability to 0.993 per cent”, rather than “reduce maintenance costs by 10 per cent” (cf. Deming, 1986).

Many companies do not have clear goals for manufacturing and even fewer have any for maintenance. This is serious, as strategies and goals are prerequisites for achieving more effective maintenance. In the survey, the respondents were asked if they considered themselves to have a written, oral or no maintenance strategy at all. If they had a strategy, they were asked if it was integrated with the corporate strategy, integrated with the production but not the corporate strategy, or if it was separated from other strategies. Figure 1 shows the percentage of companies having no, oral and written maintenance strategies respectively. Only 48 per cent of the respondents were considered to



**Figure 1.**  
Types of maintenance  
strategies

have a written maintenance strategy and 23 per cent had no strategy at all. More than two-thirds of those who had written strategies had derived them from manufacturing or corporate strategies. Chi-square tests identified significant diversion between industries, as well as between firms of various sizes. The timber industry had a lower proportion of written strategies than the average firm. Small firms, and especially small paper and mechanical firms, showed a higher incidence of no strategy (see the Appendix). The proportion of firms having fully developed written maintenance strategies is probably actually lower than the 48 per cent reported, since some of the respondents considered ISO 9000 to be the written strategy and that is not necessarily enough.

It is not enough to formulate strategies, management commitment to the maintenance goals has to be present to make the integrated system work. Attitude and communication problems between operations and maintenance are sometimes both prevalent and deep rooted and can be serious impediments to effective maintenance. Communication between maintenance and production supervisors and personnel is considered to be essential for successful maintenance (e.g. Bateman, 1995; Berger, 1993). One reason for management not giving enough attention to maintenance might be that they cannot see the connections between maintenance and profitability.

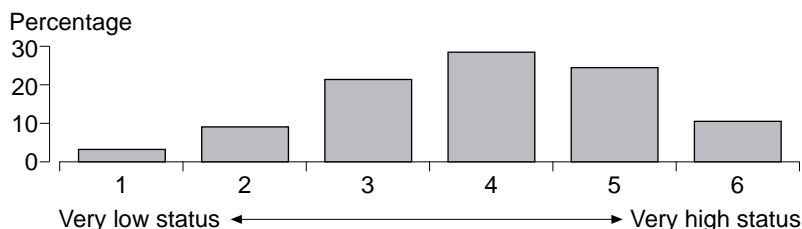
### **Human aspects**

The human aspects and the importance of a learning organization have attracted more attention since the TQM concept has been accepted in organizations. The human aspects of a maintenance management system go hand in hand with those of TQM. Deming (1986) and other TQM-influenced papers (e.g. Kappelman and Prybutok, 1995; Tippett and Waits, 1994) asserted that the links between job fulfilment and continuous improvement, customer satisfaction and performance are very strong and that job satisfaction, job commitment and pride of workmanship are the most important factors in achieving employee fulfilment and empowerment. Similar findings have been found in the area of maintenance. Steudel and Desruelle (1992) for example asserted that the combination of involvement and training at all levels of the organization is the key to manufacturing and maintenance success. Thilander (1992) showed in case studies that competence, information and motivation were important prerequisites for effective maintenance, job satisfaction and overall productivity. She also found that lack of responsibility and commitment from foremen and senior managers caused a large part of the breakdowns. Ericsson and Dahlén (1993) showed that disruptions in the manufacturing system not only depend on technology, but also on work organization, labour stability and a set of external factors. Human aspects and failure of the system are consequently close connected. Malmholt (1990) for example, has confirmed Juran's well-known dictum, that human errors cause more than half of failures of a system and that up to 80 per cent of these require action by management.

A basic condition for achieving a consensus for continuous improvement and job fulfilment in the area of maintenance is that the organization understands the importance of maintenance and that it enjoys good status. A favourable work environment without psychological or physical environmental problems is often argued to be one of two prerequisites, together with training/education, for TPM-like small group activities and continuous improvement (Nakajima, 1988). Lack of status can easily be an important obstacle to job fulfilment and empowerment. Hill (1990) highlighted a set of reasons for the lack of status of production/operations. These should be relevant for maintenance as well.

The respondents of the survey were asked about how they perceived the status of maintenance in their organization (on a scale from 1 to 6, where 1 was very low status and 6 very high). Figure 2 shows that 32 per cent of the respondents considered that maintenance had low status in their organizations (below 4 on a scale from 1 to 6). The importance of maintenance to overall success has to be better understood in these firms, or they will probably fail to correct bad maintenance practices. The overall analysis indicated significant differences across industries and firms of various sizes, while pairwise tests revealed that the status of maintenance is significantly higher in food, paper and mechanical engineering firms than in the timber industry. It also showed that status is higher in large rather than in small and medium sized firms (see the Appendix). No significant differences were found between the answers from maintenance managers and production managers.

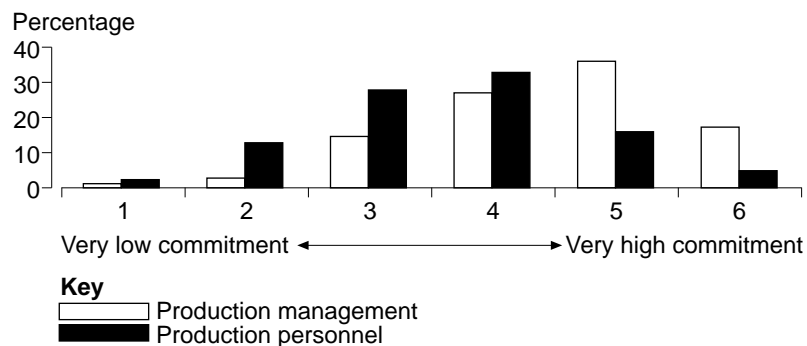
It was highlighted above that management responsibility and commitment were important for effective maintenance. The respondents were asked to mark the production management's and direct production personnel's commitment to maintenance issues. They were also asked to what extent production management and direct production personnel participate in strategic maintenance planning. Six-point Likert scales were used. The latter question was only answered by the 77 per cent of firms that consider they have a maintenance strategy. Figure 3 shows that about one-fifth of the firms had production personnel with high commitment (on levels five to six). The relatively low proportion of firms with production personnel highly committed to maintenance issues indicates that Swedish firms have not fully made maintenance into a company-wide issue. Production management was committed to maintenance issues, on levels five or six, in about half of the firms



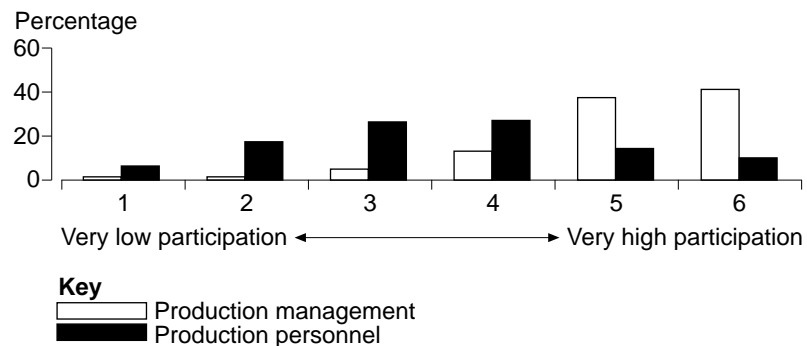
**Figure 2.**  
Perceived status of maintenance

but, still 18 per cent of the firms considered that their production management was committed to maintenance on levels one to three.

Figure 4 shows that production management participated in the maintenance strategy formulation process, on levels five or six, in four-fifths of the firms. Only one-fifth of the firms have direct production personnel that participate on levels five or six. The high level of production management participation is considered a necessary condition for linking strategic manufacturing and maintenance planning. The lower proportion of firms with high level of commitment of production management and production personnel might lead to differences in intended and realized strategies. The analysis could not indicate any significant differences across industries or sizes of firms, regarding participation and commitment of production management or participation of production personnel. However, there was significant difference across industries regarding production personnel's commitment to maintenance issues. Pairwise tests revealed that the direct production personnel in the food and chemical industries were committed to maintenance issues at significantly lower levels than production personnel in the mechanical engineering industry (see Appendix).



**Figure 3.**  
Commitment to maintenance issues



**Figure 4.**  
Participation in the maintenance strategy formulation process

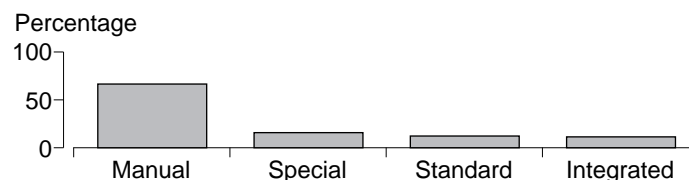


### Support mechanisms

Support mechanisms make communication and information flow easier. The feedback control loop of maintenance data is necessary for lowering the life cycle costs at an early stage and implementing a Deming plan-do-check-act-cycle (PDCA) for continuous improvement.

The maintenance feedback system is not an internal affair of the maintenance or production department. Management should not marginalize the maintenance information system, but integrate it into the overall MIS. Spare-part provisioning and capital investment in new equipment rely on proper maintenance data. Most of the life-cycle costs of equipment and products are determined at the design and prototyping stage (e.g. Ahlmann, 1994; Smith and Knezevic, 1996), and are consequently easier to reduce at this stage than during full production. Purchasing and design functions have to consider these life cycle costs. The collection and feedback of accurate data are especially important; preventive maintenance optimization models depend on them, and equipment manufacturers and planners may be persuaded to act to improve their products. Preventative maintenance (PM) and lubrication schedules published by the machine manufacturer should rely on correct and up-to-date maintenance and availability data. Despite the importance of maintenance information, it is often forgotten in the management information systems (MIS) of organizations. Sherwin (1994) for example asserts that maintenance is the only vital part that is not yet properly integrated in the computer integrated manufacturing (CIM) systems of organizations.

The survey shows that if a maintenance feedback system exists in firms it is seldom integrated with the overall management information system (MIS), but managed from a separate maintenance server. Respondents were asked about what kind of maintenance information system they used. They could choose between four alternatives; manual, custom-built maintenance system controlled from separate computer, standard system controlled from separate computer, or a system integrated into the overall MIS. Figure 5 shows that 64 per cent of the respondents relied on manual information systems and just 9 per cent had maintenance management information systems (MMIS) integrated into the MIS. Twenty-seven per cent managed MMIS from a separate computer. The integrated systems were mostly used by large firms, and especially large paper and chemical firms. Consequently, manual systems were significantly more common in small than in large firms (see the Appendix). The interpretation of what comprises an integrated system varies between firms. Some of the



**Figure 5.**  
Types of maintenance  
information systems

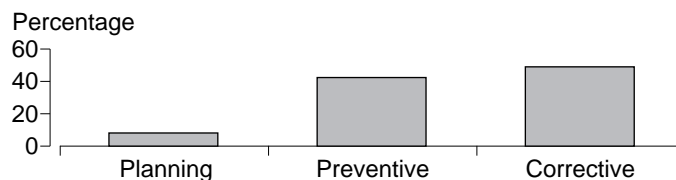
respondents who consider themselves to have an integrated system have probably not integrated it fully, e.g. are not using a mutual database, or planning PM and production together.

Benefits could be gained by integrating the maintenance information system into the overall MIS. The two systems are complementary rather than serial and the existence of the MIS should force the integration. Fully integrated computerized maintenance management systems can hardly be properly implemented until the other components of maintenance management are understood and implemented by the organization, but it plays an important role in overall maintenance management.

### Tools and techniques

Maintenance tools and techniques consist of immediate and delayed corrective maintenance and scheduled and on-condition preventive maintenance. Lots of research shows that preventive techniques are not used as frequently as they should be. Corrective methods are more expensive than preventive ones, and Mobley (1990), for example, states that costs of repair performed in the corrective run-to-failure mode will average about three times higher than the same repair made within a preventive mode. Wireman (1990) estimated that only about 22 per cent of US firms are using preventive maintenance methods. Other studies conducted in the 1980s and 1990s (Kovach, 1983; Tombari, 1982; Tomlinsion, 1993) show that the normal maintenance force operates at about 50 per cent capacity due to lack of maintenance planning and control and that an average of 60-70 per cent of maintenance time in US manufacturing firms is spent on emergencies. The conducted studies identify a trend towards more preventive maintenance, even if it is both slow and uncertain. The proportion of corrective maintenance could, as an average, be further decreased. Changes in the manufacturing environment force firms to focus on proactive techniques – e.g. the exchange of stand-alone manufacturing for cellular manufacturing systems has decreased flexibility and further increased the need for preventive maintenance (Bateman, 1995).

Figure 6 illustrates how the maintenance time of the respondents of the present survey is shared between planning, prevention and correction. The respondents were asked how much of their maintenance time was spent on strategic planning, preventive maintenance, condition maintenance and corrective maintenance. The answers were analysed in the three groups: strategic planning, preventive maintenance (preventive and on-condition maintenance) and corrective maintenance. The answers show that about half of



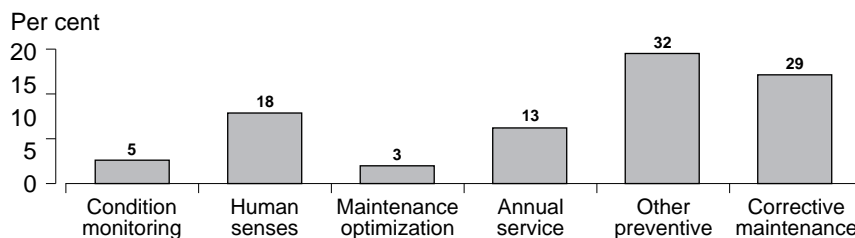
**Figure 6.**  
Maintenance-related  
time

the maintenance time is spent on corrective actions and two-fifths on preventive or condition-based maintenance. The optimum figure for corrective maintenance is considered to not exceed 30-40 per cent (Tomlison, 1993; Wireman, 1990) and most firms probably know this but are still not changing strategies or techniques. An ANOVA indicated that there are significant differences across various sizes of firms. Pairwise tests revealed that small firms spend a significantly larger proportion of their maintenance time on strategic planning than large firms (see the Appendix).

Planning of work load, overhaul, replacement, etc. are key activities in maintenance and are commonly discussed in the literature. There is an enormous number of models for planning maintenance activities and preventing failures in the literature and, in practice, there are proper models for most situations (e.g. Dekker, 1996). They are, however, not much used because of high complexity, lack of knowledge and data.

The solution for maintenance is not always just to increase planned preventive maintenance (PM). PM programmes are not always kept up to date, nor do they always work in harmony with production schedules. Proper data for calculating the schedules seldom exist and the proposed schedules often become somewhat arbitrary. All machines are not average and improved preventive polices might lead to some machines being over-maintained and others under-maintained. This results in increased life cycle costs. Instead reliability-based on-condition maintenance should probably become more important for firms. It gives advance warning of impending problems and gives rise to maintenance activities. Condition-based maintenance has, together with decentralized maintenance inspection by operators, received much interest in the literature during the last few years.

Figure 7 does, however, show that condition monitoring has not achieved as much penetration as operator inspection in practice, probably because operators are still needed for tool changing and QC duties, and the cost of training them to keep watch for developing defects is marginal, whereas condition monitoring equipment is still more expensive. The respondents of the present study were asked to rank the most important and the second most important maintenance techniques of their companies. Every first ranked answer got two points and every second rank got one point. The two most important techniques were inspection at fixed intervals and corrective



**Figure 7.**  
The importance of  
various maintenance  
techniques

maintenance, followed by on-condition maintenance by human senses and annual service. Maintenance optimization by analysing reliability data and condition monitoring did not get very high priority. Data analysis indicated significant differences across different sizes of firm regarding condition monitoring and annual service. Pairwise tests revealed that large firms use condition monitoring techniques to a significantly higher extent than small and medium-sized firms, and use annual service to a significantly lower extent than small firms. Condition monitoring was the most important technique in large paper and chemical firms. Annual service was most important in small mechanical engineering firms. Corrective maintenance was important in small and medium-sized enterprises and in the timber and iron industries. Condition monitoring and human senses were expected to be more important techniques (see the Appendix).

### **Organization**

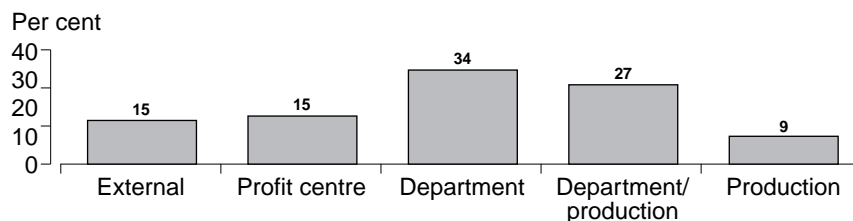
The optimum maintenance organization structure is dependent on the specific conditions within the organization. Decentralization, participation of maintenance workers in project teams, focusing on the core business and outsourcing are common and important organizational trends. Transferring responsibility from maintenance workers to machine operators and a more holistic view result in faster response time when machines breakdown and an increased level of co-operation and trust between production/operations and maintenance workers. Kelly (1989) considered the most important factors for deciding about allocating maintenance resources to be plant layout and cost of plant availability. That was not analysed and this study could consequently not be verified.

By decentralizing maintenance activities, such as planning and supervision, to the operators, the costs and performance of maintenance can sometimes be improved. A study by Maggard and Rhyne, (1992) shows that 40 per cent of the traditional maintenance mechanic's work could be done by another employee, with minimal training, and another 40 per cent could be performed with additional training, but still below the certified level. Steudel and Desruelle (1992) argue that 80-90 per cent of the maintenance work should be carried out by the operators. Another empirical study (Maggard and Rhyne, 1992) shows that 75 per cent of maintenance problems can be prevented by operators at an early stage, by frequent looking, listening, smelling and testing. However, these figures are case specific and are impossible to be used as generally optimum figures. Continuous training and education are necessary to fully decentralize maintenance to the operators.

The creation of strong strategic alliances, outsourcing maintenance and focusing on the core processes of firms have been more common and important lately. Trends towards more virtual organizations consisting of long supply chains competing in the marketplace, quality trends and internal suitability force companies to streamline their organizations and outsource parts of their support activities. As the complexity of maintenance increases, due to improved

mix of equipment and maintenance tools, it is more difficult to economically plan and co-ordinate and outsourcing may be the most appropriate form of allocation. In the more complex manufacturing environments, individuals have to specialize within their respective profiles and then the overall flexibility decreases. Flexibility can be improved by training or by co-operation with external maintenance suppliers. The benefits of outsourcing maintenance seems clear, but it still might be problematic to decide about the optimum type of contract (see Martin, 1997).

The respondents were asked how they organized the main part of their maintenance resources. They could choose between five main types of organization (see Figure 8). The answers show that it is still most common to organize maintenance resources in a centralized maintenance function or a combination of centralized function and integrated into production. Chi-square tests indicated a significant difference across industries and across size of firms. Outsourcing and decentralized production integrated maintenance by operators, are most common in small firms. Medium-sized firms are represented by a larger proportion of companies with central maintenance departments and fewer firms with production-integrated maintenance than small and large companies (see the Appendix).



**Figure 8.**  
Organization of the main part of the maintenance resources

### Conclusions

Maintenance management can be described as consisting of five linked components; strategy, human aspects, support mechanisms, tools and techniques, and organization. Most of the maintenance management components can probably be improved in the average Swedish manufacturing firm. It is necessary to formulate clear maintenance strategies that are linked to manufacturing and corporate strategies. Only half of the respondents of the survey had any written maintenance strategy, and all of these had not linked the maintenance strategy to production or corporate strategies. The figure is even lower in small firms and in the timber industry. Most firms with any kind of maintenance strategy involved production management to a great extent in the strategy formulation process. However, the commitment to maintenance issues of production management and production personnel was lower, which indicates that Swedish firms have not fully made maintenance into a company-wide issue. One-third of the firms consider that maintenance has low status in their organizations and that is a great obstacle for creating strong learning organizations and working for continuous improvement.

Decentralized maintenance is becoming more important and a combination of decentralized maintenance by operators and outsourcing is common in small firms. A centralized maintenance function, however, still dominates the majority of firms. However, outsourcing and production integrated maintenance are important in small firms. A necessary condition for planning and controlling preventive and on-condition maintenance is to have a well-developed maintenance management information system. Only 10 per cent of the manufacturing firms in the survey considered themselves to have integrated maintenance into their management information system and very few used condition monitoring or maintenance optimization to prevent failures. However, condition monitoring was the most important technique in large process-oriented chemical and paper plants with expensive stoppage costs. The most common maintenance techniques are fixed interval inspection and corrective maintenance. About half of maintenance time is spent on correction and that is probably often too much.

Swedish manufacturing firms should improve their understanding of the importance of maintenance management. Most of the necessary knowledge and technology for proper maintenance management probably exists, but too few companies have learned to use them. We consider maintenance to be the next logical progression, driven primarily by product quality, customer satisfaction considerations and long-term strategies. Research is needed in many maintenance-related areas. The present study did not focus on the relationship between various maintenance components. It is likely that the successful use of various maintenance techniques requires certain contexts, e.g. organizational design. An interesting future study would therefore be to study the links between the above discussed maintenance management components, and explain correlation the between components and also between high performance, competitive advantage and maintenance components.

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**Appendix: answers grouped in industries and sizes**

The status of  
maintenance  
management

Industry	Strategy			
	None (%)	Oral (%)	Written (%)	No answer (%)
Total in all industries	23	28	41	1
<i>Food industry</i>				
Total	19	39	39	3
< 100 employees	9	64	18	9
100-500 employees	29	14	57	0
> 500 employees	17	50	33	0
<i>Timber industry</i>				
Total	38	38	24	0
< 100 employees	36	43	21	0
100-500 employees	40	30	30	0
<i>Print/paper industry</i>				
Total	24	21	55	0
< 100 employees	55	36	9	0
100-500 employees	18	18	64	0
> 500 employees	0	11	89	0
<i>Chemical industry</i>				
Total	14	26	60	0
< 100 employees	13	26	61	0
100-500 employees	17	33	50	0
> 500 employees	0	0	100	0
<i>Mechanical engineering</i>				
Total	28	23	49	0
< 100 employees	33	24	43	0
100-500 employees	25	19	56	0
> 500 employees	27	27	46	0
<i>Iron/steel industry</i>				
Total	0	67	33	0
< 100 employees	0	75	25	0
100-500 employees	0	60	40	0

**Note:**

Chi-square tests identified significant differences between industries ( $p < 0.01$ ) as well as between firms of various sizes ( $p < 0.05$ ). Analysis of adjusted standardized residuals (at the level  $p < 0.05$ ) for each cell revealed that the paper industry had a significantly higher oral strategy, the timber industry and small firms had a significantly lower written strategy than expected

**Table AI.**  
Formulated  
maintenance strategy

JQME  
3,4

**250**

Industry	Status percentages						
	1	2	3	4	5	6	No answer
Total in all industries	3	9	20	29	27	11	1
<i>Food industry</i>							
Total	8	0	19	35	27	8	3
< 100 employees	9	0	18	18	28	18	9
100-500 employees	13	0	12	50	25	0	0
> 500 employees	0	0	29	42	29	0	0
<i>Timber industry</i>							
Total	4	17	38	21	13	3	4
< 100 employees	0	29	21	29	21	0	0
100-500 employees	10	0	60	10	0	10	10
<i>Print/paper industry</i>							
Total	2	5	12	31	33	17	0
< 100 employees	5	36	24	21	12	0	2
100-500 employees	0	0	5	10	14	66	5
> 500 employees	2	2	12	25	38	19	2
<i>Chemical industry</i>							
Total	7	12	16	30	19	16	0
< 100 employees	9	13	17	30	9	22	0
100-500 employees	6	11	17	32	28	6	0
> 500 employees	0	0	0	0	50	50	0
<i>Mechanical engineering</i>							
Total	2	9	24	27	31	7	0
< 100 employees	0	8	30	18	34	10	0
100-500 employees	2	10	24	33	25	6	0
> 500 employees	0	8	0	41	41	0	0
<i>Iron/steel industry</i>							
Total	0	11	11	33	33	11	0
< 100 employees	0	25	0	0	50	25	0
100-500 employees	0	0	20	60	20	0	0
<i>Maintenance managers</i>							
	3	9	14	30	29	11	4
<i>Production managers</i>							
	2	11	26	24	24	13	1
<i>Other management (e.g. CEO)</i>							
	3	5	19	41	23	7	2

**Note:**

Kruskal-Wallis one-way ANOVA tests indicated that there are significant differences across industries ( $p < 0.01$ ) and across various sizes ( $p < 0.05$ ), while pairwise Mann-Whitney tests ( $p < 0.05$ ) revealed that the food, paper and mechanical engineering industries have significantly higher status than in the timber industry, that it has significantly higher status than in the paper industry in the mechanical engineering industry, and that it has significantly lower status in small and medium sized firms than in large firms

**Table AII.**  
Perceived status of  
maintenance

Industry	Status percentages						The status of maintenance management
	1	2	3	4	5	6	
Total in all industries	1	3	15	27	36	17	<b>251</b>
<i>Food industry</i>							
Total	0	3	17	27	37	17	
< 100 employees	0	0	18	27	36	18	
100-500 employees	0	8	8	23	38	23	
> 500 employees	0	0	33	33	33	0	
<i>Timber industry</i>							
Total	0	0	25	21	29	21	
< 100 employees	0	0	21	21	36	21	
100-500 employees	0	0	30	20	20	20	
<i>Print/paper industry</i>							
Total	2	2	11	27	38	18	
< 100 employees	9	0	36	9	27	18	
100-500 employees	0	4	4	33	38	17	
> 500 employees	0	0	0	30	50	20	
<i>Chemical industry</i>							
Total	2	7	19	21	40	12	
< 100 employees	4	4	22	17	30	22	
100-500 employees	0	11	17	28	44	0	
> 500 employees	0	0	0	0	100	0	
<i>Mechanical engineering</i>							
Total	0	3	12	29	36	16	
< 100 employees	0	2	10	27	44	16	
100-500 employees	0	4	17	37	25	13	
> 500 employees	0	7	7	13	40	27	
<i>Iron/steel industry</i>							
Total	0	0	11	33	11	44	
< 100 employees	0	0	25	25	25	25	
100-500 employees	0	0	0	40	0	60	

**Note:** Kruskal-Wallis one-way ANOVA tests identified no significant difference ( $p < 0.05$ ) across industries or sizes

**Table AIII.** Commitment of production management

JQME  
3,4

**252**

Industry	Status percentages					
	1	2	3	4	5	6
Total in all industries	2	13	28	33	16	5
<i>Food industry</i>						
Total	3	10	47	30	7	3
< 100 employees	0	18	36	27	9	9
100-500 employees	8	0	46	38	8	0
> 500 employees	0	17	67	17	0	0
<i>Timber industry</i>						
Total	4	13	21	29	13	8
< 100 employees	0	14	29	36	7	7
100-500 employees	10	10	10	20	20	10
<i>Print/paper industry</i>						
Total	2	11	47	36	11	0
< 100 employees	0	9	27	36	27	0
100-500 employees	0	4	58	25	8	0
> 500 employees	0	20	30	20	30	0
<i>Chemical industry</i>						
Total	7	21	28	28	14	2
< 100 employees	4	17	26	30	17	4
100-500 employees	11	28	28	22	11	0
> 500 employees	0	0	50	50	0	0
<i>Mechanical engineering</i>						
Total	1	10	24	39	18	5
< 100 employees	2	11	19	35	25	0
100-500 employees	0	10	31	40	10	6
> 500 employees	0	7	20	53	13	0
<i>Iron/steel industry</i>						
Total	0	33	22	22	22	0
< 100 employees	0	50	25	0	25	0
100-500 employees	0	20	20	40	20	0

**Note:**

Kruskal-Wallis one-way ANOVA tests indicate significant difference ( $p < 0.05$ ) across industries, but not across sizes. Pairwise Mann-Whitney tests ( $p < 0.05$ ) revealed that the commitment in the food and chemistry industries are significantly lower than in the mechanical engineering industry

**Table AIV.**  
Commitment of  
production personnel

Industry	Status percentages						The status of maintenance management
	1	2	3	4	5	6	
Total in all industries	1	1	5	13	38	42	<b>253</b>
<i>Food industry</i>							
Total	0	0	8	17	33	42	
< 100 employees	0	0	0	20	40	40	
100-500 employees	0	0	11	11	11	67	
> 500 employees	0	0	20	20	60	0	
<i>Timber industry</i>							
Total	0	0	7	14	36	43	
< 100 employees	0	0	0	13	25	63	
100-500 employees	0	0	17	17	50	17	
<i>Print/paper industry</i>							
Total	3	0	0	17	44	36	
< 100 employees	0	0	0	0	67	33	
100-500 employees	5	0	0	10	40	45	
> 500 employees	0	0	0	40	40	20	
<i>Chemical industry</i>							
Total	5	0	5	14	35	41	
< 100 employees	0	0	5	25	20	50	
100-500 employees	13	0	7	0	53	27	
> 500 employees	0	0	0	0	50	50	
<i>Mechanical engineering</i>							
Total	0	2	6	8	40	43	
< 100 employees	0	0	2	7	48	43	
100-500 employees	0	3	10	5	35	48	
> 500 employees	0	9	9	27	27	27	
<i>Iron/steel industry</i>							
Total	0	0	0	22	22	56	
< 100 employees	0	0	0	50	25	25	
100-500 employees	0	0	0	0	20	80	

**Note:** Kruskal-Wallis one-way ANOVA tests identified significant difference ( $p < 0.05$ ) across sizes of firms, but not across industries. Pairwise Mann-Whitney tests ( $p < 0.05$ ) revealed that production management in small and medium sized firms participate to a significantly higher level than in large firms

**Table AV.**  
Participation of production management

JQME  
3,4

**254**

Industry	Status percentages					
	1	2	3	4	5	6
Total in all industries	6	017	26	27	14	9
<i>Food industry</i>						
Total	0	29	29	29	8	4
< 100 employees	0	20	30	30	10	10
100-500 employees	0	22	22	44	11	0
> 500 employees	0	60	40	0	0	0
<i>Timber industry</i>						
Total	0	14	29	43	0	7
< 100 employees	0	13	25	38	0	13
100-500 employees	0	17	33	50	0	0
<i>Print/paper industry</i>						
Total	11	11	25	36	8	8
< 100 employees	17	0	17	50	17	0
100-500 employees	10	0	30	35	10	15
> 500 employees	11	11	26	34	9	9
<i>Chemical industry</i>						
Total	6	28	28	14	11	14
< 100 employees	0	21	32	5	16	26
100-500 employees	13	33	27	20	7	0
> 500 employees	0	50	0	50	0	0
<i>Mechanical engineering</i>						
Total	5	13	26	24	22	8
< 100 employees	0	9	26	21	28	14
100-500 employees	8	15	28	33	15	3
> 500 employees	18	18	27	9	18	9
<i>Iron/steel industry</i>						
Total	11	22	11	33	11	11
< 100 employees	0	0	0	75	0	25
100-500 employees	20	40	20	0	20	0

**Note:**

**Table AVI.** Participation of direct production personnel  
Kruskal-Wallis one-way ANOVA tests identified significant difference across sizes of firms, but not across industries. Pairwise Mann-Whitney tests ( $p < 0.05$ ) revealed that production personnel in small firms participate to a significantly higher level than in medium and large sized firms

Industry	Manual	Special	Standard	Integrated	The status of maintenance management
Total in all industries	64	15	12	9	
<i>Food industry</i>					
Total	60	23	10	7	
< 100 employees	82	9	0	9	
100-500 employees	62	22	8	8	
> 500 employees	17	50	33	0	
<i>Timber industry</i>					
Total	84	4	4	8	
< 100 employees	93	0	0	7	
100-500 employees	70	10	10	10	
<i>Print/paper industry</i>					
Total	53	14	12	21	
< 100 employees	100	0	0	0	
100-500 employees	50	23	9	18	
> 500 employees	50	20	10	20	
<i>Chemical industry</i>					
Total	72	9	12	7	
< 100 employees	82	5	8	5	
100-500 employees	67	11	17	5	
> 500 employees	0	50	0	50	
<i>Mechanical engineering</i>					
Total	62	16	13	9	
< 100 employees	75	8	10	7	
100-500 employees	57	22	14	7	
> 500 employees	27	36	19	18	
<i>Iron/steel industry</i>					
Total	67	11	22	0	
< 100 employees	100	0	0	0	
100-500 employees	40	20	40	0	

**Note:** Chi-square tests could not identify any significant difference across industries, but across sizes ( $p < 0.01$ ). Analysis of adjusted standardized residuals (at the level  $p < 0.05$ ) for each cell revealed that small firms used manual systems significantly more frequently and special, standard and integrated systems significantly less frequently than large firms

**Table AVII.** Maintenance management information system

Industry	External	Profit centred	Department	Department/ production	Production
Total in all industries	15	15	34	27	9
<i>Food industry</i>					
Total	3	20	67	10	0
< 100 employees	9	9	73	9	0
100-500 employees	0	23	62	15	0
> 500 employees	0	33	67	0	0
<i>Timber industry</i>					
Total	13	21	29	33	4
< 100 employees	7	21	29	36	7
100-500 employees	20	20	30	30	0
<i>Print/paper industry</i>					
Total	0	5	49	34	12
< 100 employees	0	9	27	36	27
100-500 employees	0	4	62	24	10
> 500 employees	0	0	44	56	0
<i>Chemical industry</i>					
Total	17	18	29	29	7
< 100 employees	18	18	18	32	14
100-500 employees	17	22	44	17	0
> 500 employees	0	0	0	100	0
<i>Mechanical engineering</i>					
Total	24	12	27	26	11
< 100 employees	31	8	22	24	15
100-500 employees	20	16	35	25	4
> 500 employees	0	17	17	42	24
<i>Iron/steel industry</i>					
Total	0	12	44	44	0
< 100 employees	0	25	25	50	0
100-500 employees	0	0	60	40	0

**Note:**

Chi-square tests ( $p < 0.01$ ) identified significant variations across industries and sizes. Analysis of adjusted standardized residuals (at the level  $p < 0.05$ ) for each cell revealed that the food industry had significantly larger proportion of external organization and significantly smaller proportion of maintenance department than expected, that the paper industry had significantly smaller proportion of external organization than expected, that the mechanical engineering industry had significantly larger proportion of external maintenance and significantly smaller proportion of maintenance departments than expected, that small firms had significantly larger proportion of external maintenance and production integrated maintenance but significantly smaller proportion of maintenance department than expected, that medium sized firms had significantly higher proportion of maintenance department and significantly lower proportion of production integrated maintenance than expected, and that large firms had significantly lower proportion of external maintenance than expected

**Table AVIII.**  
Maintenance organization



Industry	Planning	Preventive	Corrective	The status of maintenance management
Total in all industries	10	41	49	
<i>Food industry</i>				
Total	8	46	46	
< 100 employees	9	52	39	
100-500 employees	10	47	43	
> 500 employees	2	30	68	<b>257</b>
<i>Timber industry</i>				
Total	10	33	57	
< 100 employees	10	33	57	
100-500 employees	9	33	58	
<i>Print/paper industry</i>				
Total	9	45	46	
< 100 employees	11	41	48	
100-500 employees	7	47	46	
> 500 employees	12	45	43	
<i>Chemical industry</i>				
Total	10	41	49	
< 100 employees	10	44	46	
100-500 employees	10	38	52	
> 500 employees	8	38	54	
<i>Mechanical engineering</i>				
Total	9	42	49	
< 100 employees	10	43	47	
100-500 employees	9	42	49	
> 500 employees	4	39	57	
<i>Iron/steel industry</i>				
Total	10	34	56	
< 100 employees	16	22	62	
100-500 employees	16	22	62	
<b>Note:</b>	F-test (one-way ANOVA) indicated significant differences across firm sizes regarding planning. Pairwise Scheffe's tests ( $p < 0.05$ ) revealed that small firms spend a significantly larger proportion of time on strategic planning than large firms			<b>Table AIX.</b> Planning, preventative and corrective maintenance

Industry	Condition monitoring	Human senses	Maintenance optimization	Annual service	Other preventive	Corrective
Total in all industries	5	18	3	13	32	29
<i>Food industry</i>						
Total	6	25	6	10	39	14
< 100 employees	0	37	3	12	33	15
100-500 employees	9	19	12	13	35	12
> 500 employees	12	13	0	0	56	19
<i>Timber industry</i>						
Total	3	24	0	13	18	42
< 100 employees	2	32	0	18	11	37
100-500 employees	5	13	0	6	28	48
<i>Print/paper industry</i>						
Total	10	21	2	9	32	26
< 100 employees	0	21	0	13	34	32
100-500 employees	5	17	2	11	33	32
> 500 employees	38	31	8	0	23	0
<i>Chemical industry</i>						
Total	9	14	3	6	37	31
< 100 employees	9	12	5	7	36	31
100-500 employees	4	18	0	6	38	34
> 500 employees	60	0	0	0	40	0
<i>Mechanical engineering</i>						
Total	3	15	3	18	31	30
< 100 employees	2	16	4	23	26	29
100-500 employees	4	15	2	13	36	30
> 500 employees	7	7	7	6	41	32
<i>Iron/steel industry</i>						
Total	0	11	0	7	34	48
< 100 employees	0	17	0	8	8	67
100-500 employees	0	7	0	7	53	33

**Note:**  
Kruskal-Wallis one-way ANOVA tests indicated no significant difference across industries, but across firm sizes regarding condition monitoring ( $p < 0.05$ ) and annual service ( $p < 0.05$ ). Pairwise Mann-Whitney tests ( $p < 0.05$ ) revealed that large firms use condition monitoring techniques to a significantly larger extent than small and medium sized firms, and annual service to a significantly lesser extent than small firms

**Table AX.**  
Maintenance techniques