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Total Quality Maintenance

An approach for continuous reduction in costs of quality products

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Abstract

The common thread in achieving and maintaining high Overall Equipment Effectiveness, OEE, is the availability of improved manufacturing processes capable of producing quality products without interruption. Implementing Just In Time, JIT, philosophy demands healthy processes. Any interruption of the line caused by any equipment malfunction or failure will result in a major disruption of output or even line or factory shutdown. Thus, an effective maintenance program should be evolved to provide the required availability of machinery and output quality. A new concept of condition-based maintenance, Total Quality Maintenance, TQMain, is presented. It aims to maintain not only machinery but all the elements constituting a manufacturing process, e.g. production/operation, environmental condition, personnel, methods, material, quality control. TQMain is a result of establishing a common database through integrating the maintenance program with other plant programs to form an overall plant Information Technology, IT-system. Identifying and 'eliminating' quality deviations and failure causes at early stages, and extensive use of data feedback are the suggested tools to accomplish continuous improvements and to assure high quality products.

Keywords Failure causes, Vibration monitoring, Condition control, Total Quality Maintenance, Integration of condition-based maintenance with IT-System, Benchmarking, Cost-effective maintenance strategy.

Introduction

In Sweden, the cost of maintenance and operational safety was about US\$ 23×10^9 during 1991, in most cases the total losses which arise because of maintenance omission

or ineffectiveness exceeds the purchase price of the equipment [1,2]. According to a study reported by Mobley [22], from 15 to 40% (with an average of 28%) of the total cost of finished goods can be attributed to maintenance activities in factory [9]. The study conducted by the Department of Trade and Industry in the UK revealed that poor and dangerous maintenance costs UK industry US\$ 1.95×10^9 £ 1.3 billion a year [30].

Statistically-based maintenance strategies aim, in general, to reduce the number of failures, failure cost and the cost of associated repair. The implementation of vibration-based maintenance strategy provides possibilities for acquiring early indications of changes of machinery state [5,6]. These indications could be of great importance also in detecting deviations in the product quality early and before they show on quality control charts. Cost-effectiveness is one of the criteria which should be used to select a suitable maintenance policy. Condition-based maintenance lets the machine run until just before failure see for example Davies [13], and it may be defined by two defence lines. The first line may be called proactive maintenance, i.e. the activities and efforts of detecting and correcting failure causes. The second line may be called predictive maintenance, i.e. monitoring symptomatic conditions when a process of failure is active [15].

Condition monitoring, CM, programs, especially vibration-based programs, became popular in many industries, e.g. paper mills, refineries, power stations and recently in manufacturing industry. In application, these programs are, in general, not integrated with programs for production/operation, quality control, environmental condition or cost accountancy. The information in the databases of CM programs is limited. A database for a wider range of information is required for effective diagnosis and prognosis of machinery condition. The missing information in, for example vibration-based programs may be summarised by the following: True rpm, loading frequency, quality control data, operator name, environmental conditions, material, etc. The required information is available either in other programs in the plant, which are not easily accessible, or can be collected. In many cases data are collected and stored, at considerable expense, but never used, or discarded automatically and routinely before useful analysis has been done.

The aim of this paper is to propose a new concept of condition-based maintenance strategy. In this strategy, e.g. vibration-based or age-based maintenance would be integrated with the essential activities in the plant, such as production/operation, quality

control, environmental condition. It would enable the user, on demand and at all levels from the executive manager to the operator, to get reliable information on the following:

1. Detecting deviations in the state of machinery / process at early stages and when it is possible to control machine condition by either ‘preventing’ or reducing potential failure developments.
2. The cost-effective vibration level at which to replace components suffering deterioration.
3. The acceptable deterioration rate to ‘guarantee’ no sudden failure during the lead time, i.e. the time between detecting a potential failure and action to repair it.
4. Detection of a potential failure and prediction of remaining useful working life when the machine can operate satisfactorily.
5. The probability of failure during the lead time when product quality is still acceptable.
6. Identification of failure mechanisms, failure causes and failure modes with increasing precision by relating readings to damage subsequently found and safe lead time achieved.
7. Techniques to decide whether the use of extra monitoring parameter(s) in addition to the main one will improve the technical and economical effectiveness of the monitoring system.

Total Productive Maintenance, TPM

TPM consists of a range of methods which are known from maintenance management experience to be effective in improving reliability, quality, and production. It requires operators to take over some of the maintenance staff tasks, e.g. cleaning, lubricating, tighten bolts, adjust and report their observations about changes in the machine condition [23]. All these tasks are important and useful to stop some failure causes. But, CM, e.g. vibration analysis, is of great importance for supporting the operator maintenance and to assist the operators in searching for abnormalities in the equipment.

Research on organisational development, change and implementation has revealed the major obstacles in the transformation process of implementation for overall concepts like JIT, TPM and Total Quality Management, TQM. The implementation of TPM is rather difficult, partly due to the fact that managers tend to focus on early results rather than activities aiming at reducing losses in the long run [18,20]. Improving personnel

and plant, and changing the corporate culture are ways through which TPM, perhaps as part of a TQM programme, tries to improve a company. Changing the corporate culture at a plant is one of the difficult tasks to be performed, especially when it involves small group working, the operator's role in the maintenance program and the lack of support from the maintenance department. The traditional cultural division between operator and maintenance (you bend it, we mend it) must be altered by mutual consent.

There are many factors influencing the commitment of the operators: for example

1. In general, people resist changes of any kind if benefits to themselves are not obvious.
2. Training on how to perform tasks, e.g. collecting precise data.
3. Procedures on how to perform tasks and their review.
4. Training programs for the personnel about their important role in continuous improvement activities.

Data collection and analysis is one of the most important forces driving the concept of continuous improvement. In many cases, data collection has been carried out by the operator. But, when these collected data are not analysed, the motivation for collecting data is lost. There are many false arguments against data collection experienced in industry, such as; we have not enough time, we do not need statistics because they do not provide solutions, we cannot afford it, etc. Thus, to succeed with data collection it is necessary to find a less time-consuming method that is also precise [20].

The small working groups suggested by TPM [23], for problem solving and process improvement were supposed to go through four stages, which are, self development, improvement activities, problem solving and autonomous management. However, it seems that many groups do not transit from stage 2 to stage 3. They die before they are really grown up [20], and the same phenomenon has been observed by Alänge and Sahlin [7].

In Japan the period following 1991 is called the 'period of launching prospective profit-making products and manufacturing profit-making products' and it is said that a good brain and strong muscles are required to build strong enough manufacturing capability, i.e. adopting TQM and TPM [38]. But, a centralised data acquisition and analysis system, i.e. a nerve system, is also important to enable the 'brain' to react adequately and appropriately. There can be no effective control without data feedback.

Reliability-Centered Maintenance, RCM

RCM is another newly-popular concept. It is a method for determination of maintenance needs developed within the aircraft industry and later adapted to several other industries and military branches. The availability of reliability data and operating experience is of vital importance for RCM [31].

RCM does not recognise that maintenance is an economic problem at the machine or plant level. It concentrates on improving existing plant rather than getting future plant right from the beginning, which can only be achieved by data feedback to designers [33]. One more shortcoming of RCM is that it does not make full provision for the use of condition-based techniques, so that the potential failure developments are not followed until just before failure, see for example Hollick and Nelson [17].

RCM selects condition-directed tasks when they do not know how to directly prevent or retard equipment failure [35]. Sandtorv and Rausand [31] advocated different definition of condition monitoring techniques than RCM usually uses to identify symptoms before potential failure development, but this task is selected when the machine function degradation is not evident to the operator, instead of using cost-effectiveness as a basic criterion for selection [4]. RCM advocates periodic measurements of a parameter(s) to detect failure onset in order to act [35], i.e. failure detecting, not proactive maintenance.

Total Quality Maintenance, TQMain.

Given introduction of more robotics and automation, the increasing use of computer-aided devices, and the generally accelerating advance of technology, maintenance costs are likely to be even higher in the future. T. Wireman reports from a study conducted in 1989 that the estimated cost of maintenance for a selected group of companies increased from \$ 200 billion in 1979 to \$ 600 billion in 1989 [37]. Companies where equipment failures would result in major losses or massive repair costs are advised to engage in condition-based maintenance and not to rely upon regular time-based maintenance alone [32]. This is why Yamagata NEC tried to protect itself against problems occurring between two regular inspections. They instituted a condition-based system to predict machinery state and to handle it before they became problems (Ibid).

A computer search was made of recent (1980-1991) papers in international journals on JIT, KANBAN and Manufacturing Resource Planning, MRP (II) systems. Of 140

papers surveyed only 8 made any reference to the integration of the manufacturing planning and control system with maintenance planning. In Computer Integrated Manufacture, CIM, 'everything' is integrated except maintenance [33]. Trevenna and Thornycroft [36] emphasise that in today's business environment the challenge is to ensure equipment performance and availability whilst achieving minimum cost. More attention has been focused recently on broadening the perspective of maintenance through integrating it with the production program and into a complete market-oriented system, and on the importance of utilising a feedback system in improving, e.g. productivity, quality, reliability, designs, see for example [34].

Process capability as a measure of conformity, i.e. ability to manufacture items within specified tolerances or other quality limits, depends on several factors rather than only machinery condition, see Fig. 1. The basic elements constituting a manufacturing process may be summarised as: Manufacturing machines, monitoring and maintenance policy, environmental condition, operating and maintenance staff, manufacturing methods and procedures, quality control methods and procedures, material, managerial functions such as spare parts stores, purchasing and marketing, service such as lubrication and screw tightening.

In this paper the condition of a process, e.g. manufacturing process, is defined by the states of the basic elements constituting it. In general, it is not usual that old and deteriorated machines/processes can manufacture quality products with high Overall Equipment Effectiveness, OEE and at low prices. Production stoppages following technical failures result in some extra production losses because the items manufactured during the short periods before the stoppages and immediately after repairs, are in many cases, of rejectable quality [2]. Where

$$\text{OEE} = \text{Availability} * \text{Performance efficiency} * \text{Quality rate} [23]$$

The deterioration in the condition of machinery may be started, or developed, by means of external causes, e.g. misuse, bad material batches, unsuitable lubricant, bad servicing (loose screws), external shock pulses, high environmental vibration or temperature levels, sand or other hard particles, dirt, humidity, etc. [15]. Thus, in order to prevent or minimise the influence of environmental condition, these parameters should be monitored and controlled.

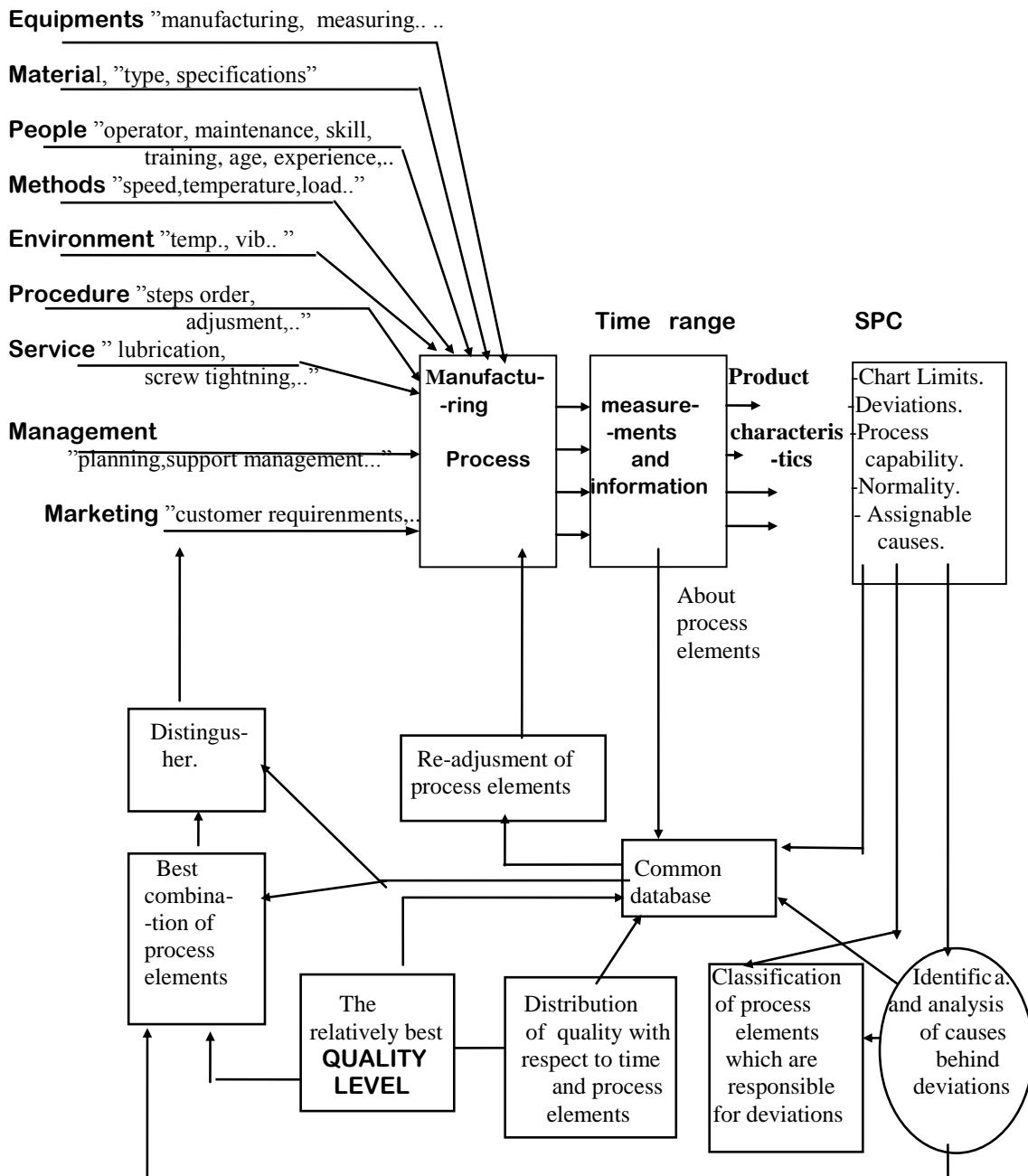


Fig.1. The concept of Total Quality Maintenance, TQMMain.

Clearly, every product or service will eventually fail, although in some cases the probability is small enough for it to be effectively perfectly reliable. The ‘zero-failure’ policy is a vision all companies strive for when adopting JIT method because inventories, queues, and lead times are minimised (no buffers) and any serious interruption or failure is very costly. Therefore, maintenance actions are usually performed at nights or holidays, which makes the maintenance cost considerably higher than usual, but still cheaper than corresponding failures during planned production time. The problem becomes worse when the machines need to be run even at nights and

holidays. All the cases discussed by Senju [32], reveal that the implementation of TPM may reduce failures, but not to zero.

One of the essential forces driving TQM and TPM is the improvement cycle, or Deming cycle (Deming called it the Shewhart cycle), i.e. Plan - Do - Check - Act [8]. Practically, this cycle has been used in a such way that one should act as soon as failure is detected. But it can be interpreted so that action should start at an earlier stage, i.e. as soon as significant deviations in the condition-based indications are observed.

TPM looks for techniques to seek out and fix the root causes of problems, no matter how difficult [32]. A study done by Bloch and Geiter [10] reveals that about 99% of the mechanical failures are preceded by some detectable indications of, condition change, confirming that there is something wrong [21]. Implementation of one of the most useful fault diagnosis tools, spectral analysis, provides a basis for identification of failure mechanisms, failure causes and failure modes for most types of faults in mechanical systems, e.g. rotating and reciprocating machines [11, 3].

The most important types of failure are those which have a direct impact on human beings and machinery security and/or on the total manufacturing cost, i.e. safety and operational failures [3]. Failure is defined in the BS Maintenance Glossary as: ‘The termination of the ability of an item to perform its required function’ [11], and is defined in RCM as ‘an unsatisfactory condition’ [25]. The definitions are equivalent in the case when the performance of an item which is not fulfilling the required function is interpreted as an ‘unsatisfactory condition’. *The required function of an item/equipment may be evaluated by a particular level of one or more of the component / machine characteristics, e.g. the vibration level.*

Implementation of a vibration-based maintenance program provides a reliable means for discovering even small variations in the machinery condition if, for example the number of the resolution lines used to analyse a specific range of frequency is large enough to reveal all the interesting frequencies [5]. In general, monitoring the development of these frequencies is a powerful tool and more effective than monitoring the overall rms, velocity, (Ibid). To achieve an effective implementation of ‘zero-failure’ strategy the monitoring system should be able to discover failure causes, potential failures and mechanisms for failure-control to reduce or to arrest development of potential failures and consequently unexpected actual failures, i.e. to maintain high Overall Process Effectiveness, OPE, at low costs. This type of comprehensive

improvement in the production process would be started through changing the concept of condition-based maintenance.

OPE may be defined as: *A measure of process effectiveness revealing the contribution of the basic process elements in the process total effectiveness, e.g. the effect of environmental conditions on machinery availability, performance of manufacturing procedures and on product quality.* This subject may be discussed in a separate paper.

Evaluation of a machine state using vibration analysis can be carried out through identifying active frequencies, i.e. fault and failure causes frequencies, and their amplitudes. Amplitude is usually used to indicate the deterioration level. When vibration levels of some frequencies are higher than the normal level, the product quality may be influenced, e.g. in paper mill machines [28]. Detecting these frequencies early may lead to keeping the quality within its specified limits for longer and in more time to plan the eventual repairs. But, inconsistent data about, e.g. rpm, loading frequency, environmental condition, confuses the assessment of the machine's condition. Overestimation of the fault development rate and level causes the user to lose some of the machine life and to increase the number of stoppages and spare parts used. The underestimation usually results also in extra production losses because of bad quality products and sometimes to production stopping at an inconvenient time. A more complete and accurately-kept database helps to avoid these losses.

The process state can be assessed by monitoring both the product characteristics and the process elements. Technical and statistical analysis is an effective tool to identify failure causes and their frequencies. These frequencies can be utilised to monitor the machine condition and product quality, and consequently which element in the process these causes are related to. The best product quality can be distinguished through selecting the suitable combination of the process elements, see Fig.1. *In order to keep things done 'right first time', 'every' element which participates in or influences the manufacturing process should be monitored so that a lead time to prepare and take the required actions is attainable.*

Total Quality Maintenance, TQMain, *is a strategy which enables the user to maintain and improve continuously the technical and economic effectiveness of process elements.* Thus, TQMain's role may be defined as: *A means for monitoring and controlling deviations in a process condition and product quality, and for detecting*

failure causes and potential failures in order to interfere when it is possible to arrest or reduce machine deterioration rate before the product characteristics are intolerably affected and to perform the required action to restore the machine/process or a particular part of it to good as new. All these should be performed at a continuously reducing cost per unit of good quality product.

A common database

Existence of a well established data acquisition and analysis system is an important prerequisite for the common database. We prefer to start by integrating programs for vibration-based maintenance and for operation/production, quality control and environmental condition, see Fig.2. The required data will be collected and gathered into the common database without the duplication that usually occurs when each department collects its own data.

We believe, but without experiment cannot demonstrate, that besides the obvious advantages, a common database, together with an integrated company-wide IT-system would probably be cheaper in the long-term than keeping maintenance data separately, and controlling the maintenance function without co-optimising with other plant activities. The common thread for any enterprise is how to maintain and improve manufacturing process technical and economical level of effectiveness at a low cost. Therefore, the selection of cost-effective maintenance strategy suiting the plant under consideration is an essential part supporting the manufacturing plan.

The integration of the plant activities may be achieved in different ways based on which activity is the backbone of this integration. The backbone activity may be defined *as the activity which plays the central role in improving the whole process*. In this paper the integration is achieved through locating the vibration-based maintenance at the core between the integrated activities, i.e. being the backbone activity, see Fig.3. TQMain is not limited to the integrated activities in this paper. The decision to expand the integration to include new activities is a function of many factors in addition to the manager or maintenance engineer request.

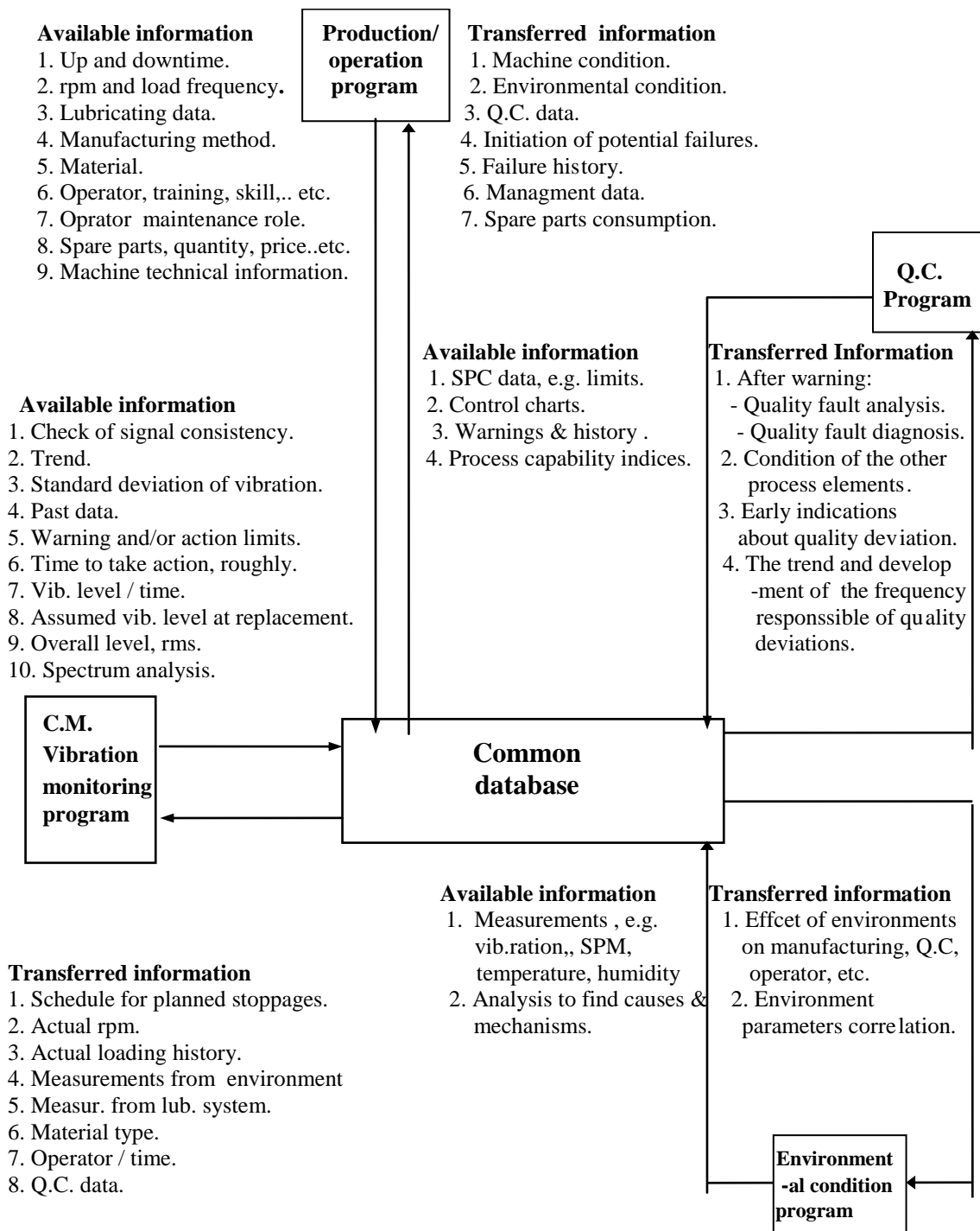


Fig.2. An example of data exchange between process elements

The author believes that the implementation of TQMmain can be carried out easily if the integration is achieved gradually and expanded after each successful extension. The selection of the activities to accomplish the integration can be decided based on the importance, criticality and cost-effectiveness impact of each element upon the process. The integration of just the programs for production/operation and vibration-based maintenance provides good opportunities for monitoring, measuring and improving

reliability, availability and productivity of the manufacturing machines. Integrating the vibration-based maintenance program with the programs for production/operation and quality control establishes the basis for monitoring, measuring and improving the quality rate in addition to the latter characteristics. The integration of the programs for vibration-based maintenance and quality control provides a possibility for monitoring, measuring and improving the quality maintenance, or in other words quality assurance. Through integrating the programs for vibration-based maintenance, production/operation, quality control, environmental condition, material and operator experience it is possible to monitor, measure and improve a modified version of OEE, which we call Overall Process Effectiveness, OPE. A reliable redesign and modification of manufacturing equipment can also be achieved, see Fig.3.

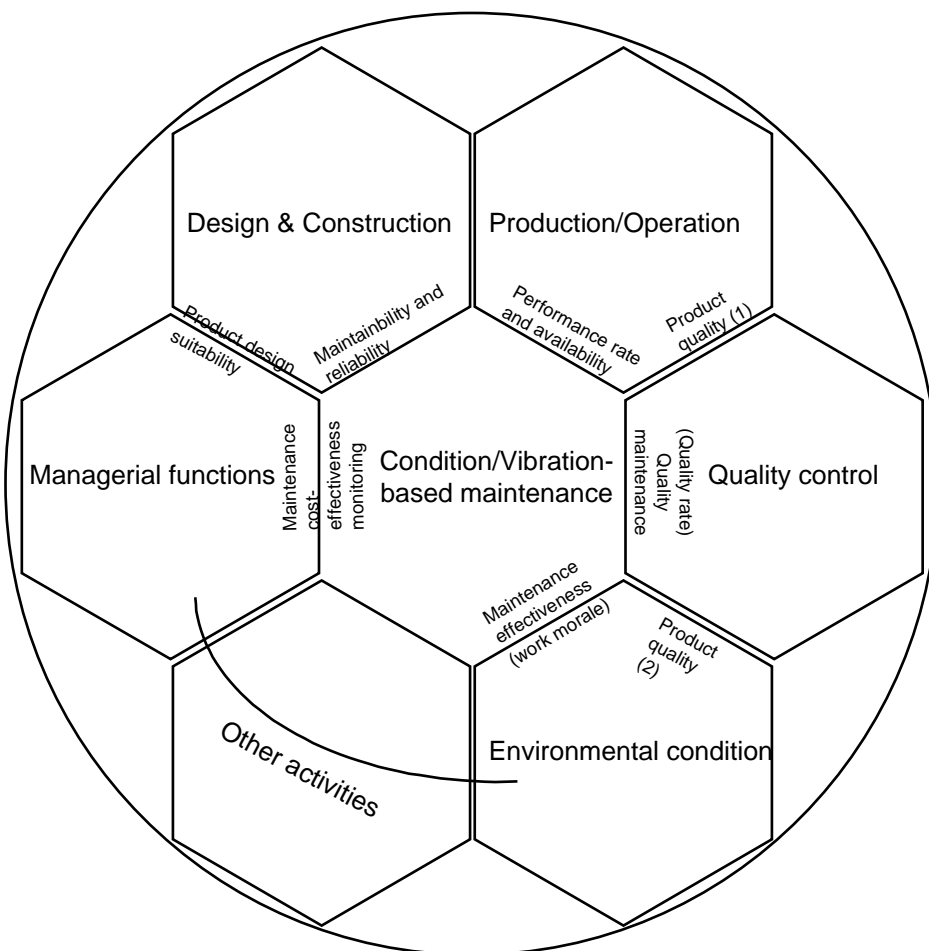


Fig.3. Correlation between integrated activities.

When using OEE as a measure of the progress achieved by a particular improvement, there is a major question to be addressed which is whether that progress is cost-

effective. One of the main reasons behind the decision of Toyota to abandon Just In Time strategy in a new factory in USA is the high cost of maintaining the automated production line [12]. TQMain would answer whether it would be cheaper to have buffer stores to permit the required actions or to duplicate the machines as JIT might need if production had to be kept up. When the cost accountancy program is integrated with the common database, a particular criterion is required to assess the cost-effectiveness of the technical improvements. This issue may be discussed in a separate paper.

Benefits of expanding the basis of the integrated activities beyond the essential elements are probably marginal; this is why it will be important to monitor the cost-effectiveness of TQMain continuously or after each improvement. The essential elements are defined in this paper as the process elements which most affect the process technical and economical effectiveness. The relevant parameters required for reliable decisions may be discussed in a separate paper.

Integrating the essential elements of a manufacturing process provides opportunities for optimising, e.g. the time to the next measurement, when a periodic monitoring system is involved, or the time to take the required action. The evaluation of the condition of the machine must include all possible factors influencing its state, i.e. after establishing a common database. This means that the optimisation with respect to the interesting variables may be possible only after integrating the selected plant activities. The optimisation of TQMain for a continuous reduction of the costs of quality products will be discussed in a separate paper. Establishing a common database, see Fig.2, provides the data needed to achieve the following results:

1. Effective diagnosis; Ambiguities in vibration spectra because of inaccurate rpm are no longer present.
2. Vibration frequencies amplitudes can be used to assess the deterioration level effectively when loading frequency is known.
3. Tracing failure causes and quality deviation reasons can be carried out effectively.
4. Monitoring all these parameters provides a reliable foundation to control them, e.g. the environmental temperature or proportion of pollution in the lubricating oil can be controlled to reduce their influence on manufacturing process.

Many possible optimisations and analysis are currently abandoned because people simply do not have the time to co-ordinate data from several sources and hunt for

missing data in polyglot IT-systems only to find ambiguities affecting the values of model parameters.

The integration of the maintenance program may be achieved by means of specific linking programs so that the personnel, e.g. maintenance staff, have access to the required information directly when they try to interpret machinery condition, e.g. vibration spectrum. Practically, this means that the required data are available on demand and at every level, and especially during the evaluation of process elements condition, process capability, OEE, OPE, cost-effectiveness, etc.

Potential benefits of integration

Today, leading firms understand the necessity of linking production planning with resource supply using dependent demands techniques like manufacturing resource planning, MRP II, in order to reduce waste and working capital. The knowledge that has been gained in linking production planning with resource supply is essential for a proactive maintenance program [14]. Databases for vibration-based monitoring programs include information on many years experience which are important for improving monitoring systems, but such improvements can not be carried out automatically by the available programs. Establishing the common database, see Fig.2, provides the basis for the implementation of extra functions, e.g. software, to enable the user to achieve the results described below with high precision:

1. The time to act, e.g. the next measurement, replacement.
2. Discovering false alarms with high probability.
3. Probability of failure during the lead time and when product quality is still acceptable.
4. Identifying the frequency components of significant failure causes.
5. Selection of a cost-effective vibration level for the frequency of a significant failure cause.
6. The information is continuously updated after each measurement and replacement.
7. The effect of each failure cause and failure mode can be distinguished to define its criticality and finally its Risk Priority Number, RPN, and whether this monitoring parameter is effective for just this case or some other parameter should be considered [3]. Thus, a FMECA database can be started and improved

continuously to create an Updated Record of Failure Mode, Effect and Criticality Analysis, URoFMECA.

The potential benefits which can be gained consequently, may be summarised by:

- (1) Lower production losses, higher availability and higher performance efficiency:
 - * Reduced technical-based stoppages through identification of failure causes at an early stage so that the machine state may be controlled effectively.
 - * Accurate diagnosis results in appreciable shortening of the downtime at each stoppage.
 - * Improving the work-environment, e.g. temperature, pollution, and maintaining manufacturing machinery functioning well improves personnel morale and increases human productivity.
 - * By observing monitoring parameters it becomes easier to increase manufacturing speed.
 - * Possibilities of arresting deterioration or reducing its rate stabilises the condition of the process without dramatic or sudden changes affecting the process productivity or process quality rate.
- (2) Improving quality rate:
 - * There is a great chance to control quality variation before rejectable items have been produced.
 - * Production losses because of bad quality, due to technical failures, are reduced, see 1.1.
 - * More effective control for process capability can be achieved. Quality related costs vary considerably between industries. The average figure for quality related costs of 10% of sales means that the organisation contains a 'ghost operation' amounting to approximately one-tenth of capacity. This is devoted to producing errors, waste, scrap, rework, correcting errors, and so on. In manufacturing industries the costs of internal and external failures can be 10-15% of turnover [26].
- (3) Higher product and machinery reliability. The improvement of the machine's reliability is usually carried out through identifying the problems causing machinery stoppages and loss of quality. One of the ways to pinpoint these problems in machinery is through maintenance data [19]. Thus, when it is possible to detect deviations in the product quality and to eliminate deviation

causes at early stages, the reliability of machinery and manufactured items are then improved consequently.

(4) Less idle invested-capital. Creating high confidence in the maintenance strategy encourages the company to reduce the number of redundant equipment, personnel, spare parts, etc. and the size of the store [5].

(5) Less penalty expenses

- * Fewer accidents.

- * Production and delivery schedules can be kept with fewer delays.

(6) Increased machinery life

In many cases it is beneficial to reduce machine load or operating speed to prolong machine life, when the cost of lost production is larger than the losses from the reduction in the performance efficiency. Receiving signals revealing early stages of deterioration, it becomes possible in many cases, to control the machine condition. For example, the vibration level will increase if aggressive particles are transmitted to a rolling element bearing. Interpretation of vibration spectra can be utilised to detect and control the state of machinery when the deterioration is still within the acceptable tolerances. Accordingly, production, delivery schedules, maintenance resources, skills, and product quality could be controlled as well this subject may be discussed fully in a separate paper.

(7) Software for special data analysis can improve the monitoring system in the following aspects:

- * A continuous adjusting of the evaluated variables like:

- Warning and action or replacement level, and time to measurement or to replacement.

- The probability of failure during the lead time.

- Updating Record of Failure Modes Effect and Criticality Analysis, URoFMECA.

- Calculating the cost-effectiveness of the system after each improvement or at demand.

- * Monitoring the improvement progress. A continuous measure of the machine/process capability indices, availability, process quality rate, process performance efficiency, OEE, OPE.

In general, the reputation of an organisation is usually built through hard work on improving quality, reliability, delivery time and price [27]. But, without effective plant maintenance it seems to be impossible to sustain a good reputation at a low price. The study by Henriksson [16] reveals that about 55% of the total maintenance costs is classified as direct, i.e. spare parts, man-hours, experts, etc. and 45% as indirect income losses, i.e. production losses resulting from failures and repairs, production losses due to bad quality, idle invested capital in spare parts store, redundant resources, loss of interest because of high prices, loss of market share.

Benchmarking

Benchmarking means striving to equal the best. In Japanese the equivalent word is *dantotsu*. Improvement can only take place relative to established standards, with the improvements thus being incorporated into the new standards. Benchmarking is the continuous process of measuring products, service and processes against the industry leaders or the toughest competitors [26].

Internal benchmarking is a comparison of internal operations. Usually, a wide range of areas may be benchmarked at short, medium and long-term targets. Benchmarking in maintenance is the search for the best result gained by a competitor using approximately the same machinery, which ultimately may lead to adopting a more cost-effective maintenance strategy. The implementation of this strategy should exhibit an exceptional improvement in the effectiveness of the process elements and especially in the total cost of manufacturing a quality product.

Before benchmarking it is important to select the relevant variables to be used for the comparison with the 'best company's' value. Concerning maintenance there are many such approaches which can be considered, of these we list the following: Downtime, Availability, Reliability of machinery, Performance efficiency, Quality rate, OEE, Direct maintenance cost, Indirect maintenance cost, income losses, Total maintenance cost, Penalties, Number or cost of accidents, Spare parts data, Investing idle capital, Total number of stoppages, Number of planned stoppages, Number of failure-based stoppages, Number of unplanned but before failure stoppages, Cost of manufacturing a quality product, etc.

The initial steps of maintenance benchmarking, i.e. selection of the right approach, should reflect and lead to the main goal [29]. The aim of maintenance benchmarking is

to improve the maintenance strategy and/or to select the cost-effective one through comparing its activities with the 'best in class' company. But, the required information to perform this comparison is not always easy to find. Which company should the 'best in class' company compare itself with if it does not implement TQMain? Implementation of TQMain explores the possibilities for further improvements and provides opportunities to improve quality, the cost of manufacturing quality products and the annual profit continuously without need to get additional information concerning the competitors. It allows a company to take the lead rather than just stay competitive.

Conclusions and comments

The quality and reliability of products and processes may be improved through detecting and eliminating common and special causes of problems at early stages. The need for overhaul can be decided on the basis of a machine's condition and the pattern of stoppages.

Establishing a common database makes the monitoring of deviations in the condition of complex and highly developed equipment by the operator easier and attainable. Maintaining the equipment can be achieved through training the maintenance staff in the interpretation of vibration spectra for identifying faults at an early stage and the operator on how to respond to program warning signals. Thus, there is no need to change our attitude towards equipment complexity as Karlsson and Ljungberg [18] have warned.

The redesign of equipment to reduce deterioration and hence, losses, is not always easy due to lack of co-operation between production, maintenance and design departments. This problem can be solved effectively by means of the common database, which provides the required information for different departments. In general, only documented evidence convinces and encourages the manufacturer to redesign and / or modify the equipment to fulfil the customer demands.

In the unusual case when some non-conformity is discovered in the product quality before it is picked up by the monitoring system because of, e.g. unexpected causes, it can be traced back to the original cause faster than usual. Data feedback of this unexpected failure cause will prevent the same error in future.

TQMain, needs no special organisation to carry out its tasks. On the contrary it may result in an overall reduction in personnel because the information is acquired without

duplication. Integrated activities give more effective diagnosis and prognosis which leads to another reduction in the efforts needed to interpret data and fewer failures means fewer man-hours required to repair.

At companies with an established IT system, the cost of integrating additional activities is negligible compared with the cost of the system. In a new design of IT system there would be more savings than might be gained by linking programs of the old system. Total Quality Maintenance provides a basis to find true optima or best approximations in more realistic situations for continuous reduction in the cost per unit of quality product.

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