Business drivers of a collaborative, proactive maintenance solution

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Business Drivers of a Collaborative, Proactive Maintenance Solution

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The elevated complexity and costs of production assets combined with the requirements for high-quality manufactured products necessitate novel design and condition-based maintenance approaches that are able to provide the required levels of availability, maintainability, quality and safety while decreasing the cost of the system as a whole and throughout the production lifecycle.

2.1 Introduction

A few years ago, maintenance was considered only a cost factor in industry, but the situation has changed radically over the last years. There are still companies whose maintenance strategy is based solely on the fact that the machine is repaired only at the stage when one of its components breaks down. For certain types of businesses, such a strategy may be working, where the degradation of a component does not generate major costs, for example.

However, mainly unpredictable degradation of industrial machines causes production standstills and thus high costs. The availability of spare parts is also affecting the costs, as they may not be immediately available. On the other hand, keeping all spare parts in the stock while waiting for the degradation of any component is not suitable, since the stocking itself is expensive. On top of this comes the cost of time spent on the repair of the machine.

The implementation of a PM strategy, and the application of a CBM platform, are not only a technological challenge but a deeper question of new business models and their acceptance. The problem is that it has been claimed that maintenance personnel tend to be conservative and not prone to change.

On a conceptual level, the economic impact of a CBM platform may be expressed as:

- Reducing the total cost of ownership – CBM allows preventive and corrective actions to be scheduled at the optimal time, and concurs to the implementation of a PM strategy;
- Reducing maintenance costs – Reduce equipment downtime, lower maintenance costs and improve equipment life cycle management;
- Increased safety where an unpredictable catastrophic system failure could cause severe damages, e.g., an explosion.

2.1.1 CBM-based PM in Industry

One of the main reasons and the single most common cause for the damage of the machines is overloading or improper use. For the person in charge of maintenance, it is important to monitor the use of the machine and guide the user so that the machine does not wear any more than in normal use. In addition, it is important to control the use of the machine so that the machine works as efficient as possible and does not cause any unnecessary environmental burdens. Typically, the OEE is measured by performance, availability and quality. When one or more of these elements are out of operating range, profits are declining.

The aim of the production plant maintenance is continuous improvement of the factory assets and increased OEE. Plant maintenance enables one or more algorithms to be assigned to each asset or asset type. The algorithms can be based on an asset's operational status (e.g., a pump's total running time) or its condition (e.g., vibrations or temperature), or a combination of both. The useful set of parameters are based on analysis of the system's critical components and their behaviour.

Using real-time data from the asset, the plant maintenance system can automatically inform maintenance personnel when it is time for inspection or corrective action well in advance. This way, the maintenance can be scheduled to interfere as little as possible with the production. Job performance can be guided, e.g., with a mobile device, and add a pictorial execution instructions or exploit augmented reality. Reporting work should be carried out as detailed as possible, because only in this way it can help to increase the availability of the machine.

Inventory management optimization is also an important issue requiring that both location(s) and the number of spare parts must be optimized. The ordering system itself should be automatic and deliveries should go to the right place at the right time. In addition, guidance should be available, that means installation and operating instructions, as well as access to the manufacturer's data.

CBM in plant maintenance system is not intended to replace established maintenance procedures. Rather, it improves the effectiveness and increases the value of such systems. As well as helping to optimize maintenance routines, it also provides a basis for continual improvement, e.g., allowing users to compare the performance of several assets of the same type and then applying the best maintenance practice across that group.

2.1.2 CBM-based PM in Service Business

Advances in information technology and the intensification of competition has forced companies to a situation where the significance of the service business in the market has increased significantly. Previously, profit was particularly due to new sales and post marketing. After-sale services were not important aspects. However, nowadays, many appliance manufacturers post-market will take up to 30–50% of their net sales [Mikkonen et al., 2009].

As a result, companies are becoming interested in the services they can provide to their customers and at the same time, gather information about their own products, such as design improvements, maintenance or warranty analysis. This information makes possible to offer customers even better services during the product's life cycle.

New sophisticated data systems in production assets enables various types of new business models. One promising avenue is MaaS, which is a close relative to Power-by-the-hour concept. Drawing on the capabilities now afforded by new wireless sensors, advanced connectivity and cloud computing, OEMs can innovate in the areas of machine support and maintenance packages. By empowering remote access and real-time monitoring capabilities, new HMI (Human Machine Interface) software makes it possible to offer preventive maintenance, quick troubleshooting advice or the ability to access machines and screens remotely for real-time service and operational parameters.

Customers are also particularly interested in the factors affecting the overall performance of the equipment. As it has been mentioned before, the availability, efficiency and quality can be influenced and improved by CBM-based PM avoiding unforeseen problems, which may become a determinant factor in the cost of a product.

This business model is becoming increasingly popular among many industries. For instance, software is typically downloaded to a computer and its maintenance, or updates, are run automatically if the monthly licence fee is payed. Some advanced cars are also gathering data and communicating with the factory about their health status and need for maintenance. Manufacturers are able to use this real driving condition data as basis to their product development, an extra asset gained as side product.

2.1.3 Life Cycle Cost and Overall Equipment Effectiveness

The main costs affecting to the asset within its life-cycle are the purchase price, use of the product and the costs associated with maintenance. The OEE has a major impact to the product's lifecycle costs throughout its life-cycle. All the decisions that are made regarding the design and manufacture of the machine affect its performance, availability, quality, safety, reliability and maintainability, and ultimately decide the purchase price and the costs associated with the ownership and disposal.

LCC is the tool to optimize this kind of economical challenge. It is most effective when it is carried out at an early design stage of the machine, making it possible to optimize the basic structure of the machine. It should also be updated and used in the following stages of the life cycle, when looking for significant cost uncertainties and risks (IEC 60300-3-3, 2004). In addition, LCC can be effectively applied to evaluate the costs associated with a specific activity, for example, the effects of different maintenance strategies, to cover a specific part of a product, or to cover only selected phase or phases of a product's life cycle. Typical LCC analysis is as follows, according to IEC-60300-3-3, 2004:

- LCC plan;
- LCC model selection or development;
- LCC model application;
- LCC documentation;
- Review of LCC results;
- Analysis update.

2.1.4 Integrating IoT with Old Equipment

In the previous sections, the cost of the life cycle of a product has been discussed. Usually, when a machine becomes obsolete or needs a repair, it is necessary to make an investment to fix the problem.

However, with new technologies such as IoT it is possible to delay this obsolescence and to monitor the wearing and condition of the machines. The IoT means having the ability to access data about the condition of the machine or product from anywhere instantaneously. By using wireless communications, managers or maintenance technicians can measure the health of their infrastructure and take proper action.

IoT can help companies improve their operations by using their own data. First of all, the data needs to be collected from various sources to make a study and gather meaningful information. This is usually done by integrating different sensors in the machines and doing various tests. The collected data are then used to develop algorithms that will monitor the status of the machine. If the algorithm detects that the machine is going to have a problem or if it already has one, an error or alarm will be sent to the proper manager.

As an example, a manager could install a temperature sensor in an old valve, where the sensor would not have any effect on its operation, and monitor its activity to see if the valve needs to be changed or it has started to wear in the most critical parts. If that is the case, the system could send an SMS to the manager informing which valve has to be changed. Depending on the automation of the system, it could also make an order of the parts needed so that when the manager gets to the valve, the spare part is already there.

This way, the break-fix mentality is eliminated and substituted with a PM approach. Improving the equipment by using IoT monitoring could lead to a reduction in costs and a prolonged life cycle of the machines.

2.1.5 CBM Strategy as a Maintenance Business Driver

There are many recognised business drivers and the implemented or relevant ones depend on the market where the company performs its business. However, the typical business drivers are profit and growth, and different stakeholder's expectations, which are normally connected with a company's policies and its productivity [Lozano, 2015].

Financial Times (lexicon.ft.com) defines business driver as "A descriptive rationale, ideally measurable, used to support a business vision or project to clarify why a change or completely new direction is necessary".

The business drivers are applied to achieve effective prioritising within a consolidated programme of business initiatives [Ward and Peppard, 2002]. Therefore, the business drivers are a set of critical forces that the business must consider. They usually characterise short, medium and long-term aspects that the business must include with the aim to meet the objectives and satisfy the CSFs. Thus, the business drivers are the core constitutes of a business strategy.

A business strategy consists of the mission, i.e., a company's primary role to set a direction for the company/department to follow, namely its mission on the market. The vision is about the future aims, and it is normally visualised as a common picture that everyone agrees on about the company. The business drivers are a set of forces that need to be met to be able to compete in the specific market, and the objectives are the targets the company/departments set to achieve its vision. The strategies define how these objectives will be met. The CSFs are a small number of key areas where things must go right for the business to flourish and be able to compete under the same (or better) conditions than the competitors. In addition, the CSFs also provide information about the actions one should take as well as how they should be measured to confirm that they have been achieved. Figure 2.1, highlights the above mentioned. It shows as well some examples of objectives in connection with improved cost/financial indicators. In addition, it highpoints the measurements and actions (CSFs) related to the objectives.

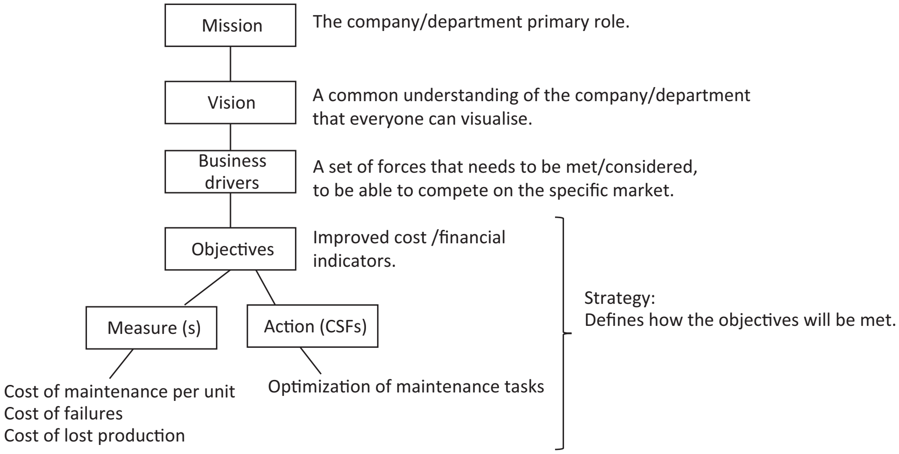

Figure 2.1 The business strategy main elements.

Thus, the departmental strategy must be connected with the business strategy, as is the case of the asset maintenance management strategy and overall business strategy.

Accordingly, in the area of industrial asset management, the maintenance department might implement a variety of maintenance strategies (see Chapter 1). The corrective is immediate or deferred, while preventive can be on condition or predetermined. The preventive maintenance (including reactive, predictive and proactive maintenance) is where the CBM falls in (is classified), and it is preferable to use whenever it is appropriate.

In CBM the equipment is periodically inspected by manual or automatic systems so that their condition may be assessed and the rate of degradations can be identified by data analytics. According to British Standards [BS 3811, 1993], CBM is the maintenance carried out according to the need indicated by condition monitoring. Then action is taken based on the CM information. The most common CM techniques used for CBM are visual monitoring, performance monitoring, vibration monitoring, and wear debris analysis.

The need for maintenance emerges from the production department that needs to have its equipment in good health to be able to run the production smoothly and efficiently, see Figure 2.2.

The connection between the three crucial components of any production system is the production, quality and asset management function, which are shown in Figure 2.2. The secondary output of production is maintenance (shown as demand for service), whose output is an increased production capacity. Both the production process and the quality of the maintenance work, which, in turn, affects equipment condition, affect the state and quality of the final product.

The asset management needs for service can be highlighted as business drivers, and the objective of PM is to avoid, diminish, or identify the onset of failure using diagnostic techniques [Ben-Daya and Duffuaa, 1995].

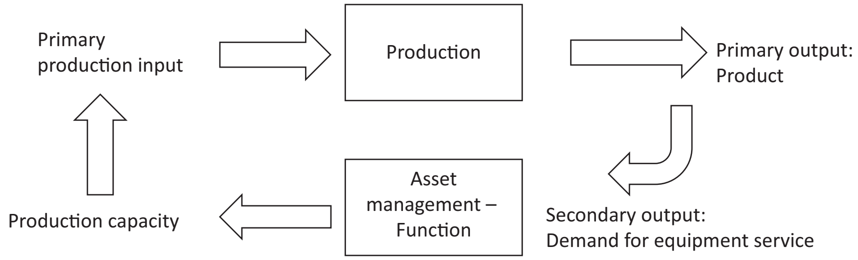

Figure 2.2 Production – maintenance relationship (modified from Ben-Daya and Duffuaa, 1995).

The expected benefits, i.e., business drivers from equipment condition monitoring, fall into two general categories, namely Financial and Soft benefits [Spare, 2001]. Figure 2.3 shows the relationships between the business drivers, a maintenance process/es and the role of performance measurements.

It is important to first identify the business drivers that will be aligned with the business strategy, in this case the maintenance department strategy. The business drivers are usually a financial measure or other performance measures that the specific company or department might have.

Business drivers connected with the financial part are, for instance, to reduce maintenance costs, reduce catastrophic failures, defer replacement (extend life), and increase equipment utilisation.

For the case of preventive maintenance, the objective is to reduce the costs of maintenance by the monitoring of equipment health and avoid unplanned failures.

Preventive maintenance objective is to reduce unplanned catastrophic failures. Condition monitoring, which is part of the CBM strategy, provides the detection of failures that might be developed before or after a scheduled maintenance service task. The approach averts the result of high cost related

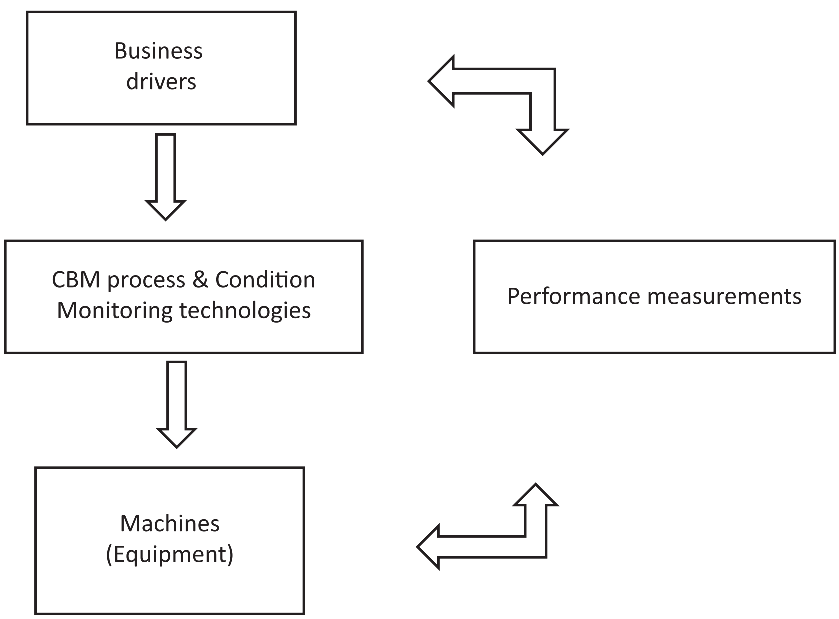

Figure 2.3 Implementing CBM in support of business drivers (modified from Spare, 2001).

to maintenance since it detects a failure in time, which results in a usually much easier and less costly service provided.

In addition, CBM provides an extended life to the equipment since the equipment is better maintained by the service given in a timely manner. Also, the CBM strategy provides an increased equipment utilisation since it results in an opportunity to increase the value of its utilisation by following a strategy that continuously monitors the health of the equipment.

Continuously, the so-called soft benefits are reliability/availability, as well as safety concerns. The reliability/availability are goals that need to be achieved by the maintenance department to be able to increase the profit or at least not increase the cost of maintenance and by keeping the machines running for the production department. Another aspect is safety, which is an important factor that provides acceptable conditions to work for the employees.

It is crucial to identify and have an understanding of different business drivers that might exist for the specific domain, and specifically the maintenance department in this case. Consequently, this should be done to be able to run the business into the right direction, i.e., by transforming the written strategy into action and implement all its parts with appropriate actions and measurements to track its deviations from the predetermined plans and act accordingly.

Furthermore, it is crucial to understand the link between production and maintenance departments to be able to see the interdependence between the two mentioned departments in a company and the need to adjust the business drivers for the successful implementation of the overall business strategy.

2.2 Optimization of Maintenance Costs

Even though maintenance has the potential to provide revenue streams, one of the main pillars for advanced maintenance is still the reduction of the maintenance costs while keeping the machinery and equipment constantly in working order. The traditional maintenance methods are not cost optimised, and ICT can help in this sense, by allowing for intelligent maintenance and concepts such as CBM.

Nowadays, the smartphones and mobile devices play a huge role in society. It was only a matter of time that these devices would be integrated in the industrial field, and more specifically in the maintenance services. Many organizations have implemented CMMSs on their smartphones or handheld devices. As smartphones are getting more powerful, they are substituting the handheld tools that have been used until now, enhancing the CMMS experience and providing the necessary tools for the occasion.

The internet connection of the smartphones enables the technician to view the maintenance history of that asset and make a first assessment of the problem. If he needs a spare part, he could order it straight from his phone and have it delivered to the exact location. Once the problem has been fixed, he could make a report and upload it directly to the history database.

A technician that needs to scan barcodes or QR codes typically uses a barcode reader. Nevertheless, with the camera of a smartphone it is possible to substitute the reader, and it could also show the info of the asset and even take you to its location. The camera could also be used to upload images of the product to another technician to solve any issues instead of describing the problem on the phone.

Most of the smartphones are equipped with NFC technology. NFC is used to read RFID tags, in a similar manner to the barcodes.

GPS, barometer, metal detector, sound meter or vibration analyser could be some of the other uses a smartphone could have.

With these examples it can be seen that the smartphone can substitute a considerable amount of handheld tools. However, it must be taken into account that even if these technologies are well-developed, they might not be comparable to the quality of other tools or suitable for all the needs a company has.

2.3 Business Drivers for Collaborative Proactive Maintenance

Corrective maintenance is carried out after failure recognition. It is aimed to restore the equipment to a state in which it can perform its required function. Corrective maintenance can be deferred or immediate. The deferred maintenance is not done immediately after a fault has occurred. The immediate maintenance refers to provide service to the equipment without any delay at a suitable time. Therefore it is also called emergency maintenance. Hedderich [1996] indicated that the maintenance philosophy must change from a purely repair function to one that focuses on the operations of the equipment. Corrective maintenance, also called as "Fix when failed" was not a good one because when things break down maintenance has failed [Blann, 2003].

Corrective maintenance had many drawbacks, which led to evolution of Preventive Maintenance or TBM. Preventive maintenance is “the maintenance carried out at predetermined interval or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item” [BS 3811, 1993] [SFS-EN 13306, 2010], and can thus be based on condition or predetermined interval maintenance. The basis for the determination of intervals can be in terms of time, number of operations, mileage etc. It is most effective when historical data exist to provide statistical failure rate for the equipment, MTBF can be accurately predicted, knowledge about the failure mode/s exist, low costs are associated with the regular overhaul of the equipment and low costs spare parts are available, etc. Preventive maintenance started to emerge in 1950s when reliability engineering started gaining popularity. The well-known bath-tub curve was based on the hypothesis that all equipment go through similar kind of deterioration and therefore, similar kinds of maintenance actions are required to keep it running. This is definitely not true because the failure in the equipment is based not only on its age, but also on the operating conditions. These operating conditions vary in terms of temperature, operator expertise, environmental factors, etc. This meant that sometimes, the maintenance actions happened before the required time, and in other cases, the maintenance was scheduled a little too late. When the maintenance happens before it is required, it leads to avoidable loss of production time and maintenance resources. A delayed maintenance action can result in the machine running up to failure, thereby loss of production time and other related problems. There are some other challenges, like inadequate data on asset performance and service history, maintenance not as a top priority for management, and nonstandard maintenance processes.

Collaborative proactive maintenance practices provide an answer to these challenges. Proactive maintenance strategies such as predictive maintenance that uses sensors for monitoring the health of the equipment by measuring vibrations, acoustic emissions, pressure waveforms, etc. further improve maintenance performance. Optimal asset performance is not dependent on maintenance practices alone. Planned maintenance activities must be scheduled to minimally impact production requirements and schedules. This necessitates close collaboration and planning between both maintenance and operations staff. Such collaborative proactive maintenance can result in improved asset reliability, greater asset uptime and availability, lower costs of servicing assets, fewer unexpected downtimes and outages, and a higher return in invested capital.

Business drivers are the crucial factors which lead to success in business. In case of asset maintenance, two broad categories of business drivers can be identified. These are Financial and Operational drivers. These two broad drivers can be further sub-divided and are shown in Figure 2.4 below.

RoI is a measure used to evaluate the efficiency of an investment or to compare the efficiency of a number of different investments. RoI measures the amount of return on an investment relative to the investment's cost. To calculate RoI, the benefit (or return) of an investment is divided by the cost of the investment, and the result is expressed as a percentage or a ratio. In the current context, it is the overall benefit accrued by the company due to its investment in a proactive collaborative maintenance approach divided by the cost of the investments.

$$\text{RoI} = \frac{(\text{Financial Benefits from the investment} - \text{Cost of the investment})}{\text{Cost of the investment}}$$

Reduction in *Operational* and *Maintenance Costs* are also important business drivers. The companies that seek to apply collaborative proactive maintenance for managing their assets look for reducing these costs. These two drivers can be analysed intelligently by studying them as a percentage of the revenues that the company is generating. This would make sense as the larger companies will spend more on operations and maintenance and yet be better off as they generate much larger revenues.

Collaborative proactive maintenance strategy achieves a reduction in these costs through various means. When the company is proactive in asset maintenance, it has the foresight to plan for maintenance breaks. The strategy

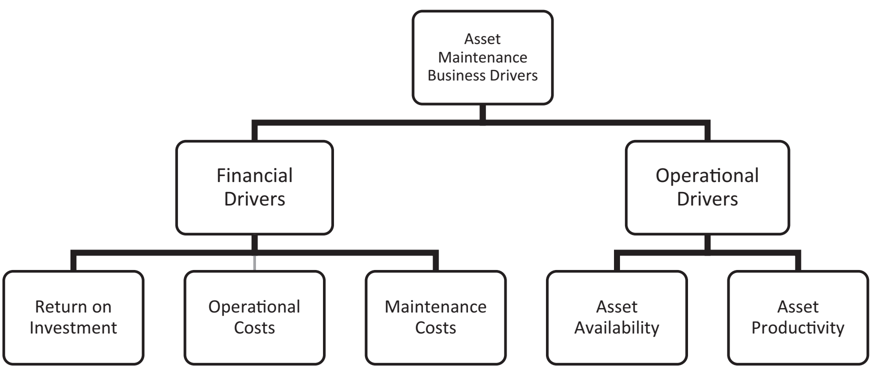

Figure 2.4 Classification of business drivers.

also enables the firms to pre-position the spare parts and the technically skilled personnel at the right place and right time. This will help in reducing costs of employing costly skilled manpower. The approach will also result in reduction in the cost of spare parts by reducing the MRO inventory.

Corrective maintenance or *fix-when-fail* is an often used strategy. However, it has serious drawbacks. It results in unplanned stoppages of production when the machine fails. This unplanned stoppage can have an adverse impact on the production schedule, leading to not fulfilling the customer demands. Corrective maintenance also has other drawbacks where a damaged part can lead to secondary faults. A broken bearing or a gear can foul with other parts of the machine and damage them too. This will increase the maintenance costs. A proactive maintenance strategy can help in removing an about-to-fail spare part, thereby avoiding damage to other parts of the machine.

Collaborative proactive maintenance strategy results in keeping the machine in a better state. A well-maintained machine, with reliable spare parts will produce better quality product. A calibrated machine will produce the products that are within tolerances. Such machine will also have a longer usable life. This can help in reducing further investments in new capital procurements at the end of life of the current machines.

Operational Drivers of asset maintenance are increase of *asset reliability* and *availability. Asset Reliability* is defined as the probability that a component or system will perform a required function for a given time when used under stated operating conditions. *Asset availability* is the asset's availability to be put to its intended use. A Proactive maintenance strategy will help in increasing both the availability and the reliability of the assets.

Another *Operational Driver* is increasing the *Asset Productivity*. It describes how effectively are the business assets deployed. This ratio typically looks at sales dollars generated per unit of resource. Resources can include inventory, fixed assets, and occasionally other tangible assets. Similar analyses may also be done not just for financial assets but also for operational assets like square footage, number of employees, etc.

The financial and operational drivers of boosting service and maintenance effectiveness in asset intensive industries are substantial. Preventive maintenance is effective, but proactive maintenance strategies such as predictive maintenance and reliability centred maintenance processes have a positive impact on nearly every asset performance measurement. Collaboration must be carried out between maintenance and operations staff to develop planned maintenance schedules that minimally affect production requirements. The companies must try to bring all maintenance planning and maintenance operations together under the control of one senior-level executive to strengthen maintenance processes across the entire enterprise, not just within individual departments or operations. The companies must use the latest analytics software to drive the business. Such software solutions are very useful in pinpointing the areas that need focus for improving the asset performance.

2.3.1 Maintenance Optimisation Models

Maintenance optimisation models are those mathematical models whose aim is to find the optimal balance between the costs and benefits of maintenance, while taking all kinds of constraints into account [Sharma and Yadava, 2011]. In general, maintenance optimisation models cover four aspects:

- A description of the system (or component), and the function and importance of the system in keeping the business operational;
- A modeling of the physical deterioration of the system in time as well as the failure behavior and consequences;
- A description of the available information about the system (i.e., state space) and the decisions available to management (i.e., action space);
- An objective function and a set of constraints along with an optimisation technique in order to find the best balance.

The maintenance optimisation models in the literature can be classified based on different aspects such as the presence of randomness in the system, the number and interdependency of failure-prone units, discretization of time, model types, optimality criterion, methods of solution and planning time horizon. Figure 2.5 summarizes these aspects within a proposed workflow in building maintenance optimisation models.

In the context of maintenance optimisation, it is common to model the uncertainty in the time-to-failure with a known probability distribution function. However, this probability distribution function is not readily available in practice, requiring data-driven maintenance optimisation policies. Alternatively, uncertainty in the failure behaviours can build on the knowledge about the failure characteristics learned from historical data. In particular, the maintenance optimisation models provide the tools that potentially rely on the output from root cause analysis, remaining useful life time analysis and alerting and prediction of assets failures in the optimal planning of maintenance and related resource allocation.

The optimisation methods for solving the mathematical formulations of the maintenance-planning problems often include linear and nonlinear

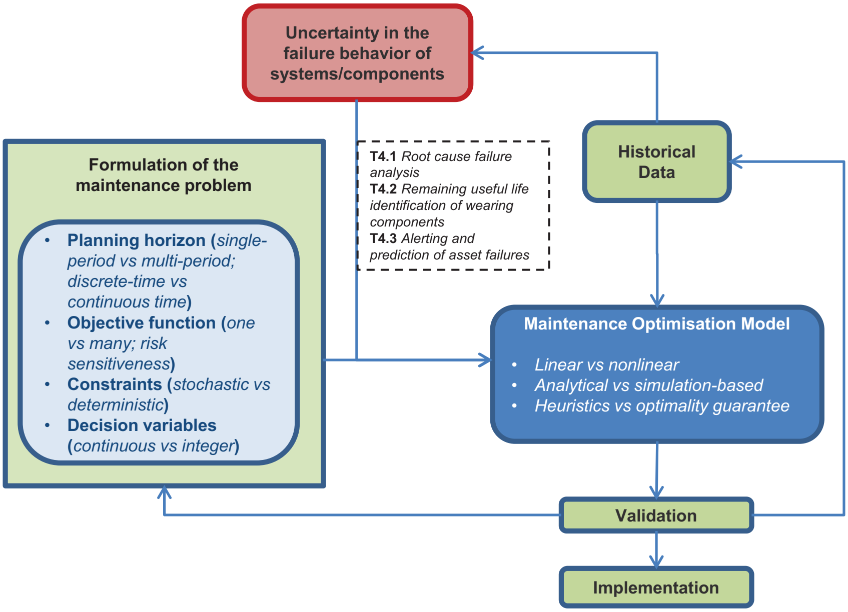

Figure 2.5 Workflow in building maintenance optimisation models.

programming, dynamic programming, Markov decision processes, decision analysis techniques, search techniques (i.e., simulation-based optimisation) and heuristic approaches.

Maintenance optimisation models yield various managerial outcomes [Dekker, 1996]: First of all, the structure of optimal polices, like the existence of an optimal control-limit policy, can be established. Second, models can assist in the timing aspect of maintenance activities: how often and at what extent to inspect or to repair a machine or a component; and if applicable, how often to preventively replace them. Finally, models can also be of help in determining effective and efficient schedules and plans for service engineers and spare-part stocking, taking all kinds of operational, physical and economic constraints into account.

2.3.2 Objectives and Scope

In general, an **optimal maintenance policy** achieves one of the two objectives: minimizing system maintenance cost (e.g., the sum of failure and proactive maintenance costs) while the system reliability requirements (e.g., system availability or uptime) are satisfied, or maximizing the system reliability measures when requirements for the system maintenance cost are satisfied.

In line with these objectives, the maintenance decision making process (Figure 2.6) is composed of two main assessments followed by the selection of the appropriate decision model [Ahmad and Kamaruddin, 2012]:

- **Operational cost assessment:** The aim of this assessment is to calculate the two types of operational costs, namely the failure cost, the setup cost for data-driven maintenance (e.g., the cost of collecting, storing, and processing data, the cost of installing new sensors for condition monitoring) and the preventive maintenance cost (e.g., the cost of performing inspections to detect failures or to perform data analytics to predict the failures in order to act before they are realized);
- **Component assessment:** The goal of this assessment is to classify the maintenance type of the equipment as either non repairable or repairable, and if so, to what extent, and to identify the structure and interdependency of the components in the system;
- **Decision (optimisation) model selection:** After the component assessment, the appropriate maintenance model is built to identify the optimal maintenance policy. The maintenance policy is the output of the maintenance model. Maintenance models can also be used to evaluate the performance of the practical policies that are not necessarily optimal.

In the remainder of this section, we use the term **maintenance policy** in its most general meaning, including an inspection (information collection) policy, repair policy, or replacement policy. That is, maintenance optimisation is a unifying approach for finding the optimal subset of policy for inspection, repair, or replacement activities.

We note that the maintenance optimisation starts at the design phase of a system of components because the level of redundancy or accessibility in product design have significant impact on the maintainability of a system. Therefore, it is of practical importance to account for the total maintenance costs in the product-life cycle during new product development. This is an

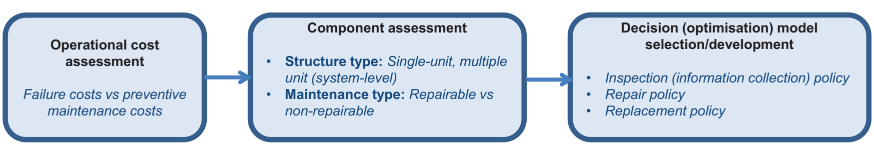

Figure 2.6 Maintenance decision making process.

example of a strategic decision in maintenance optimisation. Alternatively, operational and tactical decisions in the scope of the maintenance optimisation models consider that maintenance has to be planned and scheduled once the system is in operation, in accordance with other plans (e.g., production, planned maintenance, spare parts planning) by building on the data-driven prediction tools that capture the uncertainty in the failure behaviour of a system.

2.3.3 Maintenance Standards

It is essential to understand the definitions of maintenance when selecting a maintenance strategy. The starting point may be considered generally known standards where maintenance is defined as follows:

- Standards PSK 6201 and PSK 7501: Maintenance is the totality of all the technical, administrative and management issues designed to maintain the target object or return it to a state where it is capable of performing the required function during its entire life cycle [PSK 6201, 2003], [PSK, 2010];
- The European standard SFS-EN 13306: Maintenance consists of all technical, administrative and management issues of the lifetime of the object designed to maintain or restore the object so that the object is capable of performing the required function [SFS-EN 13306, 2010].

2.3.4 Maintenance-related Operational Planning

Maintenance optimisation models often span multiple business functions as maintenance decisions are directly linked to service-logistics operations. Based on the preliminary feedback from use-case owners, the maintenance-related operational planning can be divided into three stream:

Service logistics/transportation: Since the capital goods are often operated at remote locations in a network, unplanned maintenance requires significant logistic effort and hence can be very costly. The data-driven planning of the routes, vehicles, and skill levels of the maintenance teams, is of interest in reducing high maintenance costs.

Spare parts/service tools planning: Because the demand for spare parts is uncertain (as it is unknown when machines or certain components break down), and the spare parts should be delivered in a timely manner, most often the practical approach is to stock resources (spare parts, tools and service engineers) in all the places where such needs can arise. This leads to high inventory holding costs. The failure prediction algorithms bring an opportunity to enrich the spare parts/service tools planning via the joint maintenance and spare-parts planning models. Houtum and Kranenburg [2015] present accurate evaluation and optimisation algorithms for spare parts stocking policies.

Operational decision-making based on remote monitoring: The advanced sensor and ICT technology allows acquiring the physical conditions of systems/components remotely and with less cost. Based on these condition data, significant amount of unnecessary maintenance tasks can be avoided, by taking maintenance actions only when the failure of critical components is imminent. This can be seen as a special case of predictive maintenance, through which maintenance costs can be significantly reduced in comparison to preventive maintenance (Figure 2.7). Remote maintenance and service-logistics planning are highly relevant here.

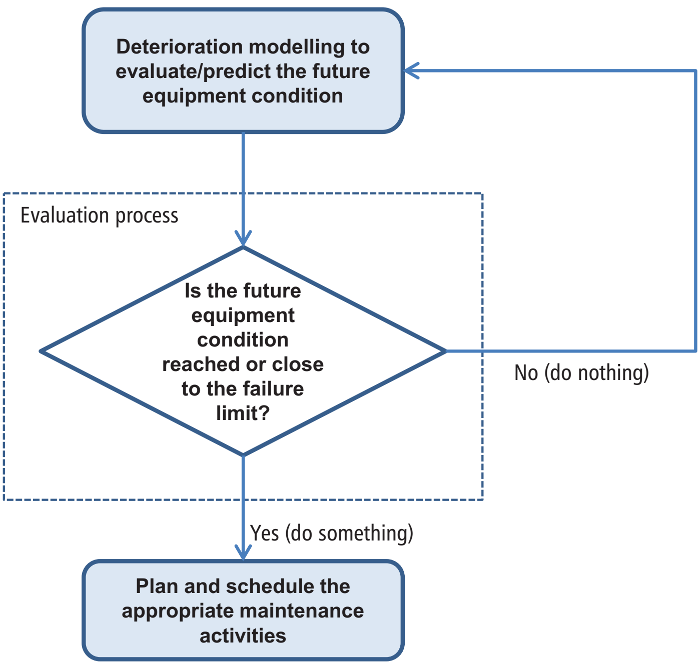

Figure 2.7 Decision framework for predictive maintenance.

2.4 Economic View of CBM-based PM

According to the standard SFS-EN 15341, 2007 (Maintenance. Maintenance Key Performance Indicators), total maintenance cost (often based annually related only to the maintenance activities performed on the asset/item). Includes costs referred to:

- Wages, salaries and overtimes for managerial, supervision, support staff and direct staff;
- Payroll added costs for the above mentioned persons (Taxes, Insurance, Legislative contributions);
- Spares and material consumables charged to maintenance (including freight costs);
- Tools and equipment (not capitalized or rented);
- Contractors, rented facilities;
- Consultancy services;
- Administration costs for maintenance;
- Education and training;
- Costs for maintenance activities carried out by production people;
- Costs for transportation, hotels, etc.;
- Documentation;
- CMMS and Planning Systems;
- Energy and utilities;
- Depreciation of maintenance capitalized equipment's and workshops, warehouse for spare-parts.

Exclusions:

- Costs for product changeover or transaction time (e.g., Exchange of dies);
- Depreciation of strategic spare parts;
- Downtime costs.

A remote access to the plant data would reduce the travel time needed to perform the service and significantly cut costs. Remote access also allows experts from different specialities and physical locations to share data and collaborate. The analysis work could be performed remotely while traveling, from home or office or from anywhere increasing work flexibility and improving personnel efficiency.

A continuous data collection piloted in the use-case enables the use of automated analysis and monitoring software more effectively. The software would monitor the data collected from the plant and alert the expert to cases that would require special attention. This enhancement is also aimed at reducing personnel costs involved.

The new business model aims to provide:

- Own fleet operation and maintenance
  - Better availability by using predictive condition monitoring;
  - Possibility to apply platform architecture and advanced maintenance concept to operation;
  - More exact timing of maintenance action based on actual condition.
- Increasing sales of O&M services and cost effective operation support
  - Possible contractual based long term maintenance agreements by using condition monitoring for energy production customers;
  - Optimal use of personnel for remote sites by using predictive tools and utilizing new operation concept concerning local and back office support;
  - Faster and optimized failure correction by using analytics and prognosis for critical components enables management of larger power plant fleet;
  - Systematic long term information collection for root cause analysis and investment planning of replacements.

Estimating the revenue of a new business model is rarely accurate and due to the high variance in the potential business models, it is impossible to show a typical revenue stream projection of a remote support service.

Previous experiences and references show that successful implementation of a remote monitoring system can reduce the unscheduled unavailability of a component by 35%–45%. This can have a serious impact on reducing the lost production, e.g., of a power plant.

Like in the traditional service model, the most significant costs of the service come from personnel costs. Utilization of machine aided monitoring these costs could potentially be reduced, but often this is not possible. In a well designed service, each member is a specialist in a certain field and their area of expertise needs to be covered.

Benefits of Collaborative, Proactive Maintenance solution could be:

- Production price (taxes, emission taxes, tariffs, government support);
- Price of energy as a function of seasonal demand (e.g., winter time demand for energy is high and so is price/revenue);
- Demand as a function of time (seasonal, each plant has a maximum energy production capacity);

- Investment cost of the critical component;
- Maintenance work required (hours);
- Work cost, based on market situation;
- Reduction of unnecessary travel to remote locations -> increases sustainability by reducing emissions caused by travelling -> increases company's public image.

2.5 Risks in CBM Plan Implementation

CBM has developed rapidly as a maintenance concept and is being considered as panacea for all ailments related to machine health. But like with all things that seem miraculous, there are a few issues in successful implementation of a CBM plan. Many implementation efforts fail and condition monitoring tools too often end up at maintenance workshops cupboards, hardly ever used [Walker, 2005]. Nearly 30% of industrial equipment does not benefit from CBM [Hashemian and Bean, 2011]. This may be due to a number of reasons. The data is gathered in large amounts, often from assets that are dispersed over large distances; sometimes even across continents. The collected data needs to be integrated from multiple sources such that effective analysis could be done. In certain cases, new assets and data acquisition sources get added. Additional resources are required to integrate this new data with existing data in order to derive meaningful insights. In some CBM plans, the collected data and the derived results are required to be assessed by an expert. There is a scarcity of good experts who can recommend corrective actions in time. Therefore, even if a condition monitoring programme is in operation, failures still occur, defeating the very purpose for which the investment was made in CBM [Campos, 2009; Prakash, 2006; Rao et al., 2003]. The basic idea behind implementing a CBM plan is to detect the impending failures and initiate corrective actions that are timely. A good CBM plan will ensure that the maintenance scheduling is neither too early (leading to unnecessary maintenance) or too late (catastrophic failures resulting in disruptions of manufacturing operations). However, it must be noted from the operational viewpoint that any prospective maintenance policy based on condition information must have clear economic benefits; otherwise the initial outlay for the CM system and associated costs cannot be justified [McMillan and Ault, 2007]. There are a large number of other factors that not only impede a smooth implementation of a CBM plan but also result in a system that is ineffective and considered as an unnecessary burden in terms of costs and workload. Through an extensive literature review, this chapter identifies these issues that can hamper a successful conversion of a theoretical plan into an effective workable solution.

CBM Implementation is not devoid of the challenges and hurdles associated with programs that require a drastic change in the way an organization functions. In this chapter, an attempt has been made to classify these issues into four major categories. These are: Technology, People, Processes and Organizational Culture. Every organization that is planning to implement a successful CBM program must pay attention to these issues and avoid the obvious pitfalls. The risks are listed below.

2.5.1 Technology

CBM is a technology rich maintenance driver that aims at taking over the functions of humans. In certain cases, only the mundane monitoring is handled by the technology while in some other advance CBM systems, even the decision making is automated. Technological barriers to a successful implementation are most important because these factors can lead to efforts getting wasted on unfruitful activities. Some of the issues are listed below.

Selection of assets to Monitor: First and foremost, the organizations must select the assets that require condition monitoring. CBM is supposed to be applied where appropriate, not as an overall policy as some techniques are expensive and it would not be cost effective to implement everywhere [Starr, 1997]. This selection should be based on technical and economical feasibilities. The selected asset must be such that it has the parameters that can be monitored with the sensors. Also, the machine should be critical enough to warrant large investments in a CBM system.

Complexity of measuring parameters: One of the most important step in CBM implementation is to decide the parameter that should be measured by the sensors. Most CBM implementation drives fail because the organizations start to measure 'what can be measured' rather than 'what should be measured'. The first challenge is to obtain effective features from many candidate features to reflect health degradation propagation in the whole life of machines [Yu, 2012]. In machine-learning-based defect detection, the accuracy of prognostics and diagnostics models subsequently dependents on the sensitivity of the features used to estimate the condition and propagation of the defects. Therefore, it is critical to devise a systematic scheme that is capable of selecting the most representative features for current machine health states [Yu, 2012; Malhi et al., 2004]. The complexity of selecting a suitable measure can be gauged from an example. Some research shows that the use of acoustic signal is better than vibration signal due to its sensitivity and accuracy [Al-Ghamd and Mba, 2006; Baydar and Ball, 2001; Tandon et al., 2007]. However, in practice, the application of acoustic signal may not appropriate due to the significant effects of noise (unwanted signals) from other equipment. In addition, alternative sources of information are important contributors to health monitoring. These sources include the OEM, ISO standards, experience of the workers, etc. The new challenge is to find ways to use these alternative sources of information in order to achieve better monitoring of assets and correct decision making [Ahmad and Kamaruddin, 2012].

Complexity of sensors: Choice of a correct sensor with appropriate sensitivity is an important step. Selecting a costlier sensor when it is not required will make the CBM system unnecessarily expensive, which will not be able to justify the cost-benefit argument. On the other hand, selecting a cheaper non-sensitive sensor when the data being measured has minute variations that require high quality sensor can also upset the cost-benefit balance as the diagnosis of the fault may not be correct. Other ICT challenges include sensor data quality related to gathering frequency, noise, and level of details of sensor data, data availability, wireless communication problem, frequency of diagnostics and prognostics, and so on [Shin and Jun, 2015]. In addition, the technologies and technical methods for the CBM approach are still in their infancy. It means that there are some limitations in ensuring the accuracy of diagnostics and prognostics [Shin and Jun, 2015]. Numerous different techniques and technologies exist but choosing the correct one, or even remembering to make the decision in due time can be a troublesome activity which can put an entire implementation effort at risk [Bengtsson, 2004].

Deciding on thresholds: The condition monitoring practice is based on the fact that a sensor is used to measure a parameter. When the value of the measured parameter crosses a pre-determined threshold, suitable maintenance actions are initiated. In practice however, deciding on the threshold is a complex process. The failure of each of equipment may be defined and classified in different ways. Some organizations consider failure as the physical event such as a breakage that stops production. The machine stops to function as a result of such a failure. In some other cases, a functional failure may occur which results in the final product of the machine to have quality flaws but the machine may continue to work. It is necessary for the organizations to determine threshold based on their requirements. The definition and determination of failure limits should be considered from both the entire machining process perspective (system/sub-system) and the overall output of the system (e.g., product quality characteristics) [Ahmad and Kamaruddin, 2012].

Noise effects: Analysing waveform data is an intricate process because of noise effects, which are unwanted signals generated by other equipment. Noise must be minimised or eliminated from the data [Ahmad and Kamaruddin, 2012]. Some noise also gets generated due to the transmission medium. It is necessary to identify which data transmission type (wire or wireless) is effective in terms of cost and reliability with least noise [Shin and Jun, 2015].

Data storage and monitoring period: In many cases, the assets that are monitored with sensors are big machines that need years of use in order to show wear in some parts, or need years to reach failures. Thus, there is a need to monitor and store huge time periods (and related data) in order to provide enough data to generate predictive models.

Data cleaning: Large data sets are required for effective data analysis and modelling. This collected data needs to be cleaned before any analysis. This is a complex task, especially for waveform-type data.

Biased thresholds: Determination of thresholds is a complex process. Often, the complexity increases due to biases that get introduced in determining these failure limits [Ahmad and Kamaruddin, 2012].

New Assets and the complexities: Newly commissioned systems have no historical data. Even the OEM is not aware of the failure patters or failure rates. In such cases, it is not possible to identify the trends or failure thresholds. Such situations are no-data situations [Si et al., 2011]. The quantity and completeness of data are insufficient to fit the full statistical models. Hence, it may be a better choice to develop physics-based models with the help of subjective expert knowledge from design and manufacturing [Si et al., 2011].

2.5.2 People

CBM aims at using technology to monitor and/or diagnose the faults in machines. The focus of CBM is to replace humans by machines to carry out mundane monitoring and intelligent decision making tasks. In spite of this, it is not possible to replace humans completely. The success of any CBM implementation program depends on a lot of people factors. Some of these are listed below.

Training and Skills: There is a need to have requisite skills in the personnel that are responsible to use CBM. Familiarity with the condition monitoring system and training for analysis of the data is required to be imparted. Advanced data analysis such as frequency analysis requires advanced skills [Rastegari and Bengtsson, 2014]. Education and training is important prerequisites for a company to increase the competence [Rastegari et al., 2013]. Other factors like technical competence and knowledge is required in order to completely implement a CBM system.

Human Factors: Other human factors also need special emphasis. Walker [2005] lists several factors like lack of direction, unwillingness to adopt a new approach to maintenance, etc. as reasons for failure of CBM approaches. Senior technicians often treat a CBM initiative as something that is unnecessary expenditure. There are also some reservations about the frequency of monitoring. Technicians often feel that it is better to spend the money in other systems which can give more money back [Rastegari et al., 2013].

2.5.3 Processes

The implementation of a CBM program is a long drawn complicated process that needs careful planning. The processes must be put in place to implement, monitor, measure and improve the system.

Economic Feasibility study: An economic feasibility study must be carried out before the implementation process. It is imperative to define the business model for new maintenance operation and identify benefits and costs [Shin and Jun, 2015]. High data collection costs must be considered in the feasibility study [Kothamasu et al., 2006]. All these support monitoring tools directly involve high costs, and not all companies are willing to invest in them [Ahmad and Kamaruddin, 2012]. Specific computerized monitoring systems and experts are required. These requirements directly involve large company investments, especially since such companies must buy and maintain these systems, as well as provide training for their use [Ahmad and Kamaruddin, 2012].

Assignments of Responsibilities: In order to have a more structured implementation, it is needed to define the responsibilities in early phase of the implementation [Rastegari and Bengtsson, 2014]. Implementation responsibilities must be written down as company documents and adhered to.

Piecemeal implementation: To get the practical benefit of CBM approach, it is necessary to consider applying CBM into not only one piece of equipment but also an integrated system level [Shin and Jun, 2015]. The implementation process should consider holistic application of the technology at all levels.

2.5.4 Organizational Culture

It is important to have encouraging atmosphere in the organization to successfully implement a CBM program. Some of the related factors are listed below.

Top management commitment: One of the main challenges to implement CBM at the company is management support. The management must comprehend the importance of the CBM's role at the company and provide the resources needed. It needs to have a long term strategy to change the way of working from reactive maintenance to proactive maintenance [Shin and Jun, 2015]. That is why, the top management must continue to support the initiative for as long as it is necessary.

Alignment of business objectives with the workforce: The workforce must be on the same page as the top management. The process must not look like a management fad in which the workforce has no interest.

Establishment, documentation and communication of objective: The overall objective of CBM must be decided and documented. The objective must be communicated down to each of the stakeholder. The communication gap often results in the worker considering CBM as another top driven agenda with no fixed goals. This leads to failure or partial implementation of CBM which provides no benefits to the organization.

Conflicting departmental priorities: There may exist conflicting priorities amongst several departments in an organization. For example, Maintenance Department may want a machine for inspection/maintenance before it fails but the production department wants high utilization of the equipment and hence does not hand over the machine to the maintenance people [Campos, 2009]. The organization must have conflict resolution rules such that the CBM implementation as well as the health of the equipment does not suffer.

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