The Role of Maintenance in Reducing the Negative Impact of a Business on the Environment

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Abstract New concepts of business management (Lean Manufacturing, Green Manufacturing or Sustainable Manufacturing) resulted in modified perception of maintenance. It is no longer a cost centre but a strategic business partner that plays a vital role that helps the organisation to achieve its eco-efficiency goals. Maintenance services have no direct impact on power consumption and other utilities or the amount of generated waste resulting from the applied manufacturing technologies. However, they may actively contribute to the reduction of environmental aspects identified in the organisation and to the improvement of its eco-efficiency. The two areas, maintenance and environment, are inter-dependable, both in terms of results of actions and the effects. What factors are in the responsibility of the maintenance? On what production system components can the activities of maintenance service affect positively?

Keywords Maintenance activities · Maintenance performance · Environmental maintenance BSC

1 Introduction

Industrial activity has been considered one of the major sources of environmental pollution, natural resources depletion, and natural environment degradation. Environmental impacts can be classified in many ways. With reference to the

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range of impact it may be classified as local, regional or global; while as regards time—past, present, and future. One may also mention environmental impact referring to the range and time of activity, the phase of production, and the target of the impact. Environmental impact can affect water, air or soil. Organisations directly or indirectly extract fossil fuels, mineral resources, organic resources, water resources, etc., from the environment and input them into business processes as energy, raw materials, parts, products or water. Environmental burden such as the consumption of natural resources and modification of the state of the land is the result of these business activities.

The knowledge of the organisation's environmental impact is an essential element of a systematic and effective improvement of achievements in this respect (Hadas et al. 2011). Environmental policy, environmental objectives, and the relevant programmes are based on information referring to environmental aspects and impact of the organisation onto the environment. This gives the organisation an opportunity to prevent and limit its negative impact and to promote pro-environmental behaviour. Consequently, the challenge they face is to prepare a comprehensive quantity and quality analysis of raw materials and energy consumption as well as waste water, waste and contaminant emission to the atmosphere.

Assuming that an organisation is a set of manufacturing factors organised and coordinated in order to run a business connected with the production of goods and rendering of services, the following question occurs: in what way do individual manufacturing factors (an organisation's units or implemented processes) contribute to pursuing of the assumed strategy? What is their influence on achieving the assumed goals?

With no doubt, one of the major elements of an organisation's structure is maintenance. As irrespective of the area of business and supplied product, each organisation has technical resources (machines, equipment) that require maintaining in operation. By maintaining we wish them to performed tasks ordered by the user efficiently, i.e. with the optimum use of resources (materials, energy, etc.). In manufacturing context, maintenance management is the process of directing maintenance organisation effectively by utilizing administrative, human, financial, and material resources in an efficient and effective way through planning, scheduling, executing and monitoring their own progress for continuous improvement. Maintenance management's role is to provide support to production, and by providing reliable equipment and processes it helps organisation to be competitive and contribute to sustainable profitability; socially, economically and environmentally (Baluch et al. 2010).

New concepts of business management, such as Lean Manufacturing, new challenges relating to economical management of natural resources (Green Manufacturing) or Sustainable Manufacturing thinking resulted in modified perception of maintenance (Jasiulewicz-Kaczmarek 2013). It is no longer a cost centre but a strategic business partner that plays a vital role that helps the organisation to achieve its goals. Well adopted maintenance policy and availability of resources (human, material, technical, information-related) support organisations in achievement of their eco-efficiency goals in every phase of their equipment's life cycle.

Regular professional maintenance ensures the most eco-efficient use of equipment and the longest, cleanest life cycle, with the smallest environmental impact. It helps customers determine when and how to modernise equipment with thorough inspections of the safety, accessibility, reliability and energy efficiency.

Thus, inclusion of the maintenance function in the pro-environmental strategy is equally indispensible at the stage of investing in new machines and equipment and later during operation and abandonment phases (Napiórkowski and Szczyglak 2011; Napiórkowski et al. 2011).

A growing number of organisations uses different forms of defining its environmental impact, plans and takes pro-active steps to limit such an impact. Planning must be connected with an effective system of achievement assessment because evaluation is based on the adage "what gets measured, gets managed". For manufacturing processes, the availability of a set of indicators would allow comparing the environmental performance over time, highlighting optimisation potentials, deriving and pursuing environmental targets, identifying market chances, benchmarking against other companies or communicating results in environmental reports (Pawlewski and Borucki 2011).

Organisations use a variety of systems to evaluate achievements as well different measures and indicators (Greiner 2001; Feng and Joung 2009; Herva et al. 2011, ISO 14031 1999; ISO 14040 2006).

None of the above, however, refers comprehensively to maintenance as an important function performed in an organisation and its contribution to the implementation of its pro-active strategy.

The paper has been structured as follows. The first part identifies major causes of pro-active steps taken by organisations. Next, the maintenance system and its role in a product's life cycle are described. Attention is drawn to elements that are important in terms of environmental impact. The third part is an attempt to connect pro-environmental actions of maintenance with the objectives and strategy of the organisation. To do to so the Environmental Maintenance Balanced Scorecard (EMBSC) model is proposed. It allows examining of environmental issues with reference to maintenance from the perspective of strategy, setting out of goals as well as achievement assessment measures and indexes. Hence, it is possible to evaluate the quantitative contribution of maintenance to the implementation of the pro-active strategy of an organisation.

2 Company Motivators of Pro-environmental Activities

The evaluation of an organisation's environmental impact once again becomes a business priority. Clients, investors, legislators expect organisations to store data concerning their business' environmental impact and to reduce impacts from harmful factors. As a consequence, pro-environmental motivators of measures taken by organisations should be sought among market (clients, investors) and legal (legislators) requirements.

Market requirements formed by clients and investors often result from two factors. The first is reputation. They prefer to buy from and invest in organisations that care about ethical principles and meet all environment protection related requirements.

Cooperation with organisations that find it hard to meet legal environmental requirements or are locally perceived as "environmentally arduous or irresponsible" has a negative impact on image and may result in a drop of profit on product or service sales.

Another significant factor is the obligations assumed when adopting strategies aiming at sustainable growth. These obligations usually translate into requirements for all supply chain participants. Consequently, cooperation with large partners (e.g. automotive, power machines, furniture, food and other industries) is more and more dependent on the possibility of proving that the criteria of sustainable development have been met. Such criteria, industry-specific, are often set by organizations that dominate the market and groups thereof. Organizations are also more likely to undergo audits, independent verification and certification in individual areas of sustainable development (e.g., SA 8000, SMETA audit—Sedex Members Ethical Trade Audit, ISO 14001, GSCP—Environmental Reference Requirements 2010, World Business Council for Sustainable Development, Eco-efficiency indicators and reporting, etc.).

A factor that may also influence actions aimed at environmental protection are legal requirements.

According to the European Union requirements, legal acts pertaining to environmental protection impose onto organisations an obligation of preventing environmental hazards or limiting thereof to minimum. Reasonable use of natural environment by organisations is regulated by means of legal instruments such as ecological permits to use individual environmental elements and resources.

Based on the applicable acts and regulations and depending on the type and scale of their activities, organisations are obliged, among others, to hold permits regarding water-sewage management, protection of air against pollution, and noise protection.

As regards waste management, an organisation generating waste is obliged to keep a record of waste on specially prepared waste sheets. Identification and definition of the range of a manufacturing organisation's impact on natural environment elements is possible through permanent and comprehensive analysis of individual stages of the production process, technological operations and available infrastructure. This allows identifying the problems and needs of organisations with regard to environmental impact, indicating the possibility of elimination or reduction of the impact, and evaluating the effects of pro-environmental actions that have been taken.

As it results from a survey performed in 2010 by PBS DGA SA, the level of legal act binding is the first factor that differentiates the frequency of occurrence of a pro-environmental action. 88 % of organisations that indicated the level to be high or very high take pro-environmental actions. To compare, a corresponding percentage among organisations that indicated low level of binding with ecology-related legislation, or which are not bound by such acts, is 57 % (PBS DGA SA 2012).

Legislative regulations provide an impetus to change from non-sustainable to more environmentally friendly operations, but their influence should not be overestimated. The industry practice shows that environmentally friendly behaviour may be the answer to problems that companies face, namely: the increasing cost of energy, raw materials, and waste disposal (Golinska 2010).

Energy, raw materials and resources saving is the key determinant of technological progress and the aim of any entrepreneur wishing for profit. Nevertheless, such saving does not represent sustainable growth. Organisations must take different actions to combine, if possible, economic effectiveness and implementation of ecological responsibility rules. It is the best for them to seek such management methods that will form long-term basis for faster economic growth and promote eco-innovation and ecological safety. As a consequence, today's task for organisations is to create both economic and ecological values.

Implementation of the task results in seeking new, eco-effective technologies. A new challenge emerges for an organisation. It is changing the approach to technologies, processes, and products. This new approach forces new look onto the product through total environmental cost. Therefore, it refers to all participants of the product life cycle (manufacturer and client) and all life cycle stages, i.e. designing, manufacturing, using, maintaining, and abandoning/recycling.

3 Position of Maintenance in the Strategy of a Sustainable Development

A traditionally perceived scope of maintenance activities referred to manufacturing processes. Commonly accepted was the assumption that the main objective of maintenance function is to optimise availability of equipment at a minimum cost. However, shifting of the production paradigm towards a sustainable development resulted in maintenance paradigm change towards product life cycle management (Fig. 1), including maintenance in the chain of values of the

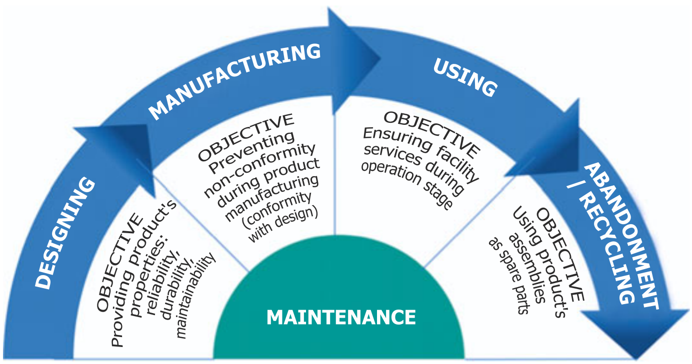

Fig. 1 Maintenance in product life cycle

entire organisation. To highlight and justify the new way of perceiving maintenance, Takata introduced the expression of ‘maintenance values chain’ (Takata et al. 2004).

Many decisions taken at the stage of designing, manufacturing and operation of a structure has a direct impact both on the effect and result in environmental and financial dimension and therefore must be adequately balanced (Johansson and Winroth 2010). For instance, a change of product structure or manufacturing method may cause a major reduction in energy consumption, amount of generated waste or environment pollution. The change itself may also significantly influence production economic results such as cost, productivity, quality and customer service. The essence is, therefore, to find a balance between ecological and economic benefits of the actions taken. This is a challenge to be faced by contemporary organisations both in terms of operational and strategic activities.

Currently, the tasks of technical services in most industrial organisations reach beyond the standard: framework of planning, completion and settlement of service and repair works. An important part of the attention of maintenance management is paid to rationalizing and optimising the decision making processes, both short- and long-term (Loska 2012), and in organisations applying the so-called good engineering practice, machinery maintenance is more than just a cost item to be avoided but first of all a proactive approach that may constitute an effective contribution to the organisation’s growth and an integral part of green manufacturing.

Green manufacturing (GM) has been recognized worldwide as a key strategy for sustainable development and advanced model for manufacturing enterprises. The concept incorporates the principles of environmental protection and energy conservation into production and service activities to reduce industrial waste, save energy and scarce resource, and minimize pollutions to natural environment, while accomplishing production economy.

Maintenance services have no direct impact on power consumption and other utilities or the amount of generated waste resulting from the applied manufacturing technologies. However, they may actively contribute to the reduction of environmental aspects identified in the organisation and to the improvement of its eco-efficiency.

What factors are in the responsibility of the maintenance? On what production system components can the activities of maintenance service affect positively?

It turns out that this is a whole variety of possibilities, ranging from performing relatively simple operations and maintenance—repair and alignment or balancing, the use of advanced methods of technical diagnostics, correct lubrication, purchasing and strategy adopted to maintain the machines.

For example, shaft misalignment can lead to a 12 % increased energy consumption and incorrectly matched or worn clutch to a 4 % loss. Replacing the gear belt pulleys belts of traditional high performance enables a new generation of 2–4 % energy savings. The use of machinery and equipment drives energy-efficient bearings allows for 30 % reduction in friction and the machines can get 15 % higher speeds. The responsibility of maintenance services is also connected with choosing strategy of maintenance and correct strategy is directly linked to the mitigation of impacts on environment by ensuring the regular monitoring of performance of the machine by means of technical diagnostics tools, the elimination of major accidents and to prevent interruptions in the production cycle, focusing on the overall equipment effectiveness (OEE). In addition, maintenance is a process whose results can be seen in the measurable values and expenditure is relatively easy to manage. All this makes that to the businesses that apply the so-called 'good engineering practice' to maintain machinery is not only a cost to be avoided, but also an active action which could constitute an effective contribution to the development of the company.

The maintenance management has a variety of tools that enable participation of technical services of an organisation in all phases of a machine life cycle, and thus, participation in the performance of pro-environmental strategy of the organisation (Fig. 2).

The first stage of a product's life cycle is its design. Basic pro-environmental prerequisites of the designing phase of a technical object include implementation of the '3R' principle (reduce, reuse, recycle), and in particular: selection of structural materials with regard to environmental burden following their degradation, considering the possible reuse of the materials once the operation ends, ensuring high reliability of the machine during operation and possibly low power demand, ensuring the machine and equipment structures are durable, adjusting to repairs, easy diagnostics and service (Cempel et al. 2006).

Total Productive Maintenance (TPM) is a maintenance strategy developed to meet the new maintenance needs (Shetty et al. 2009; Ahuja and Khamba 2008). TPM is based on a "Zero-loss" concept with zero breakdown, accident and defects, to achieve high reliability, flexibility of equipment and reduce cost through minimizing wastage of manpower, raw material, energy, consumables, etc. One of the goals of TPM is to develop maintenance free equipment. One way to do this is to make improvements at the earliest possible stage, thus, at the stage

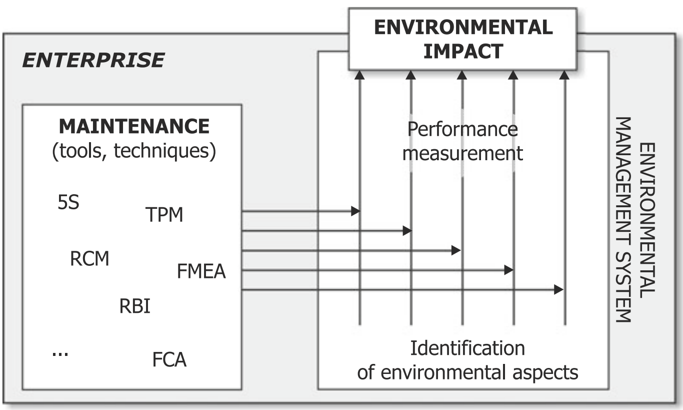

Fig. 2 Maintenance methods and techniques and their environmental impact

of designing. Achievement of the target is reached both by R&D units and engineering organisations. Engineering activity includes evaluation of the project with reference to the entire equipment life cycle cost, its weak points (Table 1). Therefore, benefits or losses may be defined that may result from defined operation and maintenance practice to ensure an ideal level of reliability, accessibility and ease of maintenance.

The next phase of a product's life cycle on which maintenance services have an impact and in which they have a proactive role is the machine's operation phase at the organisation. From the ecological point of view, maintenance of infrastructure in the phase of equipment operation is focused on ensuring systems, procedures and trainings that build the operational knowledge and skills as well as functional possibilities of the systems to prevent, manage and eliminate losses and environmental incidents.

A pro-environmental thinking should start at the operational level, i.e. from the machine and workplace perspective. The most important task for technical services and production personnel is to build a clean and well organised workplace. A solution that is most frequently used in organisations to build the 'cleanness culture' is the Japanese 5S practice. A 5S cornerstone is "the right thing in the right place at the right time"; anything else should be disposed of in a safe and environmentally correct manner. The 5S includes seiri (sort, organisation), seiton (set in order), seiso (shine, cleaning), seiketsu (standardize the cleaning), and shitsuke (sustain, discipline) and referred as the five keys to a total quality environment. The above are the key elements of the overall Management Operating System, including the elements that require managerial attention and whose supervision is only possible through sensor evaluation (e.g. sight, hear, smell).

Table 1 Examples of perspectives for equipment weak points searching

Facilitating autonomous maintenance	Can cleaning and inspection be easier?
	Can lubrication be centralized so that lubricant is supplied at just one or two inlets per equipment unit?
Increasing ease of operation	Can equipment be more resistant to operator errors, such as by changing the positions of switches and the layout of buttons on control panels?
	Can changeover procedure be simplified?
	Can standards be clarified to facilitate adjustments, or can measurement methods be made easier?
Improving quality	Have the precision settings and methods been determined (what to measure, how to measure it, limit values, etc.)?
	Is diagnostic equipment easy to set up? Does it have visual displays?
Improving maintainability	Have equipment life data been collected, and is work in progress to extend equipment life?
	Can parts replacement be simplified?
	Are self-diagnostic functions built into the equipment?
	Can oil supply and oil changing be simplified?
Safety	Are interlocking methods safe?
	Are there safety fences around hazardous equipment?

From the ecological perspective, 5S draws attention to all uncontrolled wastes and emissions that deviate from the standard, it fosters reasonable power consumption and gives a start to create and maintain standards for the working environment, introduces a change in culture. Table 2 presents examples of actions and potential benefits relating to 5S implementation.

In different organisations environment management and operational procedures are often independent of each other and are not available at workplaces. 5S practices assume a visualization of both the elaborated standards and maintenance performance. Visual management (laminated procedures at workplaces, performance boards, warning signs, etc.) may be used to improve designation of hazardous materials and waste and to improve the employee knowledge as regards the appropriate proceedings in terms of waste and emergency situations (Fig. 3). The combination of visual impulses, 5S practices, and operational procedures gives the employees a real chance of proceeding as per the applicable standards and improving of the environmental management.

In the phase of a technical structure operation in an organisation, the efficiency of maintenance actions depends on good cooperation between the machine and equipment operators and technical services staff. The cooperation is possible on the condition that both parties understand their own tasks as well as the task of the opposite party.

In real world the relation between the production and maintenance are regulated by the culture of mutual guilt. In case of failure it is the production that blames maintenance for indolence during the repair of damaged equipment, incorrect repair performance, lack of coordination of preventive actions with the production, etc. Whereas the maintenance blames the production for improper use of equipment, failure to report any damage symptoms leading to failing by the technical service to prevent such damages, etc. Such behaviour results in misunderstanding and conflicts whose tangible indicator is an increased failure frequency, low efficiency of use of the production equipment, low timeliness of repairs, large quantity of raw material waste (quality non-conformities of the products), energy loss, etc.

Breaking of the vicious circle (mutual blaming of the parties) is a prerequisite to carry out the strategy of maintenance, which on the one hand maximizes the availability and efficiency of equipment, controls the pace of equipment degradation

Table 2 Potential benefits of 5S

5S practice	Potential benefits
Sort	Improved use of space, reduced stock, reduced cost and more efficient work.
Set in order	Shortening of the task completion time, easier access, less errors, improved safety.
Shine	Clean workplaces and equipment, improved efficiency of machine and equipment operation, improved working environment and its surroundings, reduced amount of pollution and dirt.
Standardize	Improved working conditions and its quality, improved safety, reduced number of non-conformities (during task completion).
Sustain	Increased productivity and creativity, aiming at improvement and perfecting, adherence to agreements.

Fig. 3 Proper storing of dangerous chemicals

processes, and ensures environment safe and friendly actions, minimizing the total cost of operation on the other. Solutions may be found in teamwork and training whose objective is to provide knowledge and skills for operators and to include them in proactive preventive maintenance actions.

Preventive maintenance of machine and equipment is related to carrying out of a series of actions before a failure occurs. Its effectiveness depends not only on the quality of works performed by technical personnel but also on the speed and quality of information provided by the operators. Early identification of anomalies in machine operation is a necessary skill that should be built. The skill includes:

- first: ability to set the machine's parameters and conditions of work (to know how to tell normal conditions from abnormal),
- second: ability to maintain the machine's parameters and conditions of work (to know how to ensure satisfaction of normal conditions),
- third: ability to bring back the machine's parameters and conditions of work (to know when to react to abnormalities).

A program that builds such skills is the 'autonomous maintenance' carried out in organisations in relation with the implementation of the TPM. The program assumes providing operators with knowledge on the structure and principles of operation of the equipment they use and building basic skills for correct machine operation evaluation as well as performance of basic operation that is traditionally perceived as technical personnel task.

When introducing the concept of autonomous maintenance of machines and equipment, it is recommended to use the seven steps method (Table 3).

The aim of autonomous maintenance by the operators is:

First: stability of working conditions for the equipment and stopping the equipment degradation process, forming of the operator skills to perform daily routines (e.g. cleaning, lubricating) and small repairs,

Second: providing operators with knowledge on the equipment which they operate, possible problems that may occur and their reasons, as well as preventing such problems through early identification and elimination,

Third: preparing operators to proactive partnership and participation in programs (projects) of the equipment effectiveness and reliability improvement.

Including operators in the works pertaining to maintenance and handing over of responsibility and licenses to them enables better use of the knowledge of the equipment they hold, strengthens the feeling of self-esteem and enables aware participation in the organisation's target achieving.

Nevertheless, irrespective of how well the operators and technical personnel are prepared to observe current operation of the machine and identify deviations from standard conditions, equipment failures will happen and consequences thereof will pose a threat to maintenance and production quality, natural environment, human health and safety. Therefore, in the phase of operation it is necessary to have the knowledge of the machine functional failure's environmental impact and the selection of adequate operation actions and the condition monitoring system.

The methods of maintenance planning based on the identification and assessment of risk relating to equipment failure, enable planning of the production equipment maintenance in appropriate context (Narayan 2012).

Maintenance framework based on the risk assessment covers two main activities: risk assessment and technical service planning based the risk. The main objective of such activities is to reduce the overall risk that may lead to unpredictable failures. Priorities of operational actions (inspection, maintenance) are defined according to the quantitative analysis of a risk caused by failing sets of machines so that the total risk is minimized. The sets which as a result of the analysis have been classified as high risk are inspected and maintained more frequently and more accurately to ensure keeping of the allowed risk level. Organisations are more likely to promote maintenance in accordance with risk assessment. Such an approach enables defining of the appropriate proportions among individual maintenance policies, considering not only financial but also environmental and social issues (human safety).

The most frequently applied method in this area is the Reliability Centered Maintenance—RCM (Moubray 1995; Crocker and Kumar 2000; Mokashi et al. 2002; Niu et al. 2010). In the RCM analytical process all functions of any technical system, errors in performing these functions (damages) and all potential reasons

Table 3 Seven steps of “autonomous maintenance” introduction

Steps	Goals for equipment
Conduct initial cleaning	Eliminate environmental causes of deterioration, such as dust and dirt; prevent accelerated deterioration. Eliminate dust and dirt; improve quality of inspection and repairs and reduce time required. Discover and treat hidden defects.
Eliminate sources of contamination and inaccessible areas	Increase inherent reliability of equipment by preventing dust and other contaminants from adhering and accumulating. Enhance maintainability by improving cleaning and lubricating.
Develop cleaning and lubrication	Maintain basic equipment conditions (deterioration-preventing activities) cleaning, lubrication, and inspection.
Conduct general inspection skills training	Visually inspect major parts of the equipment; restore deterioration; enhance reliability. Facilitate inspection through innovative methods, such as serial number plates, colour instruction labels, thermo tape gauges and indicators, see through covers etc.
Conduct inspection autonomously	Maintain optimal equipment conditions once deterioration is restored through general inspection. Use innovative visual control systems to make cleaning lubrication/inspection more effective. Review equipment and human factors; clarify abnormal conditions. Implement improvement to make operation easier.
Organise and manage the workplace	Review and improve plant layout etc. Standardize control of work-in-process defective products, dies, jigs, tools measuring instruments, material handling equipment, aisles, etc. Implement visual control systems throughout the workplace.
Carry out ongoing autonomous maintenance and advanced improvement activities	Collect and analyze various types of data; improve equipment to increase reliability, maintainability and ease of operation. Pinpoint weaknesses in equipment based on analysis of data, implement improvement plans to lengthen equipment life span and inspection cycles.

for damage are being systematically identified, then direct effects of the above are identified, and finally, significance and consequences thereof (Fig. 4).

In the evaluation of consequences the RCM assigns any damage to one of the four categories that should be considered when elaborating the logical, decisive diagrams (‘trees’): hidden failures that may lead to multiple failures and in extreme cases to

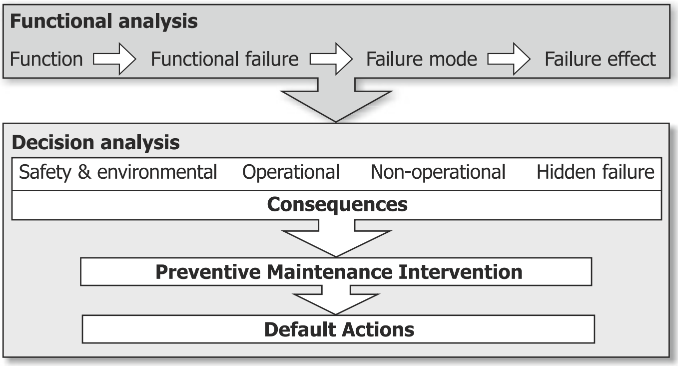

Fig. 4 The RCM process (Hipkin and Cock 2000)

catastrophic results, and open failures having an impact of human and/or environment safety, operational activity, and those which have no impact on operational activity (after a series of ecological catastrophes in the 1980s, drastic pro-ecological restrictions were introduced against business organisations in many countries; ecological consequences have gained appropriate importance in the RCM method). When all the information is provided, depending on the critical level of the failure, the most relevant maintenance policy is applied for the analyzed technical structure and specification of operational activities is created—whether preventive or not. These activities form a program of maintenance of the structure in a desired functionality adjusted to required operational parameters. Unlike other maintenance methods, the RCM allows for all options of activity: caused by diagnosed condition of the equipment, scheduled maintenance, scheduled component replacement, searching the hidden failures and single modifications (re-designing of components, change of operational procedures, additional operator training or other activities beyond the traditional scope of service works). One of the original conclusions arising from the analysis is also intentional allowing the failure to occur.

Risk based inspection (RBI) is a methodology which aims at establishing an inspection programme based on the aspects of probability and consequence of a failure. Inspection is carried out to reveal and confirm whether the process of degradation in a component is occurring. Inspection of the equipment will also give vital information on how the real process is developing compared to the expected scenario. This information can be used to define new measures to improve both the design of the equipment and the actions that are taken to preserve the risk level of the component. By conducting an RBI analysis the final results should answer what to inspect, when to inspect, where to inspect, how to inspect and what to report (Fig. 5).

The RCM process uses Failure Mode and Effect Analysis (FMEA). It is a deductive technique that consists in identification of failures at different levels of the machine structure complexity, their reasons and consequences to the entire system. The FMEA is focused on assessing the risks of Occupational health and

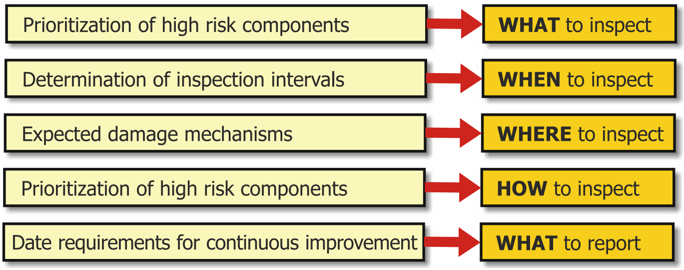

Fig. 5 Deliverables of an RBI assessment to the inspection program (DNV 2009)

safety (OHS), environment and quality management, which is based on three aspects, including "occurrence of failure" (indicating risk/probability that failure mode will occur as a result of a specific cause), "severity" (referring to an assessment of the seriousness of the effect of the potential failure mode in the process when it has occurred), and "detection" (referring to the probability that a potential failure will be detected).

FMEA analysis may be used both for the process of machine and equipment designing and for operation of machines and equipment and operation thereof, where based on historical data on the machine performance, analysis of the use environment, currently applicable legal requirements, it allows to identify possible non-conformities, their grounds and effects and to select appropriate preventing actions. In the context of environmental management the method will enable:

- systematic testing of internal environment protection and legal requirements,
- focusing on the most important activities to improve the condition of natural environment,
- delivering and influencing the most important environmental aspects,
- making aware environmental impact implementation easier.

Another tool employed to analyse reliability and safety of a system is fault-tree analysis (FTA). It provides an objective basis for analyzing system design, justifying system changes, performing trade-off studies, analyzing common failure modes, and demonstrating compliance with safety and environment requirements. It is different from a failure mode and effect analysis in that it is restricted to identifying system elements and events that lead to one particular undesired event.

Many reliability techniques are inductive and concerned primarily with ensuring that hardware accomplishes its intended functions. Fault-tree analysis is a detailed deductive analysis that usually requires considerable information about the system. It ensures that all critical aspects of a system are identified and controlled. This method represents graphically the Boolean logic associated with a particular system failure. Fault-tree analysis provides options for performing qualitative and quantitative reliability analysis. It helps the analyst understand system failures deductively and points out the aspects of a system that are important with respect to the failure of interest.

The universal objective of the maintenance process is to use the knowledge of abnormalities in machine operation and of incidents (both potential and occurring) in order to achieve optimum safety, from the point of view of people and environment, at the lowest possible cost. In industrial practice this transforms to optimisation of decision making processes concerning planning and completion of functional and servicing-and-repair works. Planning of technical service at a high level may be successful if it is based on reliable data from the operation level. This makes monitoring of the production equipment condition a key factor to support a balanced production.

A majority of machines may be monitored on continuous basis without stopping. Permanent monitoring and diagnostic systems ensure high stability and repetitiveness of the measuring process and allow uninterrupted analysis of measured values and detection of any excess of the preset limits. One of the important advantages of the continuous systems is the possibility of integration with control systems of the monitored machine, central control system, and visualization of the measured values in Supervisory Control and Data Acquisition (SCADA) systems or a superior, specialized diagnostic software. SCADA systems are currently standard elements of the machine monitoring systems. Their basic task is to acquire and visualize measuring data that describe current condition of the monitored machine and to generate warnings and alarms whenever machine working parameters exceed the preset levels. In case of failure, SCADA, as a superior system, offers a possibility of stopping the machine, its part or the entire technological line to minimize the failure spreading. Filing of measuring data—both during regular work and in alarm situations—is, however, from the maintenance perspective, only 'a raw material' that should be processed to get the valuable information. This processing is performed by specialized diagnostic software. An analysis of collected data concerning equipment operation parameters in combination with working conditions information (start-up, idle run, overload, etc.) requires extensive calculation expenditures such as frequency, modal analysis or modelling. With such a tool it is possible to relatively precisely define the condition of a given element or even define which failure of a given part may be expected or had already occurred. A well prepared monitoring system allows precise determination of the time a machine is withdrawn from operation, thus, eliminating raw material (non-conformant products), and energy losses and extending to the maximum the machines operation time, resulting in tangible financial benefits.

Another tool in the hands of technical personnel are diagnostic and forecasting test methods (Mikołajczak 2011) e.g. vibro-acoustics, vibration measuring, thermo-vision, oil analysis. Technical diagnostics, next to tribology, reliability, safety theorem and operation theorem, is one of the basic sciences on rational use of objects (Żółtowski 2008).

The objective of oil diagnostics is defining the usability of the used oil on the one hand, and checking whether is contains metallic particles that would prove wear of certain elements of the equipment, on the other (Szafrański 2011). From

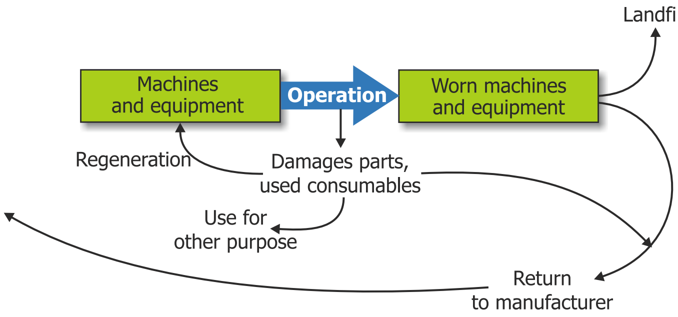

Fig. 6 'Abandonment' phase in a product's life cycle

the environmental perspective lubricants are non-renewable products. By maximizing their life span we reduce the organisation's negative environmental impact, minimize financial burden related to their disposal. Appropriately selected lubricant may have an impact on the increased level of equipment operation stability. Diagnostic tests of this area give only a small example of an organisation's possibilities to reduce environmental impact. Rational lubricating management should cover all activities, from oil selecting, through its storing, delivery to machine, its maintenance during operation, appropriate machine tooling (venting, drainage) adjusted to the conditions in the machine working environment, well designed oil analysis system, etc. As experiments show, improving actions in the area of lubricating management may lead to wear reduced by even 30 % (Jasiulewicz-Kaczmarek 2013).

Abandonment is the last phase of a machine's life cycle consisting in final withdrawal from operation. It is a condition when the machine reached its limit value of wear and further operation is impossible or uneconomical. The problem of managing of the worn parts and materials from the abandoned machine with the minimum burden to environment and certain economic result arises (Fig. 6).

Eco-design that has been developing for years is an approach where complex technical objects are designed so that recycling of materials, from multiple uses and reuse of elements (assemblies, parts) in several generations of machines for repair and modernisation is possible. Therefore, the object's abandonment phase requires taking steps resulting not only in transporting the machine to a landfill but also reuse of its elements. Each worn machine or equipment contains a series of valuable raw materials and subassemblies to be reused in repair and renovation of structurally similar technical objects. The task of maintenance personnel is to appropriately assess the fitness of assemblies and parts for other machines and equipment owned by the organisation and repairing or regenerating thereof for further use.

Despite their environmental arduousness, worn machines and equipment may constitute a source of valuable recyclables once reasonably recycled.

4 The Idea of Maintenance Performance Assessment from the Perspective of Environmental SD

Holistic approach to shaping maintenance system should include internal and external conditionings of a company, business strategy of the company and projection of how future changes in maintenance system will influence efficiency of company's functioning (Pawlowski et al. 2006).

All the aforesaid areas of activity of technical personnel must be covered by one coherent system of management where the goals, roles and tasks are defined and which is coherent with the strategy, needs and possibilities of an organisation.

The objectives of maintenance and the strategy of achievement thereof derive from the requirements of interested parties as well as goals and strategies of the organisation (Pinjala et al. 2006; Rosqvist et al. 2009), integrated at different levels of its organisational structure both top-down and bottom-up. The natural consequence is the need of designing and implementing a well-organised maintenance management system and a measuring system to assess its performance in terms of strategy. According to Alsyouf (2006) such a system should enable:

- evaluation of the maintenance function share in the organisation's business goals achieving;
- defining the strong and weak points of the implemented maintenance strategy;
- creation of stable base to develop a comprehensive strategy of maintenance improvement with the use of quantitative and qualitative data;
- re-analyzing and comparative analyzing of the implemented practices and maintenance performance with the best practices within and outside the same industry, and
- tracking the maintenance impact and indicating the relations between operational and financial activities (measures) in a holistic approach.

From a strategic point of view the process of maintenance management may be presented as a sequence of actions transforming the strategic goals into maintenance objectives and a strategy of achieving them, with a built-in system of performance metric that would enable assessment of efficiency and effectiveness thereof (Fig. 7).

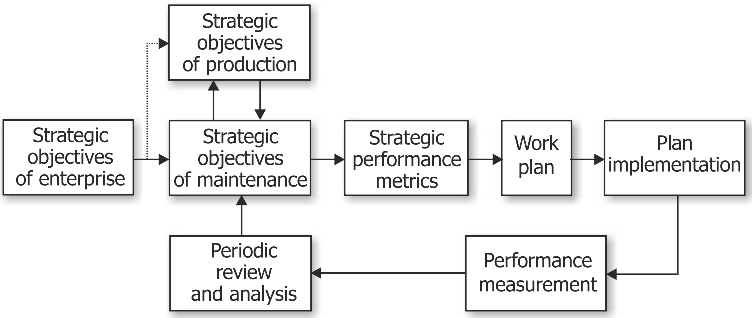

Fig. 7 Strategic maintenance-management process

A true challenge for maintenance management is to define the method of goals down-cascading, feedback up-aggregating, and integrating of activities performed by different internal organisation units of the organisation, so that the total effectiveness of maintenance and the desired business goals are achieved. This means that an organisation should define a hierarchy of goals where the maintenance objectives (e.g. 98 % availability of equipment) are means to achieve the overall organisation goals (e.g. production volume 5 tons/h).

Measuring of maintenance performance is an indispensable activity that may, for example, serve defining of the adjustment to new trends in equipment use and maintenance strategy, evaluation of employee safety and health caring, and meeting environmental challenges resulting from the organisation strategy.

Literature gives many examples of the concept of maintenance performance measuring. The Total Productive Maintenance concept (Nakajima 1988), launched in the 1980s, provided a quantitative metric called Overall Equipment Effectiveness (OEE) for measuring productivity of manufacturing equipment's (Jasiulewicz-Kaczmarek 2011). A hierarchical system of performance indicators of maintenance efficiency and the classification thereof referred to three main dimensions of maintenance performance (OEE, production costs and production quality) was proposed by Komonen (2002). Parida proposes a multi-criteria hierarchical framework for maintenance performance measurement (Parida and Chattopadhyay 2007) that consist of multi-criteria indicators for each level of management (i.e. strategic, tactical and operational). Al-Najjar (2007) proposes a model to describe and quantify the impact of maintenance on business's key competitive objectives related to production, quality and cost.

In 2007 the European standard for maintenance key performance indicators (EN: 15341 2007) was established to support the management in making the best use of the maintenance function in order to utilize all the technical assets in a more competitive way. The indicators can be used to measure the status, compare (internal and external benchmarks), diagnose (analysis of weaknesses and strengths), identify the objectives or goals, support to maintain and improve performance and continuously measure the evolution. The standard provides the management with a system of indicators to measure the maintenance performance considering the economical, technical and organisational aspects (Fig. 8). Maintenance Performance is the result of the utilization of resources in doing activities to provide actions to retain an item in, or restore it to, a state in which it can perform the required function. The Maintenance Performance is depending on influencing factors—external and internal, such as location, company culture, production process, strategies, policies and human competences—and is carried out implementing activities (example: corrective maintenance, preventive maintenance, improvements), using organisational methodologies (example: centralized, decentralized, outsourced, multiskilled, etc.), utilizing labour, information, materials, resources, tools and operating techniques.

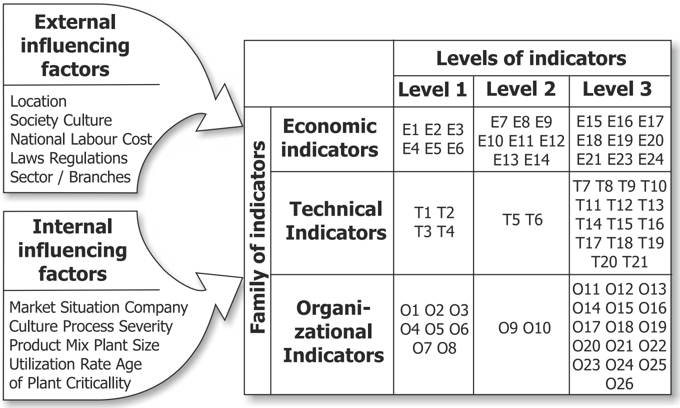

Fig. 8 Maintenance influencing factors and maintenance key performance indicators (EN: 15341 2007)

Exemplary "environmental" indicators of maintenance in this set are T12 and T13.

T12	$\frac{\text{Number of failures causing damages for environment}}{\text{Total number of failures}} \times 100$
T13	$\frac{\text{Number of failures causing potential damages for environment}}{\text{Total number of failures}} \times 100$

Many organisations find the set of indicators provided in the standard too complicated and incomprehensible. With reference to the environmental dimension of maintenance activities it is difficult to find a relation between the organisation goals and strategy and the maintenance indicators.

One of the recommended methods is the Balanced Scorecard (BSC), considered to be a balanced management system because it promotes equilibrium between short- and long-term objectives, between financial and non-financial measures, between indicators of tendency and occurrences, between internal and external perspectives of performance (Goncalves 2009). The balanced scorecard, developed by Kaplan and Norton (1992), is the most popular and balanced performance measurement framework, used by the most of industries all over the world (Quezad et al. 2009; Thakkar et al. 2007; Lawrie and Cobbold 2004; Akkermans and van Oorschot 2005). Unlike the traditional methods that focus on supervision, BSC is focused on the overall strategy and vision of the organisation and emphasizes achieving of target results.

Application of BSC gives an opportunity of better conformity between the goals worked out in the process of Environmental Management System and the organisation's strategy (Zingales et al. 2002). To obtain such a conformity the

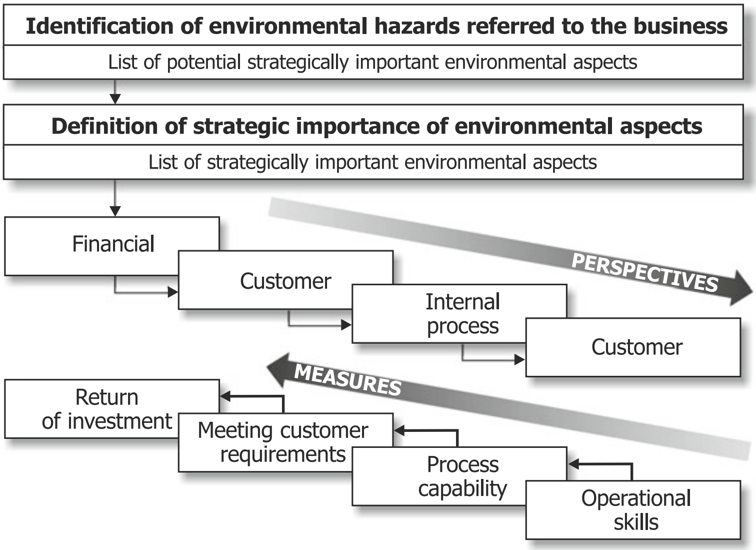

Fig. 9 The chain of cause and effect relationship from environmental BSC perspective

environmental aspects must be classified and integrated with the scorecard system depending on their strategic meaning, similarly to all potentially important strategic aspects (Fig. 9).

Environmental aspects can represent strategic core issues, for which lagging indicators have to be defined. These lagging indicators measure whether the strategic core requirements in the perspective have been achieved. Performance drivers as represented by leading indicators show *how* the results in each perspective, reflected by the lagging indicators, are to be achieved. Performance drivers are highly business specific but there are once again categories to support identification.

Figge et al. (2002) proposed to check systematically all pertinent environmental aspects by answering the following questions when going through the four conventional perspectives:

1. Does the environmental aspect represent a strategic core issue for the of our business unit (→ environmental lagging indicator)?
2. Does the environmental aspect contribute significantly to a strategic core issue and therefore represent a performance driver for the business strategy of our business unit (→ environmental leading indicator)?
3. What is the substantial contribution of the performance driver to the achievement of a strategic core issue?
4. Is the environmental aspect simply a hygienic factor, which necessarily has to be well managed but leads to no particular strategic or competitive advantage?

BSC is specific of organisations for which it was developed and allows building Key Performance Indicators to measure technical personnel management

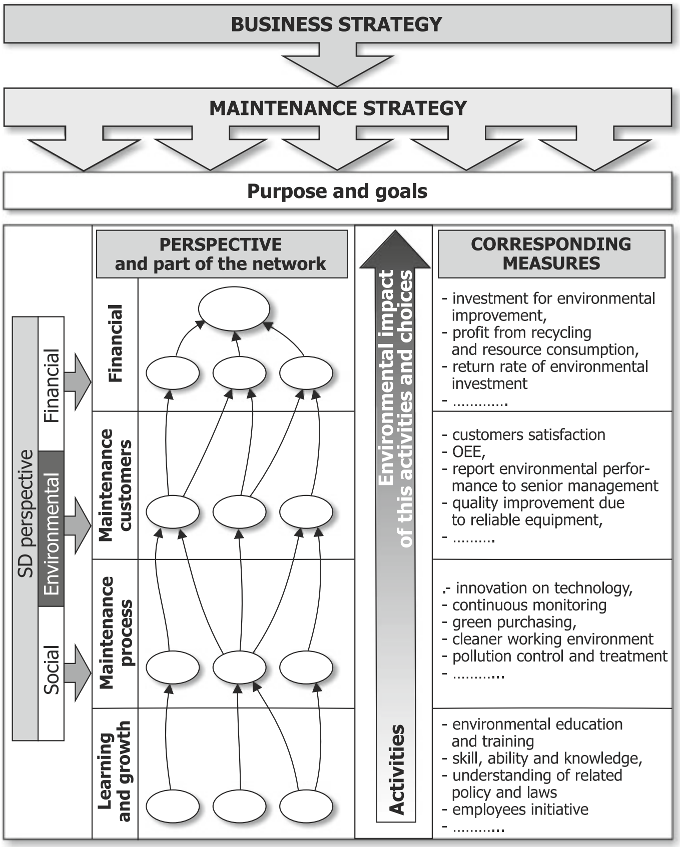

Fig. 10 Environmental Maintenance Balanced Scorecard (*EMBSC*)—a model concept

performance, referred to the organisation's strategic goals (Jasiulewicz-Kaczmarek 2012). The environmental dimension of maintenance may be described by each of the four Balanced Scorecard perspectives, for instance (Fig. 10):

- financial—meaning, for example, return of the capital invested in new diagnostic technologies,
- maintenance customers—meaning satisfaction of requirements and delivery of value mainly to internal clients (e.g. production),
- maintenance process—including but not limited to prevention of failures, identifying and implementing modifications to production equipment, management of materials, power and waste as eco-efficiently as possible,
- organisational (learning and growth)—meaning creating a new culture that values knowledge and skills, involvement in improving actions, which is reflected in maintenance, production, logistics, etc., employee daily choices and actions.

Strategic objectives of maintenance are a collection of goals and each new perspective focuses on processes that are important to achieve the goals determined in the previous perspective. In the financial perspective the stress is put on the measure of return rate from invested capital. The factor influencing the above measure is customer satisfaction expressed by the level thereof. Internal customers' satisfaction is related with cooperation conditions offered by technical personnel and the quality of services they render. All actions and decisions taken by maintenance management must conform to the needs of maintenance internal clients (maintenance is a supportive process). To react adequately to the needs and expectation of its customers, maintenance personnel must improve the parameters of service and method of delivery thereof.

The maintenance customers' perspective contains two measure groups: area activity results measure and measure of factors determining the value for customers. Service value deterring measures may be divided into service attributes (e.g. quality) and customer relations (e.g. time of service completion).

The internal processes perspective is a logical supplement of the customer perspective as regards maintenance activity assessment. In this perspective the key activities and processes influencing achievement of objectives set in previous perspectives are identified. Internal processes are assessed in terms of whether they meet customer expectations. After identifying the internal processes that are crucial from the customer perspective a metering system may be identified.

The last but not least of the perspectives (learning and growth) covers objectives and measures that determine area in which perfecting is expected in order to reach a major improvement in performance. The learning and growth targets form a basis supporting the completion of goals covered by the three remaining perspectives. When analyzing the learning and growth perspective grounds on which the long-term growth is to be based must be determined. Investment in employees, IT technologies and appropriate organisational procedures are required for a long-term and stable development.

The EMBSC model presented in the figure is an attempt of showing the importance and contribution of maintenance in the pro-environmental strategy of an organisation. Maintenance is able to create new productivity and help saving raw materials and energy, protect environment and increase profits in the industrial production. The value of such actions is countable and must be measured both in terms of management assuming responsibility for achieving the goals they set and identifying appropriate actions as well as directing the effort of employees to such achievement.

5 Conclusion

Maintenance, similarly to other functional areas of an organisation, is under constant pressure of cost cutting, achievement reporting, and mission supporting. From the point of view management these seem to be reasonable expectations because maintenance, as an auxiliary process, plays an important role in the organisation's operation. However, looking onto the activities of technical services from the perspective of a product life cycle one may notice new opportunities of strengthening the organisation's eco-effectiveness.

Practically, each phase of a product's life cycle requires maintenance. When designing a technical structure, one must allow for its total and comprehensive environmental impact. It applies not only to the use of such a structure/building but also all actions relating to maintenance thereof: lubricating, maintenance and repair. At this stage it is the knowledge acquired from organisations using the structures that matters. By monitoring the operation of equipment and performing technical servicing, maintenance service of such an organisation is a source of information on the potential to increase environmental effectiveness and often initiates changes to the building structure.

Another phase of a product life cycle that may be influenced and is actively participated by maintenance service is the stage of machine operation. From the ecological point of view, maintenance of infrastructure traffic in this phase is mainly focused onto two aspects. Firstly, by ensuring systems, procedures, and training that build the operators' skills and operational knowledge. Secondly, by ensuring material, technical, IT, and financial resources. These actions aim at prevention, management, and elimination of losses and environmental incidents when using technical buildings for manufacturing purposes.

Having such a potential of pro-environmental possibilities of maintenance, it would be highly irresponsible on the part of the management to ignore them in the process of defining an organisation's target and strategy. Therefore, the need to integrate the objectives and strategies of maintenance with the environmental objectives and strategy is obvious. How to do it?

The tool proposed herein is EMBSC. Why this tool? If we look at the scope of relation between maintenance and other functional areas of an organisation and effects desired by management we will see as follows. Eco-effectiveness is desired and expected. It may be achieved by meeting the requirements of our internal (e.g., production) and external stakeholders (although for external stakeholders maintenance actions are not visible, while the results and effects thereof are perceptible). If one wants to meet the requirements, maintenance processes must be adequately organised and then well managed. This needs people's knowledge and involvement. Thus, moving from top to bottom, we have logically passed the path of all BSD perspectives. The bottom to top order looks similarly, but here we measure the results/effects being the natural consequences of measures/decisions that were taken. One may, therefore, form cause and result relations between actions and their results and quantify the values thereof. BSC also gives an opportunity to quantify as quantity, quality, finance and non-finance, offering another important function—communication. Technical language is usually incomprehensible for economists, while the economists' language seems to be difficult to understand by engineers. This inconvenience and possible cause of conflict may be eliminated.

What else could be achieved by using the tool? For many years maintenance has been perceived as a ‘cost’. This has been partially true, as it is an auxiliary process. Therefore, from an external client’s perspective maintenance does not add value. However, from an internal client’s perspective, today maintenance is a business partner. Through provision of a reliable machinery and reduction of operational risk, maintenance generates internal value that may be included in financial indexes. EMBSC enables to understand the meaning of maintenance inside an organisation and the contribution it makes to increase the ecological effectiveness. The most often, reports on achievements are submitted to authorities and external supervision units and local personnel are not appropriately informed.

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