Sustainability: Orientation in Maintenance Management—Theoretical Background

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Abstract New concepts and approaches to corporate management, such as Lean Manufacturing, new challenges connected with natural resources management (Green Manufacturing), and thinking in a sustainable way (Sustainable Manufacturing) resulted in developing new approach to maintenance management as well. Contemporary maintenance is not only a set of operations focused on dealing with breakdowns and failures and conservation of machines and devices. Nowadays, it is more like long term strategic planning which integrates all the phases of a product lifecycle, includes and anticipates changes in social, environmental and economic trends, benefits from innovative technologies. Thus, it is necessary to include sustainable development category into processes and activities realized in the area of enterprise's technical infrastructure maintenance.

1 Introduction

According to the World Commission of Environment and Development (1987) sustainable development is that which "meets the need off the present without compromising the ability of future generations to meet their own needs". Therefore, sustainable development is about reaching a balance between economic, social, and environmental goals, as well as people's participation in the planning process in order to gain their input and support (Sneddon et al. 2006). For company sustainable development means adoption of such business strategy and such actions that contribute to satisfying present needs of company and stakeholder, as

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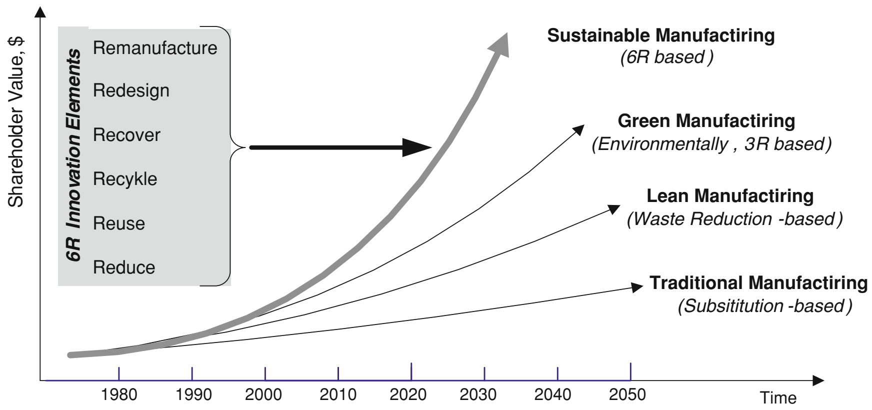

Fig. 1 Sustainable Manufacturing [adopted from (Jawahir 2007)]

well as simultaneous protection, maintenance and strengthening of human and environmental potential which will be great value in the future. Manufacturing businesses can contribute to this effort by designing products and production systems that have only a slight or optimally low impact on the natural environment in terms of resource depletion, waste emissions, energy usage, and other impacts (Michaelis 2003).

Since sustainable development is becoming an increasingly popular concept, there is a growing need to ensure the possibility of its implementation. The way to help companies improve their economical, environmental and social performance is by (Kopac 2009):

- minimizing production of waste—less waste generated and increase waste re-usage or recycle,
- using resources such as materials, water and energy efficiency,
- avoiding or at least improving management of metalworking fluids, lubricating oils and hydraulics oils,
- improving environmental, health and safety performance,
- adopting lean manufacturing and other sustainable engineering techniques,
- improving working conditions,
- using best practice in the process of producing and maintaining movement,
- training all employees about sustainable practices.

In the manufacturing sector, applying the "6R" concept of reduce, reuse, recycle, recover, redesign and remanufacture can enable improving on the lean (waste reduction-based) and green (environmentally benign) manufacturing strategies to more holistic, sustainable manufacturing to achieve exponential growth in stakeholder value (Jawahir 2007) as shown in Fig. 1.

This innovative solution which applies the principle of systemic approach allows the enterprises to look through a holistic prism at both the external relationships in a supply chain as well as the internal relationships in the context of

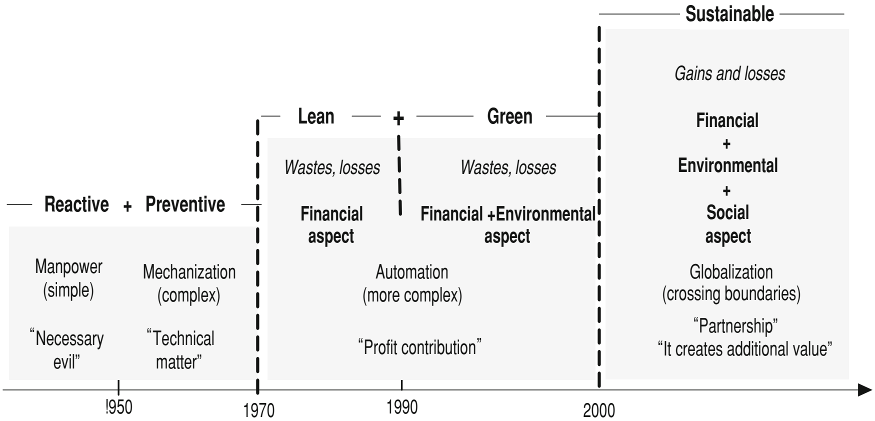

Fig. 2 The evolution of maintenance on a time perspective

implemented processes and resources used. The possibility to use the potential and full capacity of resources is a prerequisite for effective action and obtaining a competitive edge.

A company contains a large number of technical systems which all interact to achieve the pursued business objectives. Maintenance contributes more than ever to the achievement of these objectives. Proper maintenance does not only contribute to lowering the operating costs and extending equipment durability but also positively affects the overall performance of the company.

New concepts and approaches to corporate management, such as Lean Manufacturing, new challenges connected with natural resources management (Green Manufacturing), and thinking in a sustainable way (Sustainable Manufacturing) resulted in developing new approach to maintenance management as well (Fig. 2).

Contemporary maintenance is not only a set of operations focused on dealing with breakdowns and failures and conservation of machines and devices (traditionally the scope of maintenance activities has been limited to the production vs. operation chase). Nowadays, it is more like long term strategic planning which integrates all the phases of a product lifecycle, includes and anticipates changes in social, environmental and economic trends, benefits from innovative technologies (for example e-maintenance, e-diagnostic). Whereas the goal of maintenance is increasing profitability and optimization of total lifecycle cost without disturbing safety and environmental issues (aspects: loss, consequences, benefits).

Thus, it is necessary to include sustainable development category into processes and activities realized in the area of enterprise's technical infrastructure maintenance. Sustainable infrastructure maintenance is focused on prolonging assets use and providing high efficiency of technical systems at optimal resources use.

Hence, in declared and realized by enterprises sustainable development strategy, sustainable infrastructure maintenance is an important element supporting and necessary to achieve the "sustainable" status.

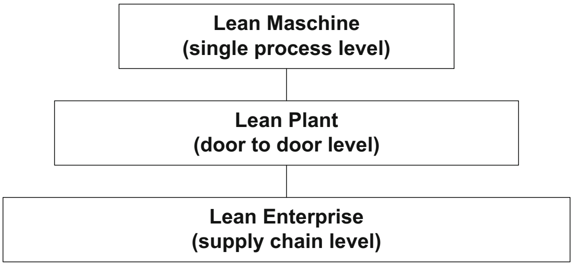

Fig. 3 Different levels of Lean manufacturing. *Source* (Simons and Zokaei 2005)

2 Lean Thinking in Maintenance Activities

Lean manufacturing (LM) is a multi-dimensional management practice including quality systems, work teams, cellular manufacturing, supplier management, etc., in an integrated system (Worley and Doolen 2006). The core motivation of lean manufacturing is that these practices can work synergistically to produce finished products at the pace of customer demand with little or no waste. Waste, in LM, is defined as anything that does not add value to the product or service from a customer's perspective (Taj and Berro 2006). To eliminate waste, LM uses tools such as workplace organization, visual communication and control, quick changeovers, pull system, error proofing, etc. (Seppala and Klemola 2004), (Olivella et al. 2008). Lean thinking tools are used at all levels of enterprise functioning (Fig. 3) and enable effective process improvement, providing a potentially greater value for customers with less effort.

The structure of a manufacturing company has changed from a labour-intensive industry to a technology-intensive, i.e. capital intensive, industry. Lean does not work without highly reliable and predictable machines and processes. A failure in equipment or facilities not only results in loss of productivity, but also in a loss of timely services to customers, and may even lead to safety and environmental problems which destroy the company image. This resulted in a rise of support processes including primarily the process of movement maintenance.

The characteristic of lean thinking, associated with maintenance to improve efficiency and reduce waste, is the use of total productive maintenance (TPM). It is a comprehensive strategy that supports the purpose of equipment improvement to maximize its efficiency and product quality (Willmott and McCarthy 2001). TPM is aimed at zero breakdowns and zero defects which deviate from the specialist maintenance function to improve global consideration, i.e., the operator, the process and environment. TPM tools such as autonomous maintenance, planned maintenance and cross training improve the *effectiveness* of the process (i.e. dealing with the reasons why things do not go according to the plan). This includes frameworks to release capacity, increase control and repeatability.

In many companies LM and TPM work together to provide a holistic approach to achieve continuous improvement driven by progressively removing inhibitors and tuning the complete supply chain (Table 1).

Table 1 The benefits of Lean TPM

Measure	Impact of TPM	Impact of lean thinking
Productivity	Reduce need for intervention Reduce breakdowns	Reduce non-value-adding activities increase added value per labour hour
Quality	Potential to reduce tolerance Control of technology Reduce start-up loss	Highlight quality defects early
Cost	Reduce material, spares	Lower inventories
Delivery	Zero breakdowns Predictability	Shorter lead times, faster conversion processes
Safety	Less unplanned events Less intervention Controlled wear	Less movement, less clutter Abnormal conditions become visible easily
Morale	Better understanding of technology	Less clutter
	More time to manage	Closer to the customer Higher appreciation of what constitutes customer value
Environment	Closer control of equipment Less unplanned events/ human error	No 'over-production' Systems geared to needs not theoretical batching rules

Source (McCarthy and Rich 2004)

Including the category of lean thinking in movement maintenance practices in literature is called Lean TPM (McCarthy and Rich 2004), or Lean maintenance (Smith and Hawkins 2004). Ricky Smith (Smith 2004), defined Lean Maintenance as a "proactive maintenance operation employing planned and scheduled maintenance activities through total productive maintenance (TPM) practices, using maintenance strategies developed through application of reliability centered maintenance (RCM) decision logic and practiced by empowered (self-directed) action teams using the 5S process, weekly Kaizen improvement events, and autonomous maintenance together with multi-skilled, maintenance technician-performed maintenance through the committed use of their work order system and their computer managed maintenance system (CMMS) or enterprise asset management (EAM) system". This promotes achievement of a desirable maintenance outcome with fewest inputs possible. Inputs include: labor, spare parts, tools, energy, capital, and management effort. The gains are as follows: improved plant reliability (availability) and improved repeatability of process (less variation).

Lean maintenance seeks to eliminate all forms of waste (Ghayebloo and Shahanaghi 2010). Ohno (1988) identified seven initial types of waste within manufacturing production (waste from overproduction; waste from waiting inventories; waste from unnecessary transport; waste from waiting times; waste from unnecessary motion (movement of people); waste from unnecessary processes; and waste from defected products) to which Bicheno (Bicheno 2000) added another seven (Fig. 4).

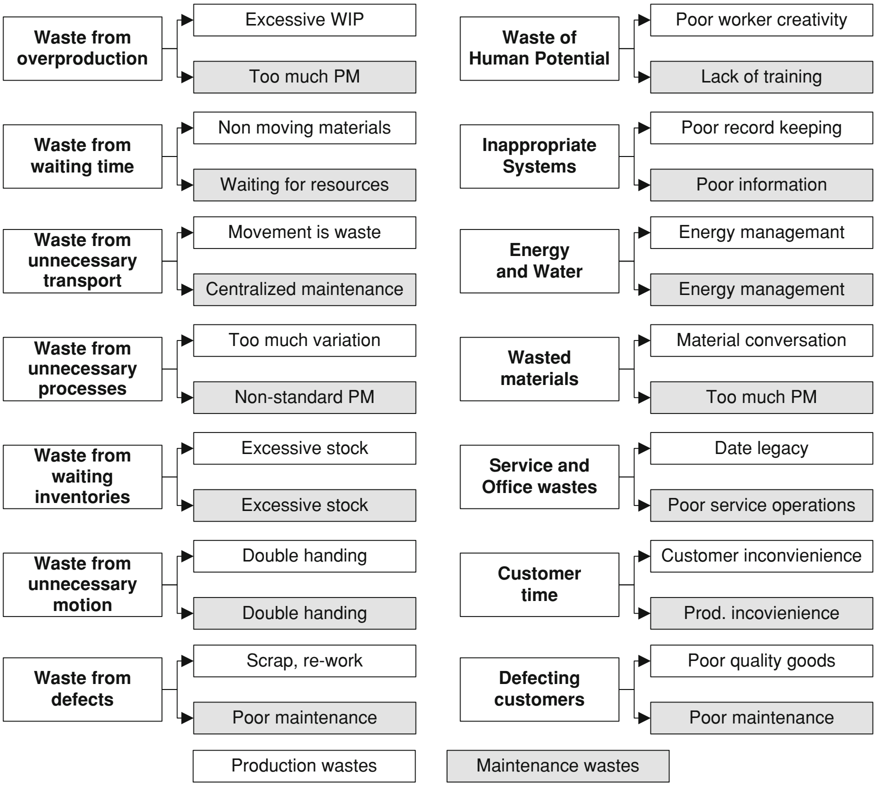

Fig. 4 Lean production waste and analogous waste within maintenance. *Source* (Davies and Greenough 2010)

One of the most important aspects of lean maintenance is developing an understanding of the maintenance processes and activities realized during maintenance processes. This involves evaluating whether each element of maintenance practice used adds value to the product and benefits the customer. In summary Lean maintenance:

- is the proactive maintenance role within the Lean Manufacturing never ending improvement process;
- transforms the role of maintenance from fixing breakdowns to quality improvement;
- raises maintenance standards to first stabilize and then optimize technology performance;
- releases maintainer time from routine activities to focus on long term solutions to technology problems;
- puts the maintenance function at the heart of Lean Manufacturing improvement process (lean maintenance is neither a subset nor a spinoff of lean manufacturing. It is instead a prerequisite for success as a lean manufacturer.

Lean manufacturing and maintenance are both essential and interconnected concepts. Maintenance must improve its ability to improve the value adding capability by delivering stabilized process and equipment performance to reduce unplanned events and waste and by delivering optimized performance to reduce quality defects, cost and delivery lead times. Lean thinking can help maintenance by the application of its proven tools and techniques to target the reduction of waste and non value added maintenance activities (Willmott 2010).

3 Green Thinking in Maintenance Activities

Green Manufacturing is defined by Allwood (Allwood 2005) as a method to "develop technologies to transform materials without emission of greenhouse gases, use of non-renewable or toxic materials or generation of waste" (the term "green", often used interchangeably with "environmentally-safe").

Manufacturing firms that have gone green are finding that it saves them money, because going green will cut down energy costs and can even save money on insurance rates.

By implementing LM companies can reduce wasted products and impact on the environment by 70 % or more. And though the main goal of Lean manufacturing is waste reduction by elimination of activities which are performed when manufacturing a product or providing a service and do not bring value to that product or service, it is close to Green Manufacturing when analyzing outputs and results of these two concepts (Table 2).

When implementing lean within organizations, equipment reliability is the predominant foundational element that enables lean operational performance. Embracing green manufacturing requires giving more focus to environmental and energy concerns during the implementation of reliability improvement projects.

Maintenance in manufacturing enterprise is a key issue and success factor, however in process approach it is usually classified as a process supporting core activity of production. Maintenance process has (or may have) an important influence on quantity and quality of production, but also on safety of people and environment. Because of all that, in enterprise benefiting from so called good engineering practices maintenance is not only a source of costs which should be avoided, but mainly activity which can be an effective input and contribution to enterprise development and be an integral part of green manufacturing called Green maintenance (GM).

In the early 1990s, the concept of GM was proposed, which required the aim of maintenance to be realized by using advanced technologies and equipment at the cost of the least resources and energy consumption, the least waste and environmental impact (Huiqiang and Yufeng 2008).

Practical realization of the concept in an enterprise depends on many factors, both internal (such as maintenance strategy, service performance planning, repairs

Table 2 Lean production losses and environmental aspects

	Overproduction (due to unplanned breakdowns etc.)
Lean production losses	More raw materials and energy consumed in making the unnecessary products
	Extra products may become obsolete requiring disposal
	Hazardous material use may result in extra emissions, waste disposal, worker exposure, etc.
	Extra inventory
	More packaging to store work-in-progress (WIP)
	Waste from deterioration or damage to stored WIP
	More materials needed to replace damaged WIP
	More warehousing costs
	Extra transportation
	More energy use for transport over production
	Emissions from transport
	More space required for WIP
	More packaging required to protect components during movement
	Damage and spills during transport
	Transportation of hazardous materials requires special shipping and packaging to prevent risk during accidents
	Defects
	Raw materials and energy consumed in making defective products
	Defective components require recycling or disposal
	More space required for rework and repair
	Overprocessing
	More raw materials consumed per unit of production
	Unnecessary processing increases wastes
	Waiting for maintenance
	Potential material spoilage or component damage causing waste
	Wasted energy from heating, cooling, and lighting during production downtime

technologies and materials, competences and awareness of employees) and external (such as service capability of equipment).

Service capability of equipment is developer at the design stage, thus machines and devices have to be designed from a holistic perspective benefiting and adding value for all participants, taking functions of technical object, safety, quality, costs and environmental aspects into consideration. Green maintainability should be considered in product design. The negative impacts of maintenance on environment are necessary to be eliminated or weakened by some measures in product design:

- materials choice: the requirements of environmental protection, energy-saving and materials-saving should be considered in materials choice (the reparability and recovery of valuable parts and parts made of rare materials are emphasized),
- structure design: the equipment or structure connections should be realized as possible as simple,

- the reliability study is recommended and the maintenance-free design is extended when the all cost of products in life cycle is considered (for example, the maintenance-free design is proposed to be used for the key equipment).

Realization of GM approach starts at the stage of taking decisions concerning new equipment as it should include environmental issues. Project assessment should be carried out with reference to overall lifecycle cost, thanks to which financial benefits or losses emerging from application of predefined practices in order to provide predefined reliability, accessibility and maintainability level.

The next factor influencing GM realization is maintenance strategy. Maintenance strategy is defined as an interrelationship description between maintenance echelons (on-site, in a repair shop, at the manufacturer, etc.) and indenture levels (subsystem, circuit board, component, etc.) including their maintenance actions (Shyjith et al. 2008). The maintenance echelon is characterised by the personnel skill, the available means and the location. When the indenture level depends on the complexity of an item structure, the accessibility to its sub-items, personnel ability level, test and measure means, safety considerations, etc. Miscellaneous strategies have been put forward for maintenance amongst which the most important ones are corrective, preventive, opportunistic, condition-based and predictive maintenance that considering each one's relevant industry and each of them has advantages and disadvantages (Al-Najjar and Alsyouf 2003; Coudert et al. 2002; Marquez 2005; Mechefske and Wang 2003; Saranga 2004; Sherwin 1999; Tan et al. 2011). The maintenance managers have to select the best maintenance strategy for each piece of equipment or system from a set of possible alternatives (reactive, preventive, proactive). They will not only be aware of the performance implications of the different strategies, they can understand some of the practices necessary to support each of the strategies (Jasiulewicz-Kaczmarek 2009).

Analysis of risk and decrease of uncertainty of assessment are the critical methods of strategic decisions concerning technical safety providing and cost minimization making. The most efficient methods are believed to be RCM (Reliability Centred Maintenance), RBI (Risk Based Inspection) and RBM (Risk Based Maintenance) (Arunraj and Maiti 2007). RCM can be defined as a systematic approach to systems functionality, failures of that functionality, causes and effects of failures, and infrastructure affected by failures. Once the failures are known, the consequences of them must be taken into account. Consequences are classified in: safety and environmental, operational (delays), non-operational, and hidden failure consequences. While RCM goal is to define level (class) of criticality of an analyzed object or element, in RBI and RBM (referring to identical ideas and ways of describing the system, similar classification of functional failures and types of failures as RCM method), attempts to calculate risk are taken.

Risk assessment integrates reliability with environmental and safety issues and therefore can be used as a decision tool for preventive maintenance planning. Maintenance planning based on risk analysis minimizes the probability of system failure and its consequences (related to safety, economic, and environment). It helps management in making correct decisions concerning investment in maintenance or related field. This will, in turn, result in better asset and capital utilization (Faisal et al. 2003).

In technical object exploitation stage, GM realization requires, except from traditional analysis, collecting and analyzing data with respect to their accuracy and environmental impact of service strategy implemented. Frequency of service performance, range of service provided, as well as material, parts, subassemblies applied should be analyzed with reference to their contribution to resources use, reuse, recovery and recycling of wastes (3R).

Technical service planning at strategic/high level can be successful only if it is supported by reliable data from operational level. It makes monitoring of condition of production equipment crucial for efficient GM (Emmanouilidis and Pistofidis 2010). Most machines can be monitored in a continuous manner, without stooping their work. Advance level in solutions available, in the area of vibration analysis, work stabilization analysis, balancing and thermographs helps in achieving perfect "health condition" of machines park. Application of the technical solutions above mentioned enables "listening" to what each machine "says" about its condition and thanks to that early diagnostics of a problem, before it leads to a serious breakdown. If there is a need to perform corrective actions, these tools provide fast and effective response, without any negative influences on production process performance.

Monitoring of a system includes also monitoring of condition of oils and lubricants as they are not renewable. Optimization of exploitation time and performance of oils and lubricants helps to decrease level of negative influence on environment, improves production process, decreases costs of energy, prolongs exploitation time of machines and devices and helps to achieve higher level of reliability. It is reasonable from business point of view. As experience and experiments show rationalization of lubricants management may lead to decrease of maintenance cost even by 30 %. Rational lubricants management has to include all the stages, from choosing the proper oil/lubricants, through its storing, supplying and using, proper machine equipment is important as well (air release, drainage), it should be adjusted to conditions of machine environment, and oil analysis system etc.

Despite maintenance department does not have a direct influence on energy and media use resulting from technology applied but it still can influence and decrease these levels. There are numerous opportunities, starting from implementation of simple services and repairs like for example alignment or balancing and including advanced technical diagnostics methods, purchasing policy or maintenance strategy. For example, problems with transmission shafts leads to 12 % higher energy use and used or inaccurate clutch May lead to 4 % of losses. Exchanging traditional passes in transmission with highly efficient new generation ones leads to energy savings by 2–4 %. The decision on application of EFF1 class engines allows to increase efficiency even by 26 % comparing to traditional electric engine. Application of energy-saving bearings in drives of machines and devices allows to decrease friction by 30 % and these machines reach maximum speed

Table 3 Examples of internal and external benefits from GM practices

Internal benefits	*Economic*
	Environmental fees decrease (for example by waste segregation, decrease of media use),
	Exploitation materials stock decrease (for example by maintenance planning),
	Decrease of CPU (cost per unit) (for example by decrease of energy use in manufacturing process)
	Environmental
	Waste generation decrease (for example by machine parameters control),
	Decrease of technological media use (for example by modernization of equipment),
	Decrease of lubricants use (for example by oils diagnostics)
External benefits	*Economic*
	Decrease of risk of serious failures and break downs by service and maintenance strategies selection based on risk analysis,
	Decrease of penalties caused by failures by developing scenarios and procedures limiting failures range,
	Increased competitiveness of organization (for example by decreased legal risk (coherence with law regulations))
	Environmental
	Elimination or decrease of penalties for improper practices
	Decrease of disturbances and harms for local societies (for example noise, emissions, pollution)
	Reduction of not renewable natural resources—gas, oil, fossil fuels

higher by 15 %. Elimination of leakiness in pneumatic installations, exchanging air system to accurate and high quality ones, using connectors and pipes of low flow resistance and optimization of compressed air system allows for saving up to 10 % of energy. Next factor is a correct choice and exploitation of compressor, especially in the context of compressing oils and pollution. Heat recovery is also important, as it can be used to warm the water in central heating system. In hydraulic systems losses are strongly connected with hydraulic oil flow resistance. Therefore new generation filters of low flow resistance can be used, like for example filters made of fibber glass or metallic net (Jasiulewicz-Kaczmarek and Drożyner 2011).

The areas of GM realization and some examples of practices applied in this area enable companies to achieve numerous benefits, both internal and external (Table 3).

One of the most import ant aspects of GM is introduction of new categories to analysis of service activities. The category is environmental issues. It is connected with assessment concerning influence of maintenance practices on natural environment and possible solutions to limit or eliminate negative influence identified. In summary, Green Maintenance:

- is a pro-active and integrating all the stages of product's lifecycle;
- includes environmental issues in planning and realization of maintenance practices;

- takes potential environmental hazards connected with equipment failures into consideration and introduces risk analysis tools into decisive processes connected with maintenance strategy choice includes maintenance in Green Manufacturing strategy realization (being "green" means realizing 3R in all the processes, main and supporting).

4 Sustainable maintenance

Sustainability in manufacturing is the new necessary paradigm which involves the integration of the economic, environmental and social perspective (known as the triple bottom line) at both operational and strategic levels. The operational level includes tools, techniques and methodologies to enable sustainability in product design and manufacturing, while the strategic level refers to organizational issues such as strategy, structure and culture of a company (Ioannou and Veshagh 2011).

The first step in transforming a company into a sustainable business is to develop a sustainability vision and sustainability strategies that include sustainability objectives. To provide ability of realization and success of the strategy, it has to emerge from resources available (including and stressing human resources), competences and experience of an enterprises as well as processes creating internal supply chain.

One of the key elements of internal supply chain in an organization is maintenance. Creating a sustainable production environment requires, among other things, the elimination of breakdowns and other sources of energy waste. The inadequate maintenance can result in higher levels of unplanned equipment failure, which has many inherent costs to the organization including rework, labour, and fines for late order, scrap, and lost order due to unsatisfied customers (Moore and Starr 2006). This has been one of the decisive drivers for changing the perception that people normally have maintenance from "fail and fix" maintenance practices to a "predict and prevent" mindset.

In contemporary maintenance not only financial aspects should be included. Also the balance between environmental (green) and social aspects of actions realized should be found and kept, and systematic approach to actions, their consequences, results and benefits expected should be applied (Table 4).

Economic, environmental and social dimensions of maintenance are interrelated and any change in the objectives of a dimension greatly influences the other two dimensions. Taking systematic approach as a key principle in building sustainable maintenance enables finding relations between dimensions (Fig. 5):

- economic: for example cost of technical services, investment in new machines, technical diagnostics tools, IT systems etc.;
- social: health, safety, ergonomics, working hours, salaries, satisfaction from work, etc.;

Table 4 The basics for assessing maintenance impact in term of gains and losses. Source (Liyanage et al. 2009)

Assessing impact in terms of *gains*	Assessing impact in terms of *losses*
What is the level of *financial impact* arising from excellent technical condition of systems/equipment of an asset due to effective and efficient maintenance practices?	What is the level of *financial impact* arising from poor technical condition of systems/equipment of an asset due to ill defined and/or poor maintenance practices?
What is the level of *social impact* arising from excellent technical condition of systems/equipment of an asset due to effective and efficient maintenance practices?	What is the level of *social impact* arising from poor technical condition of systems/equipment of an asset due to ill defined and/or poor maintenance practices?
What is the level of *environmental impact* arising from excellent technical condition of systems/equipment of an asset due to effective and efficient maintenance practices?	What is the level of *environmental impact* arising from poor technical condition of systems/equipment of an asset due to ill defined and/or poor maintenance practices?

- environmental: for example recycling, regeneration, minimization of energy, gas, water, waste, air pollution etc., and making optimal decisions from the costs and benefits point of view, hence understanding influence of stakeholders on business decisions and awareness not only of is done but also on how it is done.

The diagram introduced in Fig. 5 is general interactive presentation of relations and interdependencies between dimensions of sustainable maintenance. Thanks to that, both managers and operational level employees can understand better how decisions are made and how they influence dimensions of sustainable development. The decisions may concern for example:

- capital investment—to improve efficiency of employees, increase safety level and ergonomics in work environment;
- staff training—to provide high efficiency of employees and to continuously improve their awareness and qualifications;
- purchases of new machines and devices—machines differ with service capability, Mount of energy use, raw material consumptions etc.

Sustainable maintenance is a new challenge for enterprises realizing concepts of sustainable development. They can be defined as pro-active maintenance operations striving for providing balance in social dimension (welfare and satisfaction of maintenance operators), environmental (6R) and economic (losses, consequences, benefits). It requires introducing broad analysis concerning loss or putting into risk continuity of enterprise performance (in economic, environmental and social aspect), if maintenance strategy taken and actions realized do not provide required condition of technical infrastructure (machines, devices, installations). Therefore degradation-based anticipation (the pro-activity in maintenance) becomes essential, to avoid failing situation with negative impact on

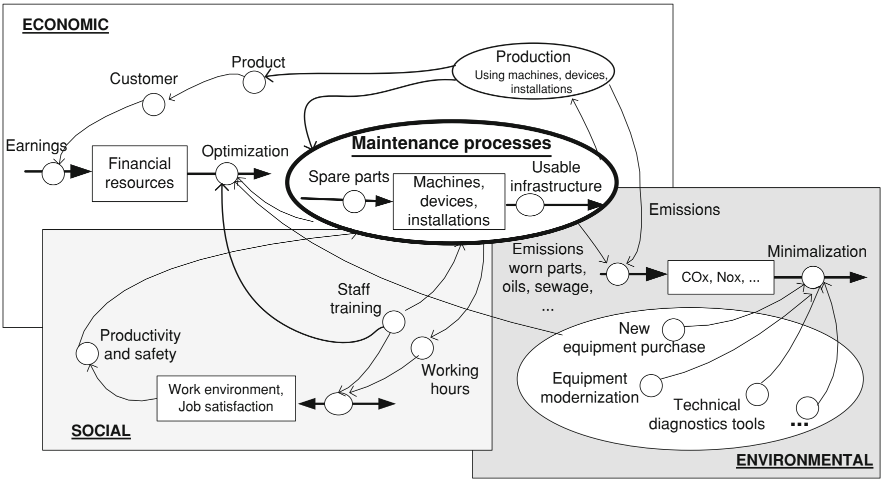

Fig. 5 General model of interdependencies in sustainable maintenance

product condition (zero breakdown maintenance). Pro-activity in maintenance make emerging the E-maintenance philosophy to support "predict and prevent" strategies while keeping maintenance as an enterprise process (holistic approach). E-maintenance is a sub-concept of e-manufacturing and e-business for supporting next generation manufacturing practices.

E-maintenance is emerging from the major changes in maintenance goal needed for supporting the new sustainable and eco-efficiency paradigms. This approach is the synthesis of two major trends in today's society: the growing importance of maintenance as a key technology and the rapid development of information and communication technology. E-maintenance seeks to implement maintenance management, wherein maintenance operations, planning and decisions data and tools to process and act upon them become available anytime, anywhere and to anyone at multiple levels of operation (Levrat et al. 2008; Muller et al. 2008; Gilabert and Arnaiz 2006) (Table 5).

Building sustainable maintenance requires not only considering technical but also social objects. Technical objects, employees and their work environment require keeping in good condition. The social dimension of the sustainable maintenance is very complex and contains many elements. The elements include: safety and health of employees, working hours (number of hours an employee works per week), payments, financial resources spent on training and investments in new equipment and software supporting people in their work.

Human mistakes which are emerging from the lack of knowledge and improper conditions of work and tools in machine work environment (setups, conservation, repairs etc.) might result in hazard to operator and employees in its environment. Many actions taken to support safety in an enterprise are taken after an incident happens. With other words, after injuries happen, actions are taken to prevent similar injuries in future (procedures are developed, trainings are conducted and

Table 5 E maintenance potential on various levels of maintenance management

E—maintenance	*Strategic level*
	It provides IT tools necessary to support decisions concerning maintenance, definition of maintenance policy and communicating it to lower levels of organization's hierarchy
	Tactical level
	It provides tools and information enabling and facilitating realization of maintenance policy defined at strategic level. It provides availability of resources to realize maintenance and service activities (CMMS data interface and ERP central system)
	Operational level
	It provides technology and tools to integrate functions connected with monitoring of degradation level and availability status of equipment and installations, supports decisions of supporting staff with diagnostics and prognostic information, supports assessment of efficiency indicators used in an enterprise.

preventions are implemented). However, it also refers to actions and events which already taken place, which is called reactive safety. Sustainable maintenance promotes pro-active safety culture based on safety awareness and responsibility for oneself and others (interdependent organization).

Safety and hygiene of work, including psychical hygiene (stress) result in high quality of work performed and high satisfaction on work. Satisfied (not only financially) employees feel more connected with an enterprise. If satisfaction from work decreases to a certain level, employees quit and leave an enterprise and an enterprise has to bear costs connected with recruitment and training new employees.

One of the most important aspects of Sustainable Maintenance is introduction of a new category, next to economic and environmental, to analysis of maintenance and service efficiency. The category is social issues and searching for balance between three dimensions: economic, environmental and social. It is connected with assessment of relations and interdependencies between them as elements of organization management system. In summary, Sustainable Maintenance: is a pro-active activity integrating all dimensions of sustainable development;

- includes social issues: working hours, salary, safety and health of employees, satisfaction on work;
- includes risk connected with keeping and using so called soft assets in organization (for example costs of developing proper competences), includes maintenance in Sustainable Manufacturing strategy (being sustainable means realization of 6R in all processes, both core and supporting).

5 Conclusion

In the hereby chapter evolution in approach to technical infrastructure maintenance issues was introduced with special respect to realization of sustainable manufacturing. In Lean Maintenance concept loss was the crucial aspect, and actions taken were analyzed mostly in financial aspects. Green Maintenance on the other hand introduces a new category for analysis of service and maintenance activities. The category is environmental approach. The consequence of such approach is assessment of the elements of practices applied in maintenance and their influence on natural environment, as well as analysis and development of solutions which enable limitation or elimination of negative influence of before mentioned practices on natural environment. Sustainable Maintenance completes the list of two categories used (economic and environmental) with the third one. The category is social issues and searching for balance between these three dimensions: economic, environmental and social.

Including the category of sustainable development to processes and actions realized in technical infrastructure maintenance area is a challenge but also a necessary support in sustainable manufacturing realization. The challenge, because it is not one, separate action but a process which requires building maintenance strategy and goals in consistency with sustainable development corporate strategy, as well as commitment and participation of all the employees, knowledge, experience and consequent performance (the process is evolutionary). Necessary support because maintenance is a crucial process in internal supply chain and if neglected or missed makes sustainable development corporate strategy only theoretical declaration of managers.

In order to understand complexity of sustainable maintenance it is necessary to apply systematic approach. All the dimensions, social, economic and environmental have to be analyzed simultaneously and not isolated as they are interconnected and changes in one dimension result in changes in the others as well. Further research on measures and indicators reflecting both static and dynamic character of the connections within maintenance itself and between maintenance and other processes should be realized in an enterprise.

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