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MAINTENANCE IN SUSTAINABLE MANUFACTURING

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ABSTRACT. Background: 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. For a company, sustainable development means adoption of such business strategy and actions that contribute to satisfying present needs of company and stakeholders, as well as simultaneous protection, maintenance and strengthening of human and environmental potential which will be needed in the future. This new approach forces manufacturing companies to change their previous management paradigms. New management paradigm should include new issues and develop innovative methods, practices and technologies striving for solving problem of shortages of resources, softening environment overload and enabling development of environment-friendly lifecycle of products. Hence, its realization requires updating existing production models as they are based on previously accepted paradigm of unlimited resources and unlimited regeneration capabilities. Maintenance plays a crucial role because of its impact on availability, reliability, quality and life cycle cost, thus it should be one of the main pillars of new business running model.
Material and methods: The following paper is a result of research on the literature and observation of practices undertaken by a company within maintenance area.
Results and conclusions: The main message is that considering sustainable manufacturing requires considerable expanding range of analysis and focusing on supporting processes. Maintenance offers numerous opportunities of decreasing influence of business processes on natural environment and more efficient resources utilization. The goal of maintenance processes realizing sustainable development strategy is increased profitability of exploitation and optimization of total lifecycle cost without disturbing safety and environmental issues.

Key words: sustainable manufacturing, maintenance generations, sustainable maintenance.

INTRODUCTION

Sustainable development became popular with the publication of the Brundtland Report [World Commission on Environment and Development 1987]. There, it was defined as a process aiming for development aspirations of contemporary generation meeting, and in the same enabling meeting these aspirations by the future generations as well. Thus 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 a company, sustainable development means adoption of such business strategy and such actions that contribute to satisfying present needs of company and its stakeholders, as well as simultaneous protection, maintenance and strengthening of human and environmental potential which will be needed in the future [Sidorczuk-Pietraszko 2007].

This new approach forces manufacturing companies to change their previous management paradigms. New management paradigm should include new issues and develop innovative methods, practices and technologies striving for solving problem of shortages of resources, softening environment

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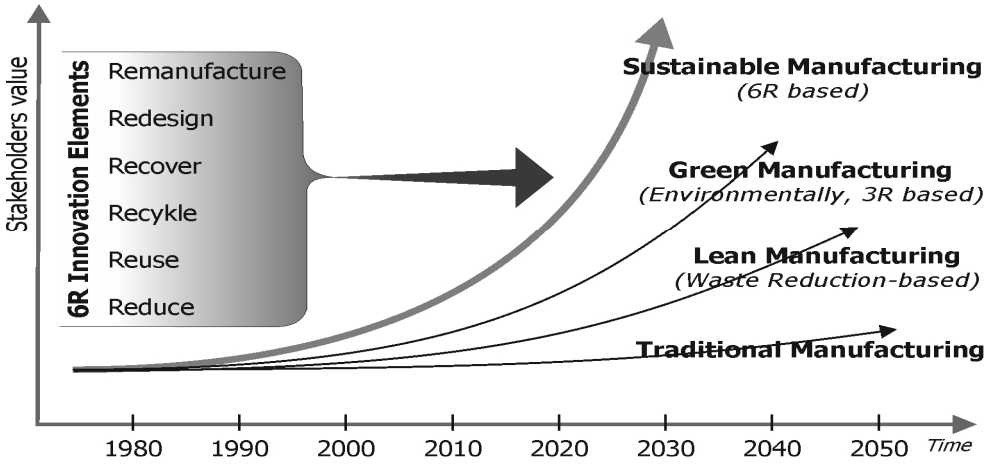
overload and enabling development of environment-friendly lifecycle of products [Saniuk et. al 2013, Saniuk et. al 2012]. Hence, its realization requires updating existing production models as they are based on previously accepted paradigm of unlimited resources and unlimited regeneration capabilities. Maintenance plays a crucial role because of its impact on availability, reliability, quality and life cycle thus it should be one of the main pillars of new business running model.

Maintenance should be considered a long-term strategic planning integrating all stages of a product lifecycle, including and anticipating changes in social, economic and environmental trends, incorporating innovative technologies to operational actions (e.g. e-maintenance, e-diagnostics). Whereas the goal of maintenance in a company realizing strategy of sustainable development is increased profitability of exploitation and optimization of total lifecycle of a product without disturbing safety and environmental issues.

SUSTAINABLE MANUFACTURING

Observation of development of a manufacturing system from a sustainable development perspective leads to the conclusion that there are four main production paradigms identifiable: mass production, lean production, green production and sustainable production (fig 1).



Source: Jayal et al. 2010

Fig. 1. Sustainable Manufacturing
Rys. 1. Zrównoważona produkcja

Mass Production systems were focused on the reduction of product cost. The consequence was limited ability to meet individualized needs and requirements of customers. Lean Manufacturing places emphasis on continuous improvement in product quality while decreasing product costs. In this case, the consequences increased the ability of manufacturers to meet individualized needs of customers, decreased direct and indirect costs and improved quality of final products. As a result, manufacturers could shape prices of final products at the level that compensated economies of scale, an effect that characterized the previous paradigm [Trzecieliński 2011]. The term green manufacturing was coined to reflect the new manufacturing paradigm that employs various green strategies and techniques to become more eco - efficient. These strategies include creating products/systems that consumes less material and energy, substituting input materials (e.g. non - toxic for toxic, renewable for non - renewable), reducing unwanted outputs and converting outputs to inputs (recycling).

Sawhney, Teparakul, Aruna, and Li [Sawhney et al., 2007] show the connection

between lean manufacturing and the environmental movement stating that "it is natural that the lean concept, its inherent value - stream view and its focus on the systematic elimination of waste, fits with the overall strategy of protecting the environment", which they call Environmental Lean (En - Lean).

The end of the 20th century and the beginning of the 21st century has seen intensive searching for new business models in accordance with the sustainable development approach. Sustainable manufacturing is a new paradigm which has to take into consideration all the three aspects of sustainable development (financial, environmental and social) and develop innovative methods, practices and technologies enabling an environment-friendly lifecycle of products. To achieve this goal, contemporary models of production must be updated to meet new requirements and leave previous assumptions on unlimited availability of resources and ability of regeneration behind.

Sustainable production was introduced at the 1992 UNCED conference in Rio de Janeiro as a guide to help companies and governments transition towards sustainable development. Several definitions exist for sustainable manufacturing and production. Alting and Jegensen [Alting & Jegensen 1993] defined sustainable production as the management of the whole product life cycle starting from design, production, and distribution, to the disposal stage. This involves minimizing material and energy resources. The U.S. Department of Commerce defined sustainable manufacturing as "the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound" [The U.S. Department of Commerce 2010]. Quinn et al. [1998] define sustainable manufacturing as "systems of production that integrate concerns for the long-term viability of the environment, workers health and safety, the community, and the economic life of a particular firm". In recent years, many aspects of sustainability in the context of manufacturing have been investigated [Velázquez et al. 2006, Nasr et al. 2011, Amrina & Yusof 2012]. Jayal et al. [2010] suggest, that sustainable manufacturing must respond to:

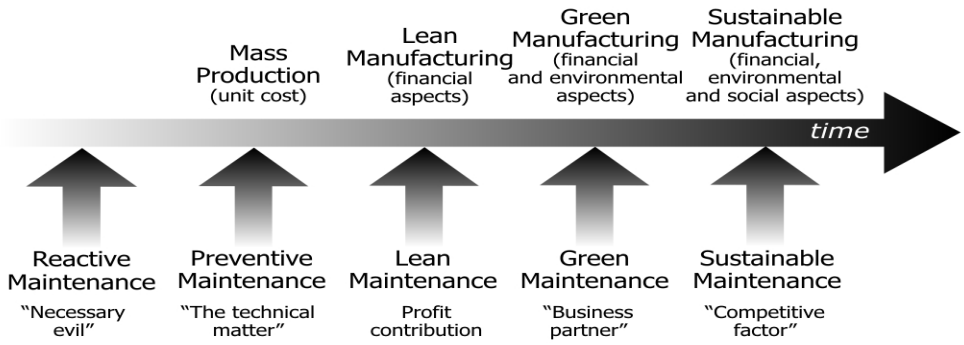
- economic challenges, by producing wealth and new services ensuring development and competitiveness through time
- environmental challenges, by promoting minimal use of natural resources (in particular non-renewable) and managing them in the best possible way while reducing environmental impact
- social challenges, by promoting social development and improved quality of life through renewed quality of wealth and jobs.

The move towards sustainability will require changes on many levels: not only production methods must be more respectful ethically and environmentally, but all the other processes performed in a company must also be changed.

A key to sustainable manufacturing is finding where and why the production process is wasting resources and energy. The consequence is that production processes have to be analyzed not only in the context of the technology applied, but also in the context of resources used (incl. human, material, technical and information resources).

MAINTENANCE GENERATIONS

A production system consists of different types of equipment and all equipment must be available and reliable at the highest level possible in order to ensure stability of a process. The maintenance department is responsible for keeping the equipment in the condition it initially was procured for and also to ensure that it can deliver outputs according to the specification. This is an important role in a production system and if it is performed successfully it can facilitate the journey towards becoming sustainable through high assets utilization, thus providing to the overall profitability. During the last decades, maintenance theory has radically changed according to the new manufacturing paradigms (fig. 2).



Source: Jasiulewicz-Kaczmarek 2013b

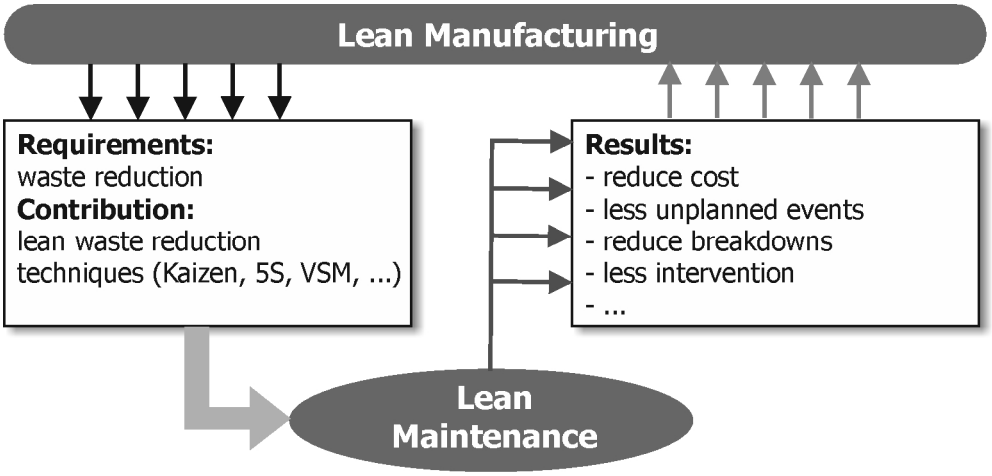
Fig. 2. The evolution of maintenance on a time perspective
Rys. 2. Ewolucja w postrzeganiu utrzymania ruchu

Until World War II, industry was not very highly mechanized, as the downtimes were not considerate. Most of the equipment was simple and over-designed. Failure consequences were not vital and had a neglectable effect. This was the time when preventing the equipment from failure was not a high priority. Therefore, industrial equipment was operated until it failed, at which point it was either repaired or replaced according to "fix it when it breaks" principle. Maintenance was considered as a production task and a necessary evil. The first maintenance approach could be described as reactive maintenance where no action is taken to prevent failures or to detect the onset of failure.

The next generation of maintenance was initiated with the industrialization process. The manufacturing plants became complex. Availability, longevity and cost were considered important factors for achieving business objectives. Maintenance became a task of the maintenance department and was considered as a technical matter according to "I operate- you fix" principle. Thus, the second maintenance approach could be described as a preventive approach.

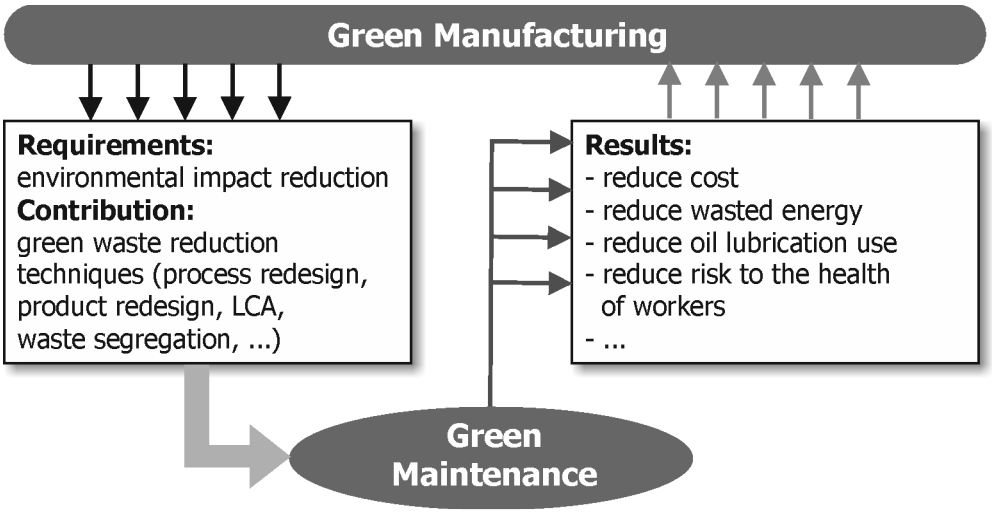
From the beginning of the 1970s, new options for maintenance realization appeared with the development of diagnostic tools and new approaches to corporate management, such as Just In Time paradigm, Total Quality Management philosophy, and waste elimination according to the Lean Manufacturing. According to the "lean" concept, "waste" is anything that does not add value to a product, a process, or a service. In maintenance system, the waste usually consists of outdated procedures, overstocked, underused inventory of equipment, material, parts, as well as wasted labor, time, transportation, exc.. All the principles, methods and technologies that can reduce the waste above listed and add value during the maintenance process are called "Lean Maintenance" [Smith 2004]. Levitt [2008], defined lean maintenance as delivery of maintenance services to customers with as little waste as possible. 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 improved plant reliability (availability) and improved repeatability of process (less variation).

The characteristic of lean thinking, associated with maintenance to improve efficiency and reduce waste, is the use of such tools as: VSM, visual displays (e.g. 5S), kanban, kaizen (i.e. continuous improvement), Six-Sigma quality, setup time reduction and preventative maintenance (fig. 3).



Source: Jasiulewicz-Kaczmarek 2014

Fig. 3. Lean manufacturing and lean maintenance
Rys. 3. Szczupła produkcja i szczupłe utrzymanie ruchu



Source: Jasiulewicz-Kaczmarek 2014

Fig. 4. Green manufacturing and green maintenance
Rys. 4. Zielona produkcja i zielone utrzymanie ruchu

As a contributor to current management techniques, lean thinking approaches are now more commonly used in maintenance area. The current production planning and shop floor control systems require dedicated solutions (tailored) using the tools of Lean, TOC, and others (depending on the organization conditions) [Hadaś and Cyplik 2010]. A similar path followed maintenance systems that use the tools of many concepts.

In the early 1990s, the idea of green maintenance was developed, 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. Green Maintenance is management of maintenance operations in an environmentally friendly way. It includes all the processes of maintenance, starting with selecting a strategy for an object's servicing (e.g., reactive, preventive, proactive), through material selection of raw materials and components necessary for equipment servicing purchasing, warehousing, maintaining (planned and unplanned) services, managing used materials, and exploitation fluids and lubricants (fig. 4).

Lean and Green manufacturing systems require efficient production and low use of resources such as energy, materials, etc. One major facilitator of this is effective maintenance. Sometimes regarded as the necessary evil, maintenance still has a negative image in the industry. But as the paradigm on manufacturing shift towards realizing a sustainable manufacturing, the changing role of maintenance should also be considered and appreciated.

SUSTAINABLE 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, labor, and fines for late order, scrap, and lost order due to unsatisfied customers [Moore & Starr 2006]. The consequences of maintenance activities are not limited to the plant's boundaries. Frequent breakdowns cause unplanned downtimes which hinder delivery of products to customers. Persistent delivery delay gives the company a poor delivery reputation. Breakdowns also influence quality of products. Defective products damage company's reputation, reducing the selling price and the number of customers. Finally, because of the unpredictable and uncontrollable nature of breakdowns, they are typically the main source of safety and environmental hazards. Companies with low safety and high environmental hazard rates also lose status in society and in the labor market

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 1).

Table 1. The basics for assessing maintenance impact in term of gains and losses
Tabela 1. Ocena wpływu utrzymania z perspektywy zysków i strat

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?

Source: Liyanage et al. 2009

Hence, to efficiently support actions realized in a company and striving for sustainable manufacturing, maintenance should cope with the following challenges:

- to identify the important stakeholders and understand their demands,
- to develop and deliver maintenance processes in all phases of the life cycle of the machine,
- to identify involved risks and chances,
- to quality the staff.

Maintenance management oriented on stakeholders is on one hand focused on goals of the stakeholders who are interested in work and results of maintenance management and on the other hand the stakeholders who influence maintenance performance success. Usually, stakeholders are groups of people who are the most important for overall success of maintenance. They have the ability to influence realization of maintenance operations and either win or lose depending on results of actions taken. A positive result of action depends on high information capacity of a maintenance system, while information capacity of maintenance is an outcome of cooperation of the system: maintenance – a stakeholder's (the environment the system operates in) maintenance system acquires resources from both external and internal sources. The ability to acquire resources from the environment and process them according to a system's own needs and needs of environment is a basic task of constructive actions and development of the system. This is why efficient management of stakeholders is so important for maintenance success. To manage stakeholders, it is necessary to identify them and identify motifs for their commitment. Stakeholders can be of both internal and external character. Examples of internal maintenance stakeholders are employees of the department, as well as production staff, logistics staff, accounting staff etc., while examples of external stakeholders are spare parts providers, exploitation material providers, service providers, designers and producers of machines and devices, etc.

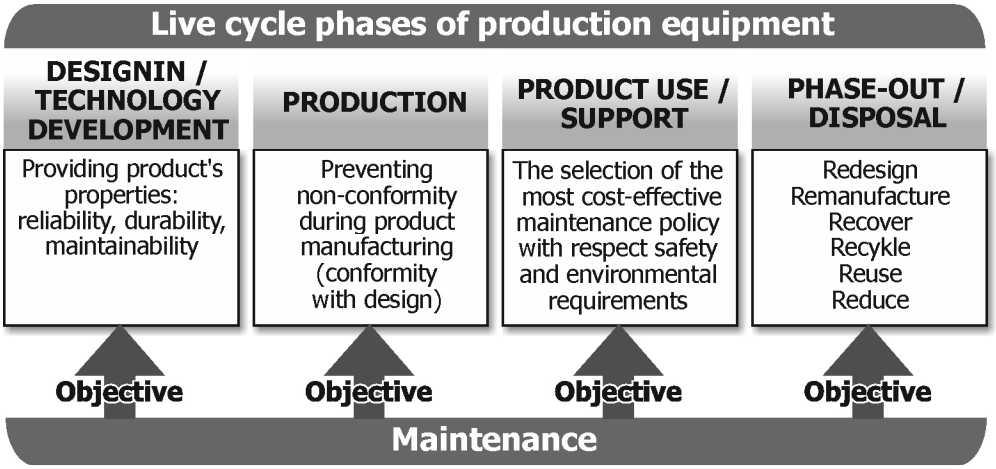
As needs and expectations of stakeholders are sometimes contradictive (trade-off relation between production and maintenance represents a classic example), for providing a sustainable approach to meeting these requirements it is necessary to identify strategic goals and priorities for maintenance. The goals emerge from goals and strategies of a company that result from obligations made towards internal and external stakeholders. This is how maintenance is included in the internal value chain of a company. The chain needs to be supported with properly designed maintenance processes at every stage of a product's lifecycle, in which technical staff and employees in other functional departments and external units (e.g., designers and manufacturers of equipment, spare part providers, service providers) take part. Hence, maintenance development from a product's lifecycle point of view requires numerous interfaces between maintenance and its stakeholders.

The system life cycle is a sequence of phases, each containing tasks, covering the total life of a system from the initial concept to decommissioning and disposal. The many decisions made during the process of a technical object's design, production and operation directly influence the effect and outcome on all the dimensions of sustainable manufacturing (fig.5). The maintenance managers hold all the instruments that allow the firm's technical service workers to participate in all phases of the life cycle of the machine and thus engage in the implementation of the sustainable manufacturing.

The first phase of a product's life cycle is its design. In the context of sustainable manufacturing it is necessary to carefully check construction materials used and their influence on the natural environment, opportunity to re-use materials after exploitation is finished, high reliability of a machine in the exploitation stage and possibly low energy demand, stability of construction of machines and devices, maintainability, serviceability, safety and ergonomics for operators and technical department staff. Maintenance staff should be proactively committed to this stage of a machine's lifecycle. Their suggestions, remarks and initiatives should be the basic input data for design.

The next stage of a product's lifecycle, which is influenced by maintenance staff and which maintenance staff actively takes part in, is exploitation of a machine in a company. From the sustainable manufacturing point of view, maintenance of machines in the exploitation stage is focused on providing systems, procedures and trainings which build operative knowledge and skills, as well as functional capabilities of systems to prevent, manage and eliminate losses, environmental incidents and problems with safety and health

of employees. Thus, knowledge of the influence of breakdowns of functional machines on the environment and safety of people is essential, as well as planning maintenance operations and monitoring systems adequate for potential consequences. Maintenance planning methods, as they are based on identification of risk emerging from a machine's failure, enable maintenance planning for manufacturing equipment in appropriate context, which refers to definition of correct proportions between predefined maintenance policies (incl. reactive, preventive, proactive and others) with respect not only to financial issues, but also to environmental and social issues (safety of people). The set of the most often used techniques includes: Reliability Centered Maintenance, Risk Based Inspection, Risk Based Maintenance, fault-tree analysis, Failure Mode and Effect Analysis, etc. Risk assessment integrates reliability with environmental and safety issues and can therefore be used as a decision tool for proactive maintenance planning. It helps management in making correct decisions concerning investment in maintenance or a related field. This will, in turn, result in better asset and capital utilization.



Source: Own study

Fig. 5. Maintenance objectives in life cycle phases of production equipment
Rys. 5. Cele utrzymania ruchu w cyklu życia wyposażenia produkcyjnego

Proactive operations seem to be the most important for sustainable maintenance in this stage of a machine's lifecycle. Proactivity in maintenance provides real opportunity for the e-maintenance philosophy to support "predict and prevent" strategies while keeping maintenance as an enterprise process. E-maintenance is a sub-concept of e-manufacturing and e-business for supporting next generation manufacturing practices.

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 decision data and tools to process and act upon them become available anytime, anywhere and to anyone at multiple levels of operation [Muller et al. 2008, Iung et al. 2009].

Disposal is the last stage in a machine's lifecycle. It is the state of terminal use value of a machine and its further exploitation is either impossible or economically unjustified. The only problem left is management of used parts and components of a machine to be disposed of at the minimum load for the natural environment and some positive

economic effects. After exploitation, each machine has a number of precious materials and components that can be used for regeneration or repair of similar technical objects. Hence, the goal of maintenance staff is to assess whether subassemblies or components of a machine disposed of fit other machines or devices owned by a company, whether they need repair or regeneration.

In every predetermined stage of a lifecycle maintenance integrates both own requirements of a company and its stakeholders. In this way, sustainable maintenance enables companies achieving numerous benefits of internal and external character.

Sustainable maintenance is a new challenge for companies that follow the strategy of sustainable manufacturing. It can be defined as proactive maintenance operations striving for providing balance in social (welfare and satisfaction of operators and maintenance staff), environmental and financial (losses, consequences, benefits) dimensions. It requires conducting broad analysis of loss and of the possibility of endangering the continuity of a company's functioning (in economic, environmental and social dimensions), if a maintenance strategy developed and implemented, and operations performed, do not provide the required technical condition of technical infrastructure (e.g., machines, devices, installations) [Jasiulewicz-Kaczmarek 2013a].

CONCLUSIONS

The main message is that considering sustainable manufacturing requires considerable expanding range of analysis and focusing on supporting processes. Maintenance offers numerous opportunities of decreasing influence of business processes on natural environment and more efficient resources utilization. The goal of maintenance processes realizing sustainable development strategy is increased profitability of exploitation and optimization of total lifecycle cost without disturbing safety and environmental issues. Including the category of sustainable development to processes and actions realized in 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.

From practical point of view it requires changes in approach to maintenance represented by managers and changes in actions performed within maintenance area. Managers have to understand that maintenance is not only about repairs and conservations of machines and devices, but also actions striving for more efficient resources management and care for safety and health of employees. Whereas maintenance striving for meeting sustainable manufacturing requirements needs to be [Jasiulewicz-Kaczmarek 2013b]:

- creative and innovative, which means focusing on problem solving and continuous search for improvement options and using innovative solutions like e.g. ICT;
- scalable, which means taking requirements and expectations of a broader group of stakeholders instead of classic approach to relations between manufacturing and maintenance (most of the effect of maintenance can be found outside the maintenance function, in other work areas of the company);
- committed and involving, which means breaking manufacturing's hegemony and creating bonds with both internal and external stakeholders (development and integration of maintenance from product's lifecycle perspective requires numerous interfaces with other systems, internal as well as external ones).

Many companies declaring realization of sustainable production strives for improvement of ecologic aspects of products and technological processes and forgetting in the same time that sustainable production is an

answer of industrial companies to challenges of sustainable development and it should refer to all its aspects (financial, environmental and social). One interesting area to continue this paper is to develop maintenance strategy in sustainable manufacturing environment and methodologies to measure their efficiency.

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UTRZYMANIE RUCHU W ZRÓWNOWAŻONYM WYTWARZANIU

STRESZCZENIE. **Wstęp:** Zrównoważony rozwój opiera się osiąganiu równowagi pomiędzy celami ekonomicznymi, społecznymi i ekologicznymi i na udziale ludzi w planowanie procesu tak, by zdobyć ich zaangażowanie i wsparcie. Dla przedsiębiorstwa, zrównoważony rozwój oznacza przyjęcie takiej strategii biznesowej i realizacja takich działań, które przyczyniają się do zaspokajania bieżących potrzeb przedsiębiorstwa i stron zainteresowanych, przy jednoczesnej ochronie, utrzymaniu i wzmacnianiu potencjału ludzkiego i środowiskowego, który potrzebny będzie w przyszłości. To nowe podejście zmusza przedsiębiorstwa produkcyjne do zmiany uprzednio stosowanych przez nie paradygmatów zarządzania. Nowy paradygmat produkcji musi uwzględnić nowe zagadnienia i rozwijać innowacyjne metody, praktyki i technologie, na rzecz rozwiązania światowych niedoborów zasobów i złagodzenia nadmiernego obciążenia środowiska, umożliwiając przyjazny środowisku cykl życia produktów. Jego realizacja natomiast, wymaga aktualizacji obecnych modeli produkcji, opartych na starym paradygmacie nieograniczonych zasobów i nieograniczonej zdolności do regeneracji. Utrzymanie ruchu odgrywa kluczową rolę ze względu na swój wpływ na dostępność, niezawodność, jakość i koszt w całym cyklu życia wyrobu, zatem powinno być jednym z głównych filarów nowego modelu prowadzenia biznesu.
Wyniki i wnioski: głównym przesłaniem niniejszego artykułu jest stwierdzenie, że aby rozważać koncepcję zrównoważonej produkcji musimy znacznie rozszerzyć granicę analiz i skierować uwagę na procesy wsparcia. Utrzymanie ruchu oferuje wiele możliwości zmniejszenia wpływu na środowisko naturalne i bardziej efektywne wykorzystanie zasobów. Celem bowiem procesów utrzymania ruchu w przedsiębiorstwie realizującym strategię zrównoważonego rozwoju jest zwiększenie efektywności eksploatacji i optymalizacja całkowitego kosztu cyklu życia wyrobu bez naruszania bezpieczeństwa i kwestii dotyczących środowiska.

Słowa kluczowe: zrównoważone wytwarzanie, generacje utrzymania ruchu, zrównoważone utrzymanie ruchu

TOTAL PRODUCTIVE MANUFACTURING (TPM) IN DER AUSGEWOGENEN UND NACHHALTIGEN PRODUKTION

ZUSAMMENFASSUNG. Einleitung: Die ausgewogene und nachhaltige Entwicklung stützt auf die Erzielung eines Gleichgewichtes zwischen wirtschaftlichen, sozialen und ökologischen Zielen sowie auf die Beteiligung von Menschen an der Prozessplanung mit ihrem bewussten Engagement und ihrer Unterstützung der Abwicklung von Prozessen. Die nachhaltige Entwicklung bedeutet für das Unternehmen die Annahme jener Business-Strategie und die Ausführung jener Aktivitäten, die zur Sicherstellung von laufenden Bedürfnissen eines Unternehmens und der interessierten Seiten beitragen bei gleichzeitigem Schutz, ferner bei gleichzeitiger Aufrechterhaltung und Verstärkung menschlichen und Umwelt-Potenzials, dessen man in der Zukunft bedarf. Die neue Vorgehensweise zwingt die Produktionsunternehmen zum Wechsel von früheren Management-Paradigmen. Das neue Produktions-Paradigma muss neue Fragestellungen berücksichtigen und innovative Methoden, Verfahren und Technologien für die Lösung von Problemen der Welt-Defizite

von Rohstoffen sowie für die Milderung von übermäßigen Umwelt-Belastungen entwickeln, damit man einen umweltfreundlichen Zyklus des Produkten-Lebens ermöglichen kann. Die Ausführung des Vorhabens bedarf einer Aktualisierung von gegenwärtigen Produktionsmodellen, die auf das herkömmliche Paradigma unbegrenzter Ressourcen und des unbegrenzten Regenerationsvermögens stützen. Total Productive Manufacturing spielt wegen seines Einflusses auf die Zugreifbarkeit, die Zuverlässigkeit, die Qualität und die Kosten innerhalb des ganzen Lebenszyklus eines Produktes eine Schlüsselrolle. Daher soll es eine der Hauptstützen des neuen Modells für Betreiben eines Business werden.

Ergebnisse und Fazit: Der Kernpunkt des vorliegenden Artikels liegt in der Feststellung, dass man bei der Erwägung eines Konzeptes für Total Productive Manufacturing die Analysen-Grenze bedeutend ausdehnen und den unterstützenden Prozessen Aufmerksamkeit schenken muss. Das TPM bietet viele Möglichkeiten für eine Milderung der negativen Beeinflussung der Umwelt sowie für bessere Ausnutzung von Ressourcen. Das Ziel der TPM-Prozesse im Unternehmen, das die Strategie der ausgewogenen und nachhaltigen Entwicklung realisiert, ist es, die Effektivität des Betriebs zu erhöhen und die Gesamtkosten des Lebenszyklus eines Produktes zu optimieren ohne die Sicherheit und Umweltschutzfragen zu beeinträchtigen.

Codewörter: nachhaltige Produktion, Generationen von Total Productive Manufacturing, ausgewogenes und nachhaltiges TPM

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