HOW DOES MAINTENANCE INTEGRATE LEAN AND GREEN MANUFACTURING PARADIGMS?

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Abstract: Lean and Green manufacturing systems require efficient production and low use of resources such as energy, material, etc. One of the major facilitators of this is undeniably effective maintenance. The lean and green philosophy encourage us to look at waste. The goal of integration of lean and green paradigms in maintenance is mostly harmonization and coordination of many aspects of activities, combination of processes, procedures, practices and creating a system which enables meeting goals predefined in a maintenance strategy in a more efficient way.

Keywords: Lean maintenance, Green maintenance, integration Lean and Green

1. Introduction

Different management paradigms, such as the lean and green have been adopted for the management of production. Lean manufacturing paradigm based on cost reduction and flexibility, focused on processes improvements, through the reduction or elimination of the all "wastes", i.e., non-value adding operations. It embraces all the processes through the product life cycle, starting with the product design to the product selling, from the customer order to the delivery [1].

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). 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 (fig. 1).

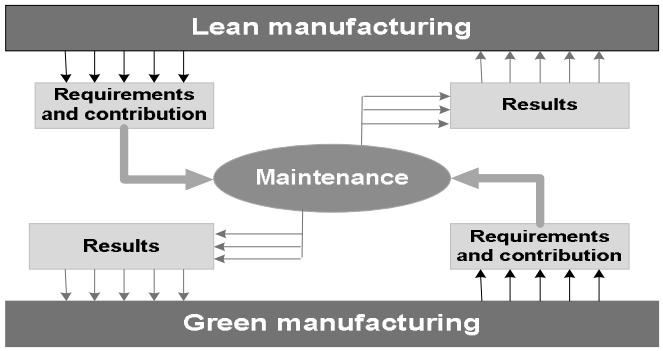

Fig. 1. Integration lean and green manufacturing paradigms in maintenance [2]

The leanness in a maintenance maximizes profits through cost reduction, while greenness maximizes profit through minimization of negative influence on environment that results from the amount of used electric energy, raw materials, lubricants management etc.
The literature shows that almost researches have been focused on the study of individual paradigms in maintenance management ([3], [4]). However the simultaneous integration of lean and green paradigms in maintenance management may help maintenance function to become more efficient, streamlined, and sustainable.
The following paper is supposed to identify common elements of the paradigms introduced for better understanding of synergy between them and overall improvement of maintenance efficiency.

This paper is organized as follows. First, a literature review related to lean and green manufacturing and maintenance management paradigms is presented. Next, integration of lean and green paradigms in maintenance area is introduced. The next chapter presents tools and techniques supporting realization of before mentioned paradigms. Finally, the main conclusion is presented.

2. Introduction

2.1. Maintenance

One of the major functions of a production and operations management is maintaining the production capability in any production system. This can only be achieved through maintenance. According to Narayan [5], maintenance concerns the combination of all technical, administrative, and managerial actions during the life cycle of an item, intended to retain it in, or restore it to, a state in which it can perform the required function. Usually, maintenance is perceived as a supporting process for main processes performed in a company and working for one customer only – production. According to this approach, maintenance is a cost. Meanwhile, complexity of contemporary manufacturing systems and their dependency on numerous internal and external factors has raised the interest of an increasing number of stakeholders in the results of maintenance. These results are perceptible not only in economic (increase or decrease of financial expenditures), but also in environmental (e.g., exploitation material use, media use) and social dimensions.

Lean and green are ones of the newer concepts or buzzwords around maintenance. The lean and green philosophy encourage us to look at waste. What is waste in maintenance? Typically (not always), the largest waste is environmental and safety issues, followed by downtime of production equipment. There are also other losses such as damage due to catastrophic failures, wasted labor due to poor management system, high cost of parts and much more.

2.2. Lean manufacturing and lean maintenance

The lean manufacturing (LM) is the practice of eliminating waste in every area of production including customer relations (sales, delivery, billing, service and product satisfaction), product design, supplier networks, production flow, maintenance, engineering, quality assurance and factory management. Its goal is to utilize less human effort, less inventory, less time to respond to customer demand, less time to develop products and less spare to produce top quality products in the most efficient and economical manner possible. Shah and Ward [6], define lean production as “an integrated socio-technical system whose

main objective is to eliminate waste by concurrently reducing or minimizing supplier, customer, and internal variability". 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 ([7], [8]).

The key in the lean philosophy is to answer the question, "How do we reduce waste?" One of the answers to this question is improvement of equipment reliability and increase of efficiency and effectiveness of maintenance activities. 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. Including the category of lean thinking into maintenance practices in literature is called Lean maintenance [9]. Levitt [10], 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 [10]. 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).

Lean maintenance seeks to eliminate all forms of waste [11]. Ohno [8] 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 [12] added another seven (fig. 2).

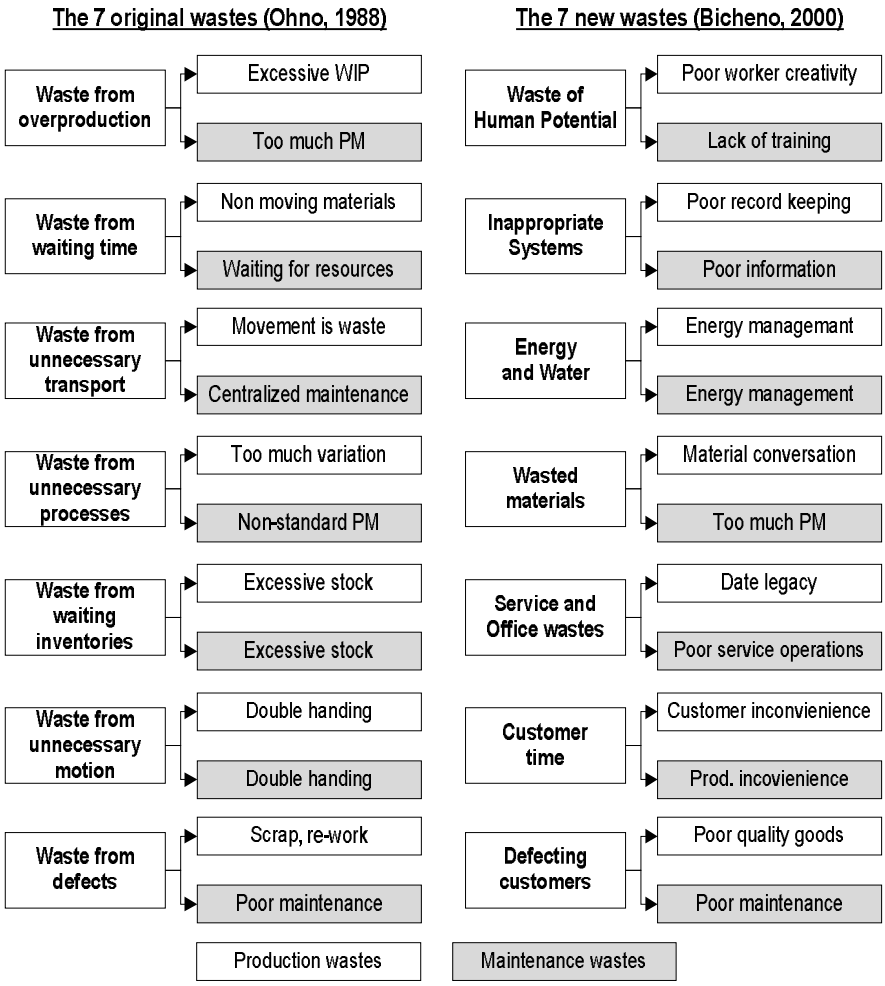

Fig. 2. Lean production waste and analogous waste within maintenance [13]

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).

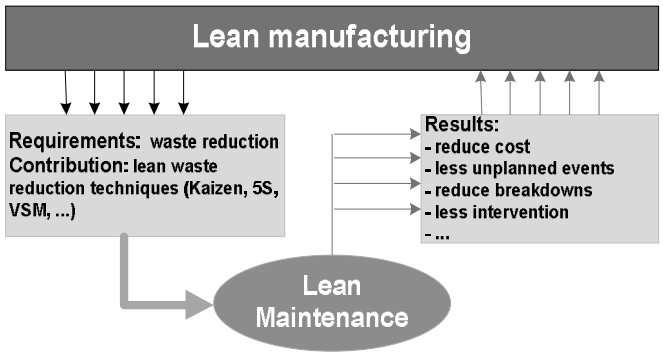

Fig. 3. Lean manufacturing and maintenance

As a contributor to current management techniques, lean thinking approaches are now more commonly used in maintenance area. Total Productive Maintenance (TPM) it is an essential Lean Manufacturing concept in maintenance area that measures breakdowns and machine stops as well as their associated risks.

2.2. Green manufacturing and green maintenance

The green manufacturing is one of the trends of industrial production which focuses on the need of environment, energy and the waste which are produced during the process. Zhou, Pan, et al [14] described green manufacturing as "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. Environmental waste is an unnecessary or excess use of resources or a released to the air, water, or land that could harm human health or the environment. Practically speaking, environmental wastes include [15]:

- energy, water, or raw materials consumed in excess of what is needed to meet customer needs.
- pollutants and material wastes released into the environment, such as air emissions, wastewater discharges, hazardous wastes and solid wastes (trash or discarded scrap).
- hazardous substances that adversely affect human health or the environment during their use in production or their presence in products.

Like other Lean wastes, environmental wastes do not add customer value. Environmental wastes are often a sign of inefficient production, and they frequently indicate opportunities for saving cost and time. Many people believe that green production only requires the execution of pollution controls or recycling when manufacturing goods. The reality, however, is that green production processes attempt to minimize the impact the manufacturing process brings on the environment at every stage.

In the early 1990s, the concept of green maintenance 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. 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. The negative influence of maintenance in the natural environment can be limited by considering service operations in the life cycle of the product, from its idea development, through design, manufacturing, exploitation and disposal. Green maintenance strategy is realized in the life cycle according to the idea of recycling economy [16].

The areas of green maintenance realization and some examples of practices applied in this area enable companies to achieve benefits (fig. 4).

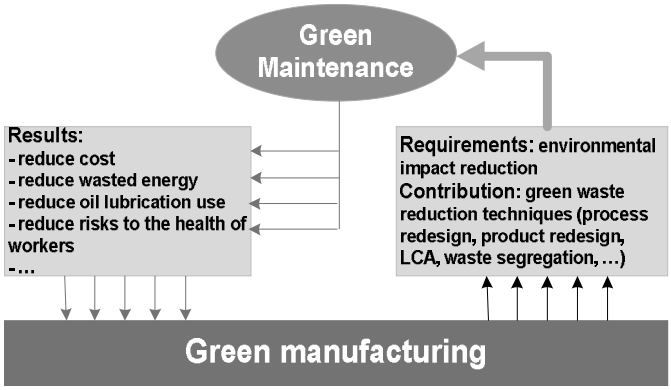

Fig. 4. Green manufacturing and maintenance

Green maintenance means all activities that keep or restore the equipment to its prescribed state on the condition of taking into account the highest efficiency of using resource and the lowest environment pollution. Not only does it aim at the physical object of keeping and restoring the equipment to its prescribed state, but also aim at the sustainable development object of lowest environment pollution and highest efficiency of using resource for all activities start from maintenance to discarding as use loss.

3. Integration of Lean and Green paradigms in maintenance

Integration of paradigms is, generally speaking, believed to be a process beneficial for a company. It allows to improve resources management, communication, image of a company and enterprise ability to meet the predefined goals.

Some authors ([17], [18]) provide an overview and comparison between lean and green paradigms in manufacturing area. Integration of lean and the environment provides certain techniques and strategies for improving lean results and enhancing the environmental performance. Lean and environment help in eliminating environmental hazards, and providing a safer environment for the employees. The productivity can be increased by improving the quality, time and cost and by eliminating environmental hazards. Lean events and activities helps in identifying the environmental benefits and eliminating potential risks. Explicit consideration of environmental waste in Lean initiatives can also improve the work environment for employees. Similar to ergonomic concerns, eliminating

environmental hazards can reduce potential worker exposure to toxic substances and create a clean, safe workplace.
The goal of integration of lean and green paradigms in maintenance is mostly harmonization and coordination of many aspects of activities, combination of processes, procedures, practices and creating a system which enables meeting goals predefined in a maintenance strategy in a more efficient way. The base is using shared resources and guidelines of all the integrated approaches.

Maintenance is an element of an operational value chain and its goal is to create value for customers (both internal and external). To stress and justify the new way of maintenance interpretation Takata [19] introduced the term "maintenance value chain". The chain has to be supported with properly designed maintenance processes at each stage of product's life cycle influenced by maintenance staff as well as by staff of other functional areas and external organizational units. Hence, development and integration of maintenance from life cycle perspective requires many interfaces with other internal and external systems leading to cooperation between maintenance and its stakeholders (fig 5).

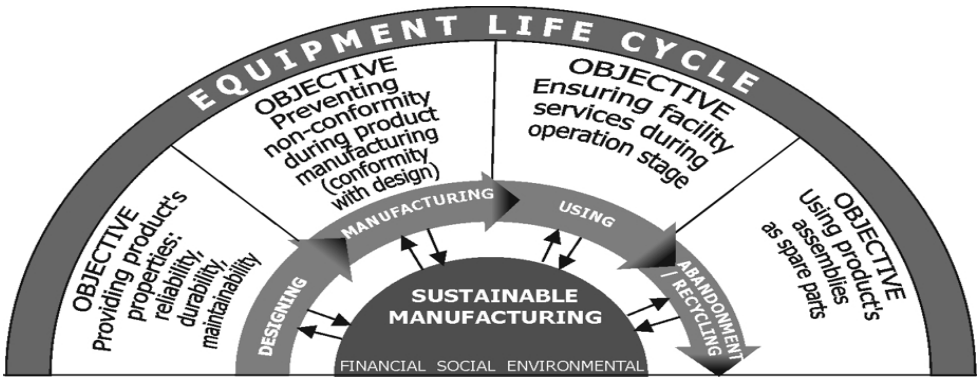

Fig. 5. Maintenance objectives of equipment life cycle – sustainable manufacturing point of view [20]

The basic goal is to build "zero" culture, which is "zero breakdowns", "zero complaints", "zero failures", "zero waste", "zero mistakes" etc. The idea supporting the approach is Total Productive Maintenance (TPM). Including TPM into maintenance strategy provides efficient management of technical infrastructure by integration of various stakeholders (planning, production, material management etc.) in all the equipment's life cycle [21].

4. Total Productive Maintenance

Total Productive Maintenance is a unique Japanese philosophy. TPM provides a comprehensive, life cycle approach to equipment management that minimizes equipment failures, production defects, and accidents. It involves everyone in the organization, from top-level management to production mechanics, and production support groups to outside suppliers [22].

Building „zero culture" requires integration of requirements of both paradigms, lean and green as well as efficient use of techniques and supporting tools. The solutions most often used in TPM realization include:

- Value Stream Mapping (VSM) – a waste characterization begins with an understanding of the maintenance processes that generate a waste. We must obtain enough information about the process to enable proper characterization of the waste, for example, by reviewing process flow diagrams or plans and determining all inputs and outputs. The method enables identification of waste in process and improvement opportunities for unnecessary operation or for environmental aspects such as materials, technological media, water etc.
- Identification of hazards and risk analysis– for example 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. Another tool employed to analyse reliability and safety of a system is fault-tree analysis (FTA). It provides an objective basis for analysis of system design, justifying system changes, performing trade-off studies, analysis of common failure modes, and demonstrating compliance with safety and environment requirements.
- Visual displays (e.g. 5S) - it is 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. This approach applied with methodology and rigor exhibits visible and computable results on cleanliness, environment, in-house atmosphere, brand image of the firm, quality but also safety. It also establishes an approach of continuous improvement. It is an evolutionary cycle which follows the principle of the Deming wheel called Plan - Do – Check – Act (PDCA). Full implementation of 5S requires looking not only at the quantity, usefulness, and frequency with which an item is used in a work area, but also the risk or toxicity of the item. It also means paying close attention to what ends up in waste streams and how to manage those wastes [23],
- Ishikawa diagram - among the current techniques, the diagram of Ishikawa allows to look for the causes of problems. The efficiency of this diagram bases on two points: it helps to simplify a complex problem and it facilitates the group work by directing avenues of research while avoiding neglecting certain important factors. In order to apply the „5M" method in the maintenance field it is necessary to group the activities in the five different categories:
    1. Man power (M1) necessary to the maintenance process, which refers to: the operators who perform the maintenance, the planners of the process and third parties who have activities within this process;
    2. Means of work(M2) used for the achievement of the maintenance, represented by equipment, computer systems, sample stands;

3. Materials necessary (M3) for the maintenance process; they include: spare parts, maintenance materials, components;
4. Maintenance method (M4) which refers to the adopted maintenance system, as well as the pertaining infrastructure specific procedures;
5. Management (M5) environment where the maintenance activity takes place, made of the pertaining spaces and infrastructure, which contributes to the maintenance process, the external environment which used the products of the equipment, the assembly of the ergonomical conditions;

– development of standards for operations, which is decreasing manufacturing process variety (e.g., number of non-conformities products etc.).

In many companies lean, green and TPM work together to provide a holistic approach to achieve continuous improvement driven by progressively removing inhibitors and tuning the complete internal and external supply chain (table 1).

Tab. 2. Lean, green and TPM impact on maintenance performance [2]

Productivity and Quality	*Impact of TPM*
	reduce need for intervention, reduce breakdowns, potential to reduce tolerance, control of technology, reduce start-up loss
	Impact of lean thinking
	reduce non-value-adding activities increase added value per labor hour, highlight quality defects early
	Impact of green thinking
	reduce wasted energy from heating, cooling, and lighting during production downtime
Cost	*Impact of TPM*
	reduce material, spares
	Impact of lean thinking
	lower inventories
	Impact of green thinking
	Decrease of environmental fees (e.g.,. by waste segregation, decrease of amount of media use)
Safety and Morale	*Impact of TPM*
	Less unplanned events, less intervention controlled wear, better understanding of technology, more time to manage
	Impact of lean thinking
	less movement, less clutter, abnormal conditions become visible easily, less clutter closer to the internal customer, higher appreciation of what constitutes internal customer value
	Impact of green thinking
	reduce risks to the health of workers, increase of workers' consciousness (e.g., by training programs)

Environment	*Impact of TPM*
	closer control of equipment, less unplanned events / human error
	Impact of lean thinking
	no 'over-production' systems geared to needs not theoretical batching rules
	Impact of green thinking
	reduce risks to the environment, reduction of non-renewable resources use, product life cycle management

Adopting a proactive TPM style of operation hones the skills of the maintenance and operations group to facilitate the Lean and Green transformation.

5. Conclusion

Generally maintenance is believed to be a process supporting core processes of a company executed for one customer – which is production and it is taken used increasinas a cost. However, complexity of contemporary manufacturing systems and their dependence on numerous internal and external factors caused increase in parties interested in maintenance outcomes. The outcomes are influencing not only economics (increase or decrease in cost consumption) but also ecology (e.g., by use of exploitation materials and others).

These approaches should be coupled with product design, safe equipment operations, life cycle issues such as zero defects, design for maintainability, zero waste, remanufacturing and reuse processes. 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 natural environment (fig 6).

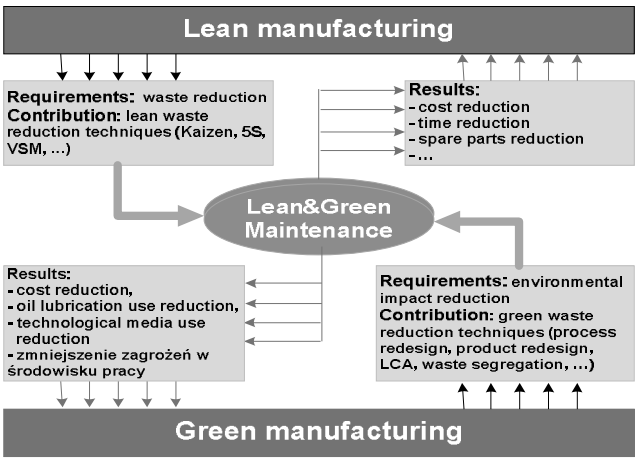

Fig. 6. Lean & Green maintenance – results

Including tools and techniques applied in lean and green approaches to maintenance actions and processes is supposed to increase their efficiency and create a basis for development of the area towards sustainable development.

References

1. Anand G., Kodali R.: A conceptual framework for lean supply chain and its implementation. International Journal of Value Chain Management, Vol. 2(3), 2008, pp. 313-357.
2. Jasiulewicz-Kaczmarek M.: Integrating Lean and Green Paradigms in Maintenance Management. IFAC 2014: The 19th World Congress of the International Federation of Automatic Control (in review).
3. Smith R., Hawkins B.: Lean maintenance; reduce cost, improve quality, and increase market share. Elsevier Butterworth-Heinemann, 2004.
4. Ruan Y., Chen X., Xu X.: Research on the Repair strategy of Green Maintenance. http://www.deltahttp://www.delta3n.hu/world-congress-on-maintenance-2008/session2 /31-research-on-the-repair-strategy-of-green-maintenance.pdf (Accesed 20.10.2013)
5. Narayan V.: Business performance and maintenance: How are safety, quality, reliability, productivity and maintenance related? Journal of Quality in Maintenance Engineering 18(2), 2012, pp.183-195.
6. Shah R., Ward P.T.: Defining and developing measures of lean production. Journal of Operations Management, Vol. 25(4), 2007, pp. 785-805.
7. Taj S., Berro L.: Application of constrained management and lean manufacturing in developing best practices for productivity improvement in an auto-assembly plant. International Journal of Productivity and Performance Management, Vol. 55(3/4), 2006, pp. 332-45.
8. Ohno T.: Toyota Production System: Beyond Large Scale Production. Productivity Press, 1988.
9. Smith R.: What is Lean maintenance? Maintenance Technology Magazine, 2004, available at: http://www.mt-online.com/october2004/what-is-lean-maintenance?Itemid=90 (Accessed 21.01.2014).
10. Levitt J.: Lean Maintenance. Elsevier Butterworth-Heinemann, 2008.
11. Ghayebloo S., Shahanaghi K.: Determining maintenance system requirements by viewpoint of reliability and lean thinking: a MODM approach. Journal of Quality in Maintenance Engineering, Vol. 16(1), 2010, pp. 89-106.
12. Bicheno J.: The New Lean Toolbox: Towards Fast Flexible Flow. PICSIE Books, Buckingham, 2000.
13. Davies C., Greenough R.M.: Measuring the effectiveness of lean thinking activities within maintenance, 2010, Available at: http://www.plant-maintenance.com/articles/Lean_Maintenance.pdf (Accesed 21.01.2014).
14. Zhou M., Pan Y., Chen Z., Yang W., Li B.: Selection and evaluation of green production strategies: analytic and simulation models. Journal of Cleaner Production, Vol. 26, 2012, pp 9-17.
15. EPA.: The Lean and Environment Toolkit, 2007.
16. Jasiulewicz-Kaczmarek M., Drożyner P.: The Role of Maintenance in Reducing the Negative Impact of a Business on the Environment. [In:] M. G. Erechtchoukova et al. (eds.), Sustainability Appraisal: Quantitative Methods and Mathematical Techniques for

Environmental Performance Evaluation, EcoProduction, Springer-Verlag Berlin Heidelberg 2013 pp. 142-166.
17. Bergmiller G.G., McCright P.R.: Lean Manufacturers' Transcendence to Green Manufacturing. Proceedings of the 2009 Industrial Engineering Research Conference, Miami, FL, May 2009.
18. King A.A., Lenox M.J.: Lean and Green? An empirical examination of the relationship between lean production and environmental performance. Production and Operation Management, 10 (3), 2001, pp. 244-256.
19. Takata S., Kimura F., van Houten F.J.A.M., Westkämper E., Shpitalni M., Ceglarek D., Jay Lee J.: Maintenance: Changing role in life cycle management. Annals of the CIRP, 53 (2), 2004, pp. 643-656.
20. Jasiulewicz-Kaczmarek M.: Sustainable Maintenance – the next generation of maintenance management. International Conference on Innovative Technologies, IN-TECH 2013, Budapest, 10. -12.09.2013, pp. 193-196.
21. Nakajima S.: TPM Development Program: Implementing Total Productive Maintenance. Productivity Press, Portland, OR, 1989.
22. Ahuja, I.P.S., Khamba, J.S.: Total productive maintenance – literature review and directions. International Journal of Quality & Reliability Management, Vol. 25(7), 2008, pp. 709-56.
23. Jasiulewicz-Kaczmarek M.: The role of ergonomics in implementation of the social aspect of sustainability, illustrated with the example of maintenance. [In:] Arezes, P, Baptista, JS, Barroso M, Carneiro, P, Lamb P, Costa N, Melo, R, Miguel, AS & Perestrelo, G (eds.) Occupational Safety and Hygiene. CRC Press, Taylor & Francis: London, 2013, pp. 47-52.

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