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Integrating Lean and Green Paradigms in Maintenance Management

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Abstract: New paradigms introduced in production management area, such as Lean Manufacturing, new trends emerging in the area, including those referring to natural resources (Green Manufacturing) caused changes in the way of understanding supporting processes, especially maintenance processes. 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.

Keywords: Green Maintenance, Lean Maintenance, TPM, waste

1. INTRODUCTION

Different management paradigms, such as the lean and green have been adopted for the management of production. Lean manufacturing is a multi-dimensional management practice including quality systems (Mazur&Gołaś, 2011), work teams, cellular manufacturing, supplier management, etc., in an integrated system (Worley and Doolen 2006; Gurumurthy and Kodali 2011, Stachowiak *et al* 2013)). This 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 (Anand & Kodali, 2008; Saniuk, Cagáňová & Čambál, 2013).

Other pertinent issue in manufacturing management is the environmental sustainability. 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). This manufacturing concept is not just restricted to addressing the social and environmental impact of a pollution-centric process. Green manufacturing addresses process redundancy, ergonomics and cost implications due to faulty methods of producing goods. Faster and cheaper are no longer the only two criteria in manufacturing a product or evaluating an existing process line. Several other factors such as materials used in manufacture, generation of waste, effluents and their treatment (or possible elimination), life of the product and finally, treatment of the product after its useful life are all important considerations. 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).

Maintenance in the manufacturing sector assumes a critical role as a support activity. An acceptable level of performance of the industry is simply unattainable without an effective maintenance management support

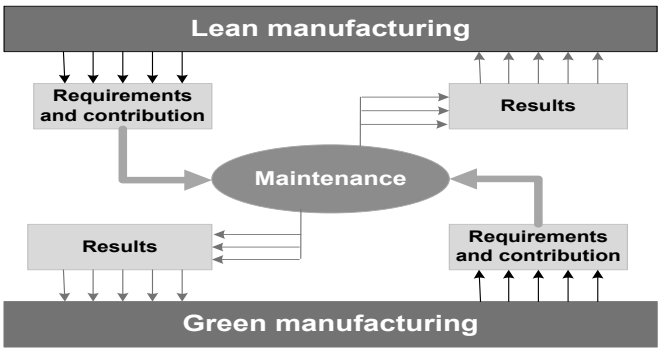

Fig. 1. Integration lean and green manufacturing paradigms in maintenance.

The literature shows that almost researches have been focused on the study of individual paradigms in maintenance management (Smith & Hawkins, 2004; Ruan, Chen & Xu, 2008). However the simultaneous integration of lean and green paradigms in maintenance management may help maintenance function to become more efficient, streamlined, and sustainable.

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 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. MAINTENANCE MANAGEMENT PARADIGMS REVIEW

2.1 Maintenance

According to Narayan (2012), 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. Today, maintenance has become a management issue, with its function as a contributor towards profit. This indicates the need for the maintenance operation to align with the business objectives and increase value for the enterprise.
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 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 (2007) 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 LM 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& Berro, 2006; Ohno, 1988).
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 (Górny, 2013). Including the category of lean thinking into maintenance practices in literature is called Lean maintenance (Smith, 2004a). Lean Maintenance is defined 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" (Smith, 2004b). 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 (Levitt, 2008). 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 (Ghayebloo & Shahanaghi, 2010). Bicheno (2000) added another seven categories to classic waste categories composition defined by Ohno (1988). Every waste category defined for production processes is related to maintenance (Davies & Greenough) e.g.:
1. Unproductive work – efficiently doing work that does not increase equipment reliability.
2. Delays in motion – waiting for production equipment to be available to carry out preventive maintenance.
3. Unnecessary motion – unneeded travel, trips to parts stores, and looking for tools required to do a job.
4. Poor management of inventory – not having an adequate amount of the right parts at the right time.
5. Rework – having to repeat tasks due to poor workmanship.
6. Under-utilization of resources – maximizing resources available and harnessing the skill sets of the maintenance teams.
7. Ineffective data management – collecting data that is of no use or failure to collect data which is important.
8. Misapplication of machinery – incorrect operation or deliberate operational strategies leading to maintenance work being done when it needn't be.
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. 2).

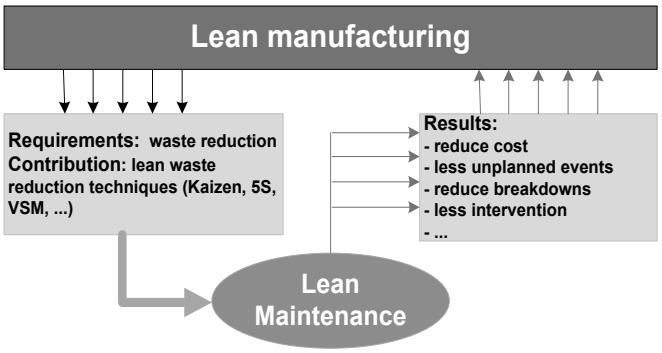

Fig. 2. Lean manufacturing and maintenance

As a contributor to current management techniques, lean thinking approaches are now more commonly used in maintenance area

2.3 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. Allwood (2005) defined green manufacturing 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". Zhou, Pan, et al (2012) 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 (EPA, 2007):

– 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. They also represent costs to the enterprise and society in general. Environmental wastes are often a sign of inefficient production, and they frequently indicate opportunities for saving cost and time. Green manufacturing consists of some practices: pollution prevention, toxic use reduction and design for environment. In addition to reducing and eliminating hazardous inputs and outputs in all phases of product life cycle, i.e. design, synthesis, processing, packaging, transportation and product use in manufacturing industries, green manufacturing can result in lowering raw material costs through recycling wastes instead of purchasing virgin materials, increasing production efficiency through less energy and water usage, reducing environmental and occupational safety expenses due to smaller regulatory compliance and potential liabilities, and improving corporate image by decreasing perceived environmental impacts on the public.

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 lifecycle 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.

The areas of GM realization and some examples of practices applied in this area enable companies to achieve benefits (fig. 3).

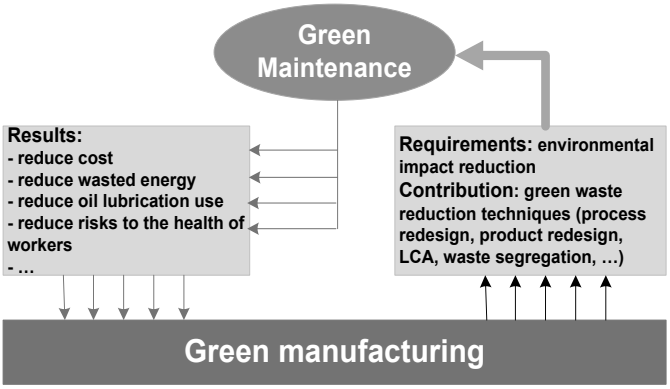

Fig. 3. Green manufacturing and maintenance

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

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 (Bergmiller & McCright, 2009; King & Lenox, 2001) 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. It is important to note that an organization as a single system, rather than as a set of independent operational systems and management practices . Furthermore, lean, green and other management paradigms are viewed as different forms (derivatives) of the same system, tailored to address the particular needs of different stakeholders.

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 (2004) introduced the term "maintenance value chain". The chain has to be supported with properly designed maintenance processes at each stage of product's lifecycle influenced by maintenance staff as well as by staff of other functional areas and external organizational units. Hence, development and integration of maintenance from lifecycle perspective requires many interfaces with other internal and external systems leading to cooperation between maintenance and its stakeholders. From internal perspective, maintenance is a support process providing services for its stakeholders. Hence, if parties are interested in lean and green management, their maintenance has to be green as well.

The characterization of lean and green paradigms in maintenance management referred to: purpose, manufacturing focus, inventory strategy, approach to choosing supplies and product design presented in the table 1.

Table 1. Lean and Green characteristics

	Lean	Green
Manufacturing focus	Focus on cost reduction, elimination of waste or non-value added activities	Focus on sustainable development
Inventory strategy	Minimizes inventory	----------
Approach to choosing supplies	Supplier attributes involve cost and high quality	Green purchasing
Product design	Maximize performance and minimize cost	Eco-design and life cycle for evaluating ecological risk and impact

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 lifecycle (Nakajima 1989)

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 (Ahuja and Khamba, 2008). The basic goal is to build "zero" culture, which is "zero breakdowns", "zero complaints", "zero failures", "zero waste", "zero mistakes" etc. 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. (fig. 4)

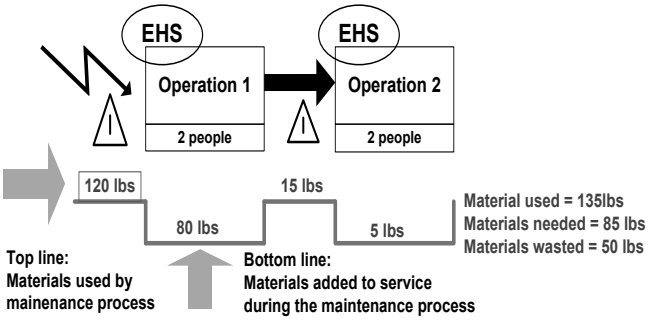

Fig. 4. Example "Materials Line" showing materials use versus need (EPA, 2007)

– 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 (Bajda et.al 2011).

– 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. The above are the key elements of the overall Management Operating System, including the elements that require managerial attention and whose supervision is only possible through sensor evaluation e.g. sight, hear, smell (fig. 5). 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 (Jasiulewicz-Kaczmarek, 2013),

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

– training operators by maintenance staff - training operators in better standards of loading, starting and operating manufacturing equipment (Tytyk & Butlewski, 2011),
– single minute exchange of dies (SMED) - practice that helps reduce changeover durations in order to adjust the manufacturing process based on product demand has the potential to reduce the amount of waste generated from raw and unprocessed materials left over in the manufacturing processes

Fig. 5. Visualization of lubricants use and tools to be applied

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 2).

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

Table 2. Lean, green and TPM impact on maintenance performance

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 lifecycle management

5. CONCLUSIONS

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 increases 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).

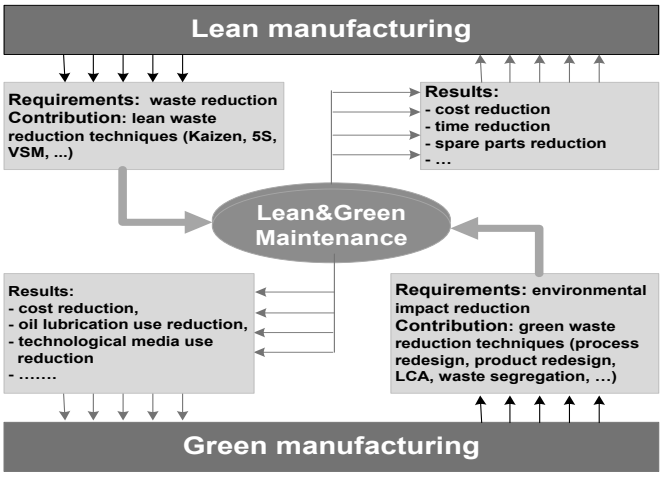

Fig. 6. Lean & Green maintenance - results

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.

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