TOTAL INDUSTRIAL WASTE MANAGEMENT BY ADVANCED TEQUNIQUES

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Abstract: Today's throw-away society is quickly becoming a thing of the past. In its place is a new way of thinking about the products we manufacture, their impact on the environment, and what happens to them when they've outlived their usefulness. At Waste Management, our Sustainability Services team can guide you to this emerging frontier and help you tread lightly on the environment at every stage of the supply chain. *The term zero waste (ZW) is continuously encouraging both producers and consumers to adopt sustainable approaches in order to reduce their expenditures as well as to help in making a better world. In the past, researchers have highlighted numerous techniques to tackle physical waste, however the chemicals which are normally generated from this waste is more critical and limitedly reported. Zero Waste Manufacturing (ZWM) is believed as a roadmap for future of manufacturing by which the burning issue of "Waste" can be tackled. However, ZWM can be supported with recycling and reusability of the produced wastes in another manufacturing process, use of optimization tools and sustainable manufacturing theories, development of precision manufacturing systems, etc. our aim is to completely recycle the waste generated by manufacturing process in eco-friendly way. We mainly focused on large manufacturing sectors in India like automobile spare parts, gear manufacturing, manufacturing of heavy equipment etc..*

Keywords: *Waste management, ZWM, Manufacturing, Advanced Techniques.*

1. Introduction

More and more organizations are aiming to eliminate waste entirely by reducing or reusing, in some way, all the products and by products of their manufacturing and business operations. This initiative is called "zero-waste." And, as idealistic as it sounds, it's a goal whose time has come. Nature itself provides a good example, as living things die, decay, and replenish the earth, preparing the way for new growth.

In historic terms, zero-waste can be seen as the next wave of the industrial revolution. And like that era, it signals a profound cultural shift. Taking cues from the Lean Manufacturing or Six Sigma movements, it's a way of doing business that seeks to either eliminate non-product output (the material that doesn't end up in your products, which you pay to get rid of) or transform it into product output that generates value. Some advocate taking this even further, by making the goods you sell sustainable by designing them with end-of-life in mind.

European Union waste policy is built on the concept of the Waste Hierarchy. This seeks to rank waste management options, with the most sustainable option being to avoid producing the waste in the first place. Waste producers are urged to "move their wastes up the hierarchy", for example by recycling instead of landfilling. Some European governments have introduced economic instruments, such as taxes on landfill and incineration, to help facilitate this movement.

Fig 1 Zero Waste Manufacturing

There has been much debate as to the position which energy-from-waste incineration should occupy on the hierarchy, some putting it on a level with recycling while others press for it to be classed as mere disposal. Likewise, there is debate as to whether composting constitutes recycling or recovery. The important point to remember is that the hierarchy only provides a general guide, and the waste producer should look carefully at the characteristics of each waste stream before deciding on the Best Practicable Environmental Option. For some wastes, such as bulky, inert demolition wastes, the most sustainable option is likely to be landfill, despite its position at the bottom of the hierarchy. Geographical factors such as the distance to a reprocessing or energy-from-waste plant will also help to determine the Best Practicable Environmental Option.

Till now, zero waste manufacturing (ZWM) is a philosophical term that encourages the manufacturing systems to produce parts/needs without contributing towards waste. As per the availability of manufacturing/construction/synthesis tools and systems within the small scale, medium scale and even large scale industries, it is not possible to completely eliminate the waste associated with these. However, one may also leads towards ZWM; if he/she is able to re-cycle or re-design or re-use the waste produced from one process in an another process. Hence, the objective of this work is to discuss the recent innovation towards re-cycling and reusability of the waste in manufacturing/constructional applications. A special attention has been paid on various sustainable manufacturing processes such as: machining, foundry and sheet metal operations, in order to discuss how far we have made it for ZWM. Further, a brief insight on additive manufacturing has also been outlined as future manufacturing.

2. Elements of a waste management strategy

Good waste management involves much more than ensuring that wastes are safely and legally disposed of. The aim should be to achieve the Best Practicable Environmental Option (BPEO) for each waste stream.

A typical strategy for the management of industrial waste might contain the following elements:

- ✓ Initial audit of wastes produced (source, quantity, composition and hazards) and current waste management procedures
- ✓ Risk assessment to ensure that storage and handling procedures do not present a health, safety or environmental risk
- ✓ Investigation of opportunities for waste reduction, reuse, recycling and recovery
- ✓ Assessment of waste treatment options
- ✓ Determination of Best Practicable Environmental Option for disposal of remaining wastes and treatment residues
- ✓ Audit of potential waste management contractors and selection of the contractor offering the best service.

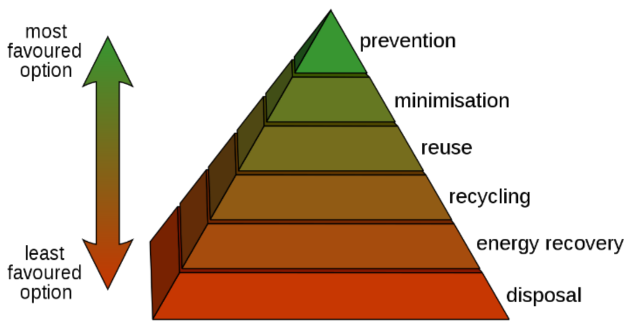

Fig2. Waste Hierarchy

3. ZWM through re-cycling of wastes

As discussed earlier, the advancement of technology has led to an increase in the amount and type of waste being generated, leading to a disposal crisis. In an article by Batayneh et al.,(2007), authors have precisely explained the hierarchy of waste It can be clearly understand that, the waste can be significantly controlled or treated either through re-use or re-cycle. However, both these terms are always confusing with each other. Let us suppose, we have an obsolete computer whose parts such as: hard disk, screen, graphic cards, cabinet, etc., can be used at some other place. This is called re-use. Whereas re-cycling involves re-processing, may be thermally, chemically or mechanically, of the materials (not the system) through material recovery and synthesis operations. This section aims to review the re-cycling approaches applied on different types of waste materials while addressing their suitable engineering applications. As the theme of this review is ZWM, so we have particularly focused the engineering applications and exempted all other types of waste which involves: municipal and sewage waste.

3.1 Polymers Plastics waste

Plastic/Polymer recycling is a way to reduce environmental problems caused by polymeric waste accumulation generated from day-to-day applications of polymer materials, mainly from packaging and construction (Hamad et al., 2013). It is very hard to think of a modern civilization without plastics as these have found a countless applications in household appliances, greenhouses, mulches, coating and wiring, packaging, construction, medicine, electronics, automotive and aerospace components. The various plastics produced throughout the world can be proportionate in terms of their percentages as: 31% polyethylene (PE), 17% polyvinyl chloride (PVC), 15% thermoset, 14% polypropylene (PP), and 9% polystyrene (PS), respectively. In addition, other kinds of plastics, such as: acrylonitrile butadiene styrene (ABS), polyamide (PA) or nylon-6, poly-lactic-acid, etc., not mentioned here comprise 14% of the world production. Thermoplastics contribute roughly 80% in the total plastic consumption and are used for typical plastics applications such as packaging but also in non-plastics applications such as textile fibres and coatings (Dewil et al., 2006). While plastics are found in all major solid waste categories including containers and packaging plastics such as: sacks, wraps, soft drink, milk, bags and water containers (USEPA, 2002; USEPA, 2008). In durable goods, plastics are found in appliances, furniture, casings of lead-acid batteries, and other products. In the UK, recent studies highlighted that, the plastic waste make up 7% of the final waste stream (Parfitt, 2002). And the packaging accounts for 37.2% of all plastics consumed in Europe and 35% worldwide (Clark and Hardy, 2004). The largest component of the plastic waste is low density polyethylene/linear low density polyethylene (LDPE) at about 23%, followed by 17.3% of high density polyethylene, 18.5% of PP, 12.3% of PS/extended PS), 10.7% PVC, 8.5% polyethylene terephthalate and 9.7% of other types (Association of Plastics Manufactures in Europe, 2004).

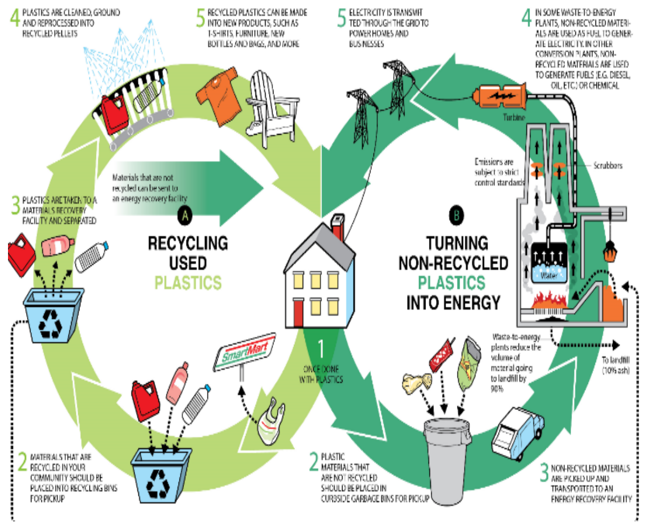

Fig 3. Plastic Recycling

In mechanical re-cycling, the plastic is ground down and then reprocessed and compounded to produce a new component that may or may not be the same as its original use (Cui and Forssberg, 2013). This process was promoted and commercialized all over the world back in the 1970s. Mechanical re-cycling of PSW can only be performed on single-polymer plastic, e.g. PE, PP, PS, etc. Mechanical re-cycling involved numerous steps in waste treatment and preparation, hence being a costly and an energy intense process. Normally, the starting step in mechanical recycling process involves size reduction of the plastic to pallets, powder or flakes, which is achieved by milling, grinding or shredding (Zia et al., 2007). Further in chemical re-cycling, the polymer waste is turned back into its oil/hydrocarbon component in the cases of polyolefin's and monomers in the case of polyesters and polyamides, which can be used as raw materials for new polymer production and petro-chemical industry (Sasse and Emig, 1998). The chemical recycling can be categorized into advanced process like: pyrolysis, gasification, liquid-gas hydrogenation, viscosity breaking, steam or catalytic cracking and the use of plastic waste as a reducing agent in blast furnaces (Al-Salem, 2009). Moreover, the energy recovery process was found particularly to be an attainable solution to plastic waste in general and municipal waste. A number of environmental concerns are associated with this method, mainly emission of certain air pollutants such as: CO2, NOx and SOx.

3.2 Electric and electronic waste (e-waste)

Like other hazardous wastes, the problem of e-waste has become an immediate and long term concern as its unregulated accumulation and recycling can lead to major environmental problems and endangering human health (Technical Report: e-waste in India by Agnihotri, 2011). The creation of innovative and new technologies and the globalization of the economy have made a whole range of products available and affordable to the people changing their lifestyles significantly. Electronic products, an indispensable part of human's life, are providing us comfort, security, entertainment, easy and faster acquisition and exchange of information. But on the other hand, it has also led to unrestrained resource consumption and an alarming waste generation. It comprises a whole range of electrical and electronic items including: refrigerators, washing machines, computers and printers, televisions, mobiles, i-pods, etc., and many of which contain toxic materials. E-waste consists of all waste from electronic and electrical appliances which have reached their end- of- life period or are no longer fit for their original intended use and are destined for recovery, recycling or disposal. It includes computer and its accessories monitors, printers, keyboards, central processing units; typewriters, mobile phones and chargers, remotes, compact discs, headphones, batteries, LCD/Plasma TVs, air conditioners, refrigerators and other household appliances (Lalchandani, 2010).

The pyrolysis oils can be used for fuel or chemical feedstock. This new method has been highlighted as a clean and non-polluting technology which offers a new way to recycle valuable materials from WPCBs. Alagusankareswari et al., (2016) used non-biodegradable e-waste in concrete and tested the mechanical properties of the samples thereby. Brandl et al., (2001) also applied the microbiological processes to mobilize metals from e-waste materials. Soo et al., (2013) conducted a study to look into possibilities of the recycling of CRT manufacturing waste sludge as additive in asphalt concrete mix materials. Specimens of varying compositions of asphalt and CRT sludge were prepared by following standard operating procedures and tested for their stability, flow rate, porosity and density. E-waste is currently being filled in the land which is depleting the quality of fertile sand (Barba- Gutierrez et al., 2008; USEPA, 2000). Spalvins et al., (2008) concluded that e-waste disposal in modern-municipal solid waste landfills is unlikely to result in lead leachate concentrations of regulatory concern.

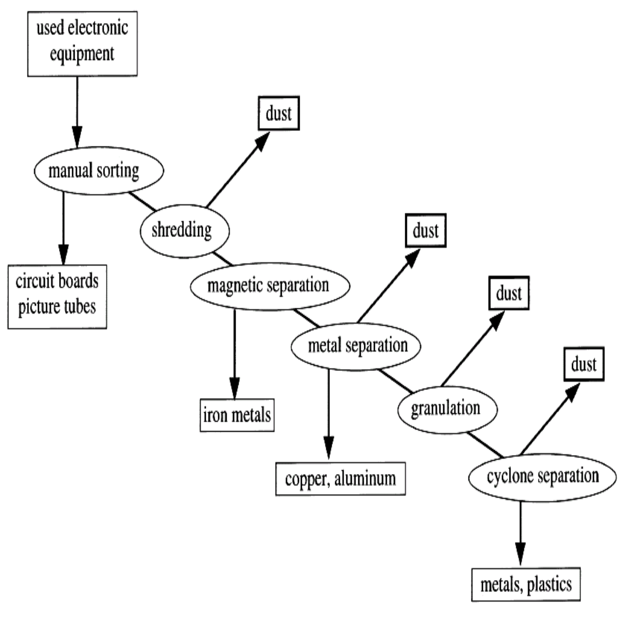

Fig 4 Generic e-waste treatment flow diagram

Many e-waste contaminants are spread into the air via dust. This is a major exposure pathway for humans through ingestion, inhalation and skin absorption (Mielke and Reagan, 1998). A report by the Basel Action Network and the Silicon Valley Toxics Coalition, Exporting Harm: Trashing of Asia' asserts that 50 to 80% of e-waste collected for recycling in the US is exported to developing Nations (Heart, 2007). The aerial contamination with dioxins has resulted in the levels of human exposure to 15–56 times higher than the WHO recommendations (Chatterjee, 2007). E-waste is chemically and physically distinct from other forms of municipal or industrial waste. It contains both valuable and hazardous materials that require special handling and recycling methods to avoid environmental contamination and detrimental effects on human health. Effective electronics recycling requires the involvement of human as without our awareness and courage, it would not be possible. This essentially means that consumers need to know where to take their electronic devices and when they become obsolete or defunct. The best option for dealing with e-wastes is to reduce the volume. For this, designers should ensure that the product is built for re-use, repair and/or upgradeability. Recovery of metals, plastic glass and other materials reduces the magnitude of e-waste.

3.3 Machining scrap, tires, glass, ceramics wastes, etc.

Apart from plastic and e-waste, other types of wastes such as: machining scrap, paper, tires, glass, ash, composites, ceramics, etc., also contributes towards devastation of resources, energy, economy and environment. Literature has shown tremendous examples of utilization and reduction of these wastes. Some of those have been discussed in this section the strength characteristic of CNC waste with recycled aggregates in concrete mix. In their work, different proportions of CNC waste aggregate (1 and 2%) were added in concrete castings and were subjected to several tests (such as: workability test, compressive strength test and bulk density, water absorption, impact value test, crushing value test, fineness modulus), as per the IS specification. It has been found that the compressive strength was gradually increased by 50% with 2% of CNC waste. Similarly, Vijayakumar et al., (2012) used THE lathe scrap as fiber reinforced concrete in the innovative construction industry. In a similar way, Sengul, (2016) presented the results of an experimental program wherein steel fibers recovered from scrap tires and were used to produce fiber reinforced concretes at different percentages. Some mechanical properties such as: compressive strength, splitting strength and flexural strength were determined. And the load-deflection behaviors including the post-peak responses were monitored by means of a closed-loop bending test set-up. Test results showed that, the steel fibers recovered from scrap tires affected the mechanical behavior of concrete as similar to the commercial steel fibers.

4. ZWM through sustainable manufacturing

In this competitive world, the quality of manufactured products is turned into a challenging issue for its market share as the waste management is considered as a major challenge. The influence of the production activities on the global environment becomes remarkable, and the effective countermeasures in the reduction of waste and energy conservation are strongly required in manufacturing processes. Environmentally conscious manufacturing has received increasing interest in the last couple of years owing to preventive legislations. This credit goes to the Europeans who initiated the trend of "Product Take-Back" from the customers, which also acted as an encouragement for many American industries. King and Lenox, (2001) described "green" as '*the good public spillover of Lean*' and explain these positive side-effects in the efforts towards waste reduction and the cutting back of pollution. It involves green design of products, use of environmental friendly raw materials, eco-friendly packing, distribution, and reuse after end of life of product. It slows the depletion of natural resources and lowers the trash. Its emphasis is on reducing parts, rationalizing materials, reusing components. It covers a number of manufacturing issues, including '6 Rs' i.e. reduce, reuse, recycle, recover, redesign and remanufacturing.

Fig 5 Waste Hierarchy

Sustainable development has become an important part of approaches to integrate economic, environmental, and social aspects. The Department of Commerce recently identified sustainable manufacturing as one of its high-priority performance goals. The concept of sustainable production was emerged at the United Nations conference on environment and development in 1992, and was concluded that the major source for environmental degradation is unsustainable production and consumption patterns. The choice between competing alternative designs is usually made on the basis of some quantitative score derived from a procedure that evaluates the net environmental impact over the life of the product like life cycle assessment/costing. This exercise is usually faced an fateful problem to greater practical implementation of sustainability initiatives and lead to efforts in developing more readily implemented life cycle cost assessment methods proposed a sustainable manufacturing approach to minimize the use of energy, material and to maximize the part life. The mutually beneficial relationship between sustainability and economic performance is now generally accepted as true.

5 Environmental Issues in Manufacturing: The Clean(er) Production

In the past, the relation manufacturing/environment was based on the assumption that the environment was able to absorb a certain pollutant load without significant imbalances; therefore, environmental damage could be avoided by controlling the way, the time, and rate at which pollutants were released.

Against this background, the uncontrolled release of many harmful substances, led to a costly repair to remedy the damage of the past and to isolate pollutants through the end-of-pipe system. These actions settled pollution problems at local level, but created new problems. In fact, the end-of-pipe systems often simply transfer pollution from upstream to downstream of the production chain, *i.e.*, from an environmental receptor to another without, therefore, resolving the problem. In addition, the end-of-pipe measures, although not as costly as the repair of damage to the environment, contribute to an increase in production costs and require a regulatory control that have proven to be ineffective due to high costs and the amount of work needed. Awareness of these limits has gradually shifted the focus from reactive actions (pollution control) to preventive actions. While reactive actions focus on measures to reduce risks and damage caused by waste and harmful substances after being produced, preventive actions focus on the conditions and circumstances to avoid damage before it occurs. The preventive strategy includes product reformulation/redesign, modifying consumer models, reducing the use of harmful substances and waste minimization; prevention is better than cure‖ is the basis of environmental policies aimed at encouraging the implementation of so-called cleaner technologies. The Organization for Economic Co-operation and Development (OECD), has adopted a more process-oriented production strategy and defines cleaner technologies as Technologies that extract and use natural resources as efficiently as possible in all stages of their lives; that generate products with reduced or no potentially harmful components; that minimize releases to air, water and soil during fabrication and use of the product; and that produce durable products which can be recovered or recycled as far as possible; output is achieved with as little energy input as is possible. Cleaner technologies can be adopted through substantial change in production processes, or integrating partial changes in current processes to recover and boost by-products otherwise unused. Adopting cleaner technologies to improve functional performance and redefining commodity markets, implies changing production processes to improve overall environmental conditions. It, thus, represents stepping up restructuring systems and an important opportunity to retrieve efficiency.

The evolution of the clean approaches to the manufacturing issues can be referred to the conceptualization of the Industrial Ecology (IE). As previously mentioned, IE aims at reducing waste and pollution by using by-products or waste deriving from certain production processes, such as raw materials for others. Applying IE in production systems implies adopting a manufacturing approach in which the environment provides a positive contribution to the system's competitiveness by maximizing efficiency in the use of raw materials and natural resources. In the field of IE, tools for the design, assessment and management of production systems from the perspective of eco-compatibility have gradually found a place If, from a theoretical point of view, principles and tools of IE provide solutions that enlarge the perspective of environmental management in manufacturing, from the operational point of view is still missing, by companies a strategic vision of this variable, which has not yet been fully internalized while representing the next pillar of competitiveness.

6 From Efficiency to Eco-Efficiency: The Relationship Value/Waste in Manufacturing

When, in 1999, the World Business Council for Sustainable Development (WBCSD) developed the concept of eco-efficiency, its intention was help measure performances in terms of economic and environmental sustainability in business. The WBCSD affirmed that ―the eco-efficiency is achieved by providing competitive products and services that satisfy human needs and lead to higher quality of life, progressively reducing the ecological impact and use of natural resources throughout the life cycle of a product, in line with the carrying capacity of the Earth" [2]. Eco-efficiency indicators primarily serves as a decision-making tools for internal management to evaluate performance, set targets, and initiate improvement measures; they also represents important tools for communicating to internal and external stakeholders. In order to calculate eco-efficiency, the WBCSD has developed the following equation, which merges value and ecological aspects into an efficiency ratio:

Eco-efficiency = product or service value/environmental influence

This relation summarizes the above-mentioned goal of ―create more value with less impact‖. Eco-efficiency progressively leads the assessment of the environmental impact of processes and products to be one of the main strategic and operational criteria of choice in business. Issues relating to the reduction of resource use, as well as the decrease of airborne, waterborne, and soil emissions and waste released should be dealt with a preventive approach integrated into the production process. Such an approach

includes the redesign of products, the introduction of cleaner technologies, the reduction of harmful substances, a change in patterns of consumption, the minimization of waste. The environmental impact in the life cycle of a processes, products or economic activities is minimized when it is possible to reduce the amount of materials and energy flowing through them; if the reduction is achieved without reducing the level of service, and, thus, the final value, an improvement in the overall process efficiency can be obtained by eliminating waste and unnecessary costs. Eco-efficiency makes a direct connection between environmental goals and firm profitability by incorporating the efficient use of the environment into the firm's strategic planning.
In the light of the notions/concepts of efficiency and eco-efficiency, over the past two decades numerous studies have been developed. Starting from the clean (including the IE approaches) or the lean manufacturing standpoint they have investigated the links between the concepts of value, waste, productivity, strategies, competitive advantage, and their application to manufacturing contexts, even in the broad sense of the supply chain/life cycle perspective.

7 "Clean" Manufacturing and Competitiveness

Already, in 1995, Porter and Van der Linde stated that pollution is often a form of economic waste, considering scraps, harmful substances, energy discharged into the environment has forms of resources that have been used incompletely, inefficiently, or ineffectively. In this article, focusing on the concept of resource productivity, they explore hidden costs along the life cycle of a product that are also sources of pollution, and that reveals flaws in the product design or process development. Later, Handfield et al. published in the Journal of Operations Management a taxonomy of environmentally friendly operation management best practices within the VC (1996), integrating interviews with managers of five major companies operating in the furniture industry. The results of this work have shown that to be successful, strategies for environmental management should be integrated into every stage of the VC, and how, their implementation may lead to benefits in terms of competitive advantage. In 1998, Easty and Porter analysed the potentials of IE as a tool for shaping firm strategy and competitiveness. They observed that IE, moving from the goal of resource productivity, may lead to innovations that improve efficiency, lower costs, and raise the value created by a production process. In particular, thy stated that the systems perspective of IE can help companies find ways to add value or reduce costs both within their own production processes and up and down the supply chain. However, they also point out that, despite having a high value as a tool for the discovery of new sources of competitive advantage cannot be a fundamental element of the entire production strategies, because there are other sources of cost reductions or increase in value and why, in the short period, the increase in costs due to investments green, would grant a temporary competitive advantage to competitors. From a more practical point of view, Tsoulfas and Pappis addressed the problem of identifying environmental principles for the design and operation of supply chains, moving from a background of environmental principles for achieving eco-efficiency and building of environmentally friendly organizational systems. Using a ―cradle to grave‖ approach they provide some remarks regarding the benefit for companies: first, a sustainable approach can lead to internal cost savings from a more efficient use of resources; second, sustainability can open new markets; third, opportunities abound to assist other companies and communities in emerging markets. The external validity of the assumptions that the implementation of eco-efficient business strategies is associated with higher firm value has been verified by Sinkin et al.

7.1 "Lean" Manufacturing and Environmental Issue

However, in 1996, Florida emphasized the links between the concepts of lean and clean manufacturing, exploring the relationship between advanced production practices and innovative approaches to environmentally conscious manufacturing. Through a survey and a field research, he brings to light two sets of results that support the existence of this positive connection. First, that LM approaches create opportunity for the development of green strategies moving from the same principles: continuous and productivity improvement, quality, cost reduction, and technological innovation; second, that close relations among the actors of the supply chain (from suppliers to end users) can enable the simultaneous adoption of the lean and green strategies. Some authors reached the same findings, analysing the relations between the quality and the environmental management standards. Subsequently, King and Lenox, conducting an empirical analysis of the environmental performance of more than 17,000 manufacturing companies during the period 1991–1996, found that those companies that adopt the ISO 9000 standards was more likely to adopt the ISO 14000 standards. In addition they show that LM can positively contribute to the adoption of green strategies, acting on the marginal costs of pollution prevention and on the managerial capabilities. During the same period, other researchers obtained conflicting results, such as Rothenberg *et al*, analysing the relationship between LM and environmental performance in 31 automobile companies between North America and Japan. The statistical part of their study showed no significant links between emissions reductions and JIT procedures, especially in respect of the investments in technology. The qualitative analysis instead revealed direct positive relationships between some aspects of the LM (buffer minimization, work systems, and human resource practices) and the propensity of managers to improve the efficiency in the use of resources, as the LM focuses on general waste reduction, provides managers with the basic skills and an attitude focused on continuous improvement. A clear representation of the indirect effects on the environment of the LM has been provided by Moreira *et al.*. One of the most significant contributions to the ongoing debate on lean and clean manufacturing comes from the U.S. Environmental Protection Agency (EPA). Since the early 2000s, the EPA has initiated a series of surveys among the largest U.S. firms to investigate the links between the use of Lean approaches and environmental performance. Those studies have shown that the adoption of Lean approaches in many cases had enabled the company to achieve significant improvements on resource productivity with important implications on the environment. In particular, the report of 2003 states that "Lean manufacturing is a leading manufacturing paradigm being applied in many sectors of the U.S. economy, where improving product quality, reducing production costs, and being "first to market" and quick to respond to customer needs are critical to competitiveness and success. Lean principles and methods focus on creating a continual improvement culture that engages employees in reducing the intensity of time, materials, and capital necessary for meeting a customer's needs. While lean production's fundamental focus is on the systematic elimination of non-value added activity and waste from the production process, the implementation of lean principles and methods also results in improved environmental performance"

The authors highlight the need to develop tools to solve such conflicts and help the managerial decision making to find solutions that take into account Lean, Green a Supply Chain Management goals. In respect of this, studies have been published trying to reproduce, in a comprehensive model, these different perspectives. Newly, Haj Mohammad *et al.* Hypothesized a model that suggests that supply management as well as LM activities provides means by which environmental actions can be encouraged. Although the study sample was limited to a sample of Canadian manufacturing plants, the empirical evidence provides the interesting findings that a suitable route to facilitate the implementation and adoption of environmental practices is by setting an adequate operating context based on lean and supply management principles.

Reducing or eliminating waste.

At Waste Management, we help you address the myriad of sustainability issues you face by finding and implementing the right waste elimination and reduction solutions. In the process, we are able to draw on a vast infrastructure and network of provider alliances.

8. Resource flow analyses.

Our experts will examine the environmental impact of your product or service, including its raw material input, conversion processes, conveyance system, non-product output, consumer use, and final disposition.

8.1 Sustainable operations review.

We'll examine your operation from input through output and, specifically, look for opportunities to help you:

- Save money by eliminating or reducing non-product output
- Source or design product inputs with "next-life" potential
- Engage your supply-chain partners in sustainability
- Design customer products with improved sustainability attributes
- Increase success through organizational and behavioral changes
- Design comprehensive material flow and recovery systems

9. Resource productivity.

We can help you develop sustainable business operations that reduce waste by concentrating on resource productivity and next-life solutions. We can work with our network of outside sources and recyclers to find homes for manufacturing residuals – some of which end up right back in your facilities as new materials.

9.1 Zero-waste successes.

Across the country, manufacturing companies of all sizes are discovering the cost savings and environmental benefits of working with Waste Management's Sustainability Services team to eliminate or greatly reduce their waste. Here are just a few examples.

9.2 Aluminium Production

Waste Management helped this company recognize the value of materials that were discarded as a by-product of the manufacturing process. Through innovative process improvements and committed execution strategies, the result was more than $500,000 annualized savings in landfill and raw material costs.

9.3 Automotive Manufacturer

Since 2000, Waste Management has managed resources for this manufacturing plant, which has achieved zero-landfill status. The automaker has now taken the next step, redirecting the waste from this plant toward alternative energy generation, which now creates energy to power homes in the surrounding community.

9.4 Manufacturer of Heavy Equipment

This Fortune 200 manufacturer of heavy construction/mining equipment worked with Waste Management to minimize plant and vehicle emissions and optimize use of renewable resources. At one company location, the landfill diversion rate has already improved from 30% to 80% in its first full year.

9.5 Major Manufacturer

Waste Management achieved $175,000/year in first- year savings. Our collaboration with the production floor teams drove down labor costs while increasing diversion successes. A closed-loop recovery system added an incremental $75,000/year in savings from non-traditional waste recycling.

9.6 Beverage Producer

In this relationship with a major beverage producer, Waste Management evaluated the company's supply-chain management of obsolete and off-spec product. The result was a national reverse-logistics and zero-landfill program solution.

10 Conclusions

Cost, time, and quality have been the pillars on which was focused the competitiveness of manufacturing companies over the last century. More recent trends focusing on a renewed interest in environmental issues and socio-ethical values have gradually imposed the transition towards low impact economies. The full integration of the environmental variable in the production decision-making should lead to a more rational and eco-efficient use of resources and reduction of pollution and wastes. However, a gap still remains to simultaneously achieve the economic and the environmental goals, e.g., due to the companies' limited economic resources, the lack of knowledge of some tools, the business size and the resistance to change. An interesting and promising perspective for integrating the Lean Manufacturing (LM) and the Industrial Ecology (IE) approaches and tools. LM, perspective yet includes the most important management variables (cost, time, quality, value) and is aimed at implementing solutions to manage them efficiently; approaches and tools developed within IE research field allow to manage the environment aspects of manufacturing in an eco-efficient way. Both LM and IE have a system-oriented perspective of analysis and focus on the reduction of wastes. The identification and intervention tools can be in that case the Life Cycle Assessment/Life Cycle Costing, and the Eco-Design procedures. The recognized complexity of such tools and the lack of empirical studies are limiting their diffusion as support tools for an eco-efficient manufacturing, especially in the case of small-medium enterprises; this can be considered one of the major potential challenges in integrating the two perspectives of LM and IE and the next steps of the research will be directed in such a direction. Emerging new manufacturing technology widely known as 3D printing or additive manufacturing (AM) has the attributes of ZWM. So by using these techniques we completely achieve Zero Waste Management target.

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