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INDUSTRIAL WASTE MANAGEMENT WITHIN MANUFACTURING: A COMPARATIVE STUDY OF TOOLS, POLICIES, VISIONS AND CONCEPTS

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ABSTRACT

Industrial waste is a key factor when assessing the sustainability of a manufacturing process or company. A multitude of visions, concepts, tools, and policies are used both academically and industrially to improve the environmental effect of manufacturing; a majority of these approaches have a direct bearing on industrial waste. The identified approaches have in this paper been categorised according to application area, goals, organisational entity, life cycle phase, and waste hierarchy stage; the approaches have also been assessed according to academic prevalence, semantic aspects, and overlaps. In many cases the waste management approaches have similar goals and approaches, which cause confusion and disorientation for companies aiming to synthesise their management systems to fit their waste management strategy. Thus, a study was performed on how waste management approaches can be integrated to reach the vision of zero waste in manufacturing.

Keywords: waste management, industrial waste, manufacturing

1 INTRODUCTION

An increase in global manufacturing activities is evident. Globalisation, industrialisation, and economic development has led to an increase in product demand and increased manufacturing activity – we have seen a 35% increase of global manufacturing activities over 2001-2010 while the global GDP increased by 26% (Wiktorsson, 2012), which also lead to larger volumes of industrial (material) waste (Tojo, 2004). Since the introduction of the concept "sustainable development" (WCED, 1987) and commitment to the United Nations Commission on Sustainable Development (EU, 1987), the apprehension of limited resources on the earth has been noticed remarkably (Tojo, 2004).

In the last 20 years, industrial waste has become a critical issue and causes concerns with regards to global sustainability and environmental effects (Macarthur, 2012). In 2010, the total generated waste from households and economic activities in the EU-27 amounted to 2 570 million tonnes while Germany, France and UK have the most portion in the generated waste. Manufacturing accounted for 280 million tonnes of waste generation in 2010 (around 10.9 % of the total) while generated waste from households accounted for 221 million tonnes in the EU-27. UK, Poland, Italy, Germany and France together generated around 60% of total manufacturing waste in 2010, whereas UK produced around 23 million tonne (8% of total manufacturing waste) and Sweden produced 7.8 million tonne manufacturing waste (2.7 % of total manufacturing waste). However, waste quantity is one problem while the quality of waste is the other – being hazardous or non-hazardous, valuable or non-valuable. Current industrial waste management challenge is to keep high quality grades of material in the industrial system.

The scope of waste management is wide and encompass different terms. Both industrial waste and depletion of virgin material put pressure on manufacturing companies to find new viable approaches that are in line with environmental, social, and economical sustainability. Different approaches have been created in academia and industry in the past few years, but evidence of actual use of them is not clear. They also overlap each other by having similar goals and proposing similar approaches toward waste management (Lilja, 2009). Examples of such concepts are zero waste, waste minimisation, zero emission and waste prevention. To support conquering of mentioned challenges, this paper contributes to the field of sustainable manufacturing by presenting a comparison of tools, policies, visions and concepts for industrial waste management.

2 RESEARCH DESIGN

A structured literature search was done as complement to former reviews on waste management approaches that are applicable for manufacturing industry. Of the identified papers addressing industrial waste management, 80 papers were reviewed to identify and contrast different waste management approaches. The search incorporated the key words "industrial waste" and " waste management approach" as well as their combination with "manufacturing" and "automotive". The search was focused on papers addressing a situation similar to that in Swedish manufacturing industry and specifically automotive industry; however, papers addressing waste management outside of this scope were also included in the study. The selecting method was based on both keywords a qualitative up-stream and down-stream search for relevant references. The empirical base for the paper relies upon discussions with experts in industrial workshops, in order to verify the results. In addition to the 18 waste management approaches presented in this paper, an additional 19 were identified but omitted. The exclusion was either based on that an approach had a limited link to industrial waste management, or that an approaches was a subsets of another one that is addressed in this paper, e.g. *eco-industrial parks* and *industrial symbiosis* are applications to the concept *industrial ecology*, and *Individual Product Responsibility* and *Extended Product Responsibility* are subsets of the policy/tool *product stewardship*.

3 WASTE MANAGEMENT APPROACHES

3.1 Zero waste

The *Zero waste* focuses on waste prevention, minimisation and reusing by considering waste as valuable resource rather than a problem for companies. It aims to utilise the concept *material efficiently* and uses all material inputs in the final product or changes it into other inputs for another process(Tang, 2008). Matching input and output of different industries is one of the key challenges that need to be solved, possibly by *industrial ecology* through eco-industrial parks, industrial symbiosis, and new technologies (ZeroWIN, 2010, Atlas, 2001). On a smaller scale products also need to be designed to meet the requirements of multiple lifecycles, for example through *eco-design* and design for disassembly and reassembly (Tang, 2008). With the same intention, *Environmentally Conscious Design and Manufacturing(EDCM)* addresses the existing and future relationships between design, manufacturing, and environment. Environmentally conscious technologies and design practices help manufacturers to minimise waste and turn it into a profitable product (Zhang et al., 1997). The *zero waste* vision and *closed-loop* are both directed towards preventing waste rather than managing generated waste, however *zero waste* can be integrated with other approaches including *industrial ecology*, *cleaner production*, pollution prevention, *zero emissions* and natural capitalism. (Curran and Williams, 2012). Furthermore, tools including *Green performance map, eco-mapping* and *waste diversion planning system* can be commonly used to pursue *zero waste* vision as all are based on eliminating wasteful usage of energy, material, emissions and resources.

Regulatory factors commonly play a key role to encourage waste minimisation activities; however, geographically limited regulations generally drive costs in the short term. Therefore it is easier to establish and enforce regulations when the economy is good.

3.2 Waste prevention

The *waste prevention* is a vision that focus on both quantitative and qualitative reduction of waste, i.e. lower volumes and lower toxicity before the material or product is converted to waste (Lebersorger, 2008, Lilja, 2009). This definition covers the top three steps of the *waste hierarchy*: prevention, reduction and reusing. However, *waste prevention* neither include recycling, energy recovery, nor product design for recycling and remanufacturing (Lilja, 2009). Discarded material is in this vision considered as waste, even if they are recycled regardless of if money is paid for the material. The *waste prevention* can be strengthened by *product stewardship* via standards, legislations and *cleaner production* through technology optimisation and innovative technologies. Other approaches including *eco-design*, *Environmental Management Systems (EMS), Environmentally Conscious Design and Manufacturing(EDCM)*, *eco-efficiency, eco-mapping* and *Green performance map* contribute in obtaining such vision while all of them cover waste prevention step in *waste hierarchy*.

Material efficiency and *waste prevention* both are crucial approaches towards *zero waste* (ZeroWIN, 2010). However, *material efficiency* is a preferred life cycle approach rather than *waste prevention* since the majority of the environmental benefits from waste prevention stem from the decreased requirement to produce materials (Lilja, 2009), as elaborated: "*Waste prevention is the goal ranked highest in the waste hierarchy, but the materialisation of this goal needs actions that are not alternatives for investments in waste recycling, waste recovery or final disposal*".

3.3 Cleaner production

The objectives of the *cleaner production* is to enhance productivity and environmental performance, reduce environmental effects, improve raw material efficiently, reduce water and energy usage, decrease emissions and design for environmental cost-effective products i.e. *Eco-design* (Li and Chai, 2007, EPA, 2003). In comparison with the *eco-efficiency* (Gravitis, 2007), *cleaner production* is based on environmental efficiencies that have internal economic advantages, whereas *eco-efficiency* is based on economic efficiencies that have environmental advantages. Neither of these concepts cover waste utilisation in late life-cycle phases. For instance, unlike end-of-pipe waste management solutions, *cleaner production* focuses on the manufacturing phase of the product life cycle (Gumbo et al., 2003). In addition, this vision cover the least area on *waste hierarchy* among the other visions by just considering reduction stage and it is in line with (Kuehr, 2007) study which put *zero emission* as the next step of *cleaner production* towards sustainability.

Cleaner production and *eco-efficiency* focus on reducing materials inputs and reducing wastes at the level of the firm, whereas *industrial ecology* characterises a development that moves forward from dealing with localised environmental impacts (Gibbs and Deutz, 2005). At the firm level *eco-design*, pollution prevention and green accounting can contribute; LCA tool and process-based strategies e.g. industrial symbiosis are used at the inter-firm level; and material and energy flows are used at the global level (ZeroWIN, 2010). *Cleaner production* pertain also cleaner technology, *Environmental management systems* and *best practice* concepts (Zhang et al., 1997). Cleaner technology associated by using innovative technologies that have economic and environmental benefits for source reduction and eliminating or reducing hazardous waste (Curran and Williams, 2012). Although technological progresses has helped industries to some extend reduce the environmental damages, *best practice* does not solely consist of changes in process but it also include changes from old way of thinking to continuous improvement of all aspects of companies' operations and activities. An example of related tool is *waste diversion planning system* which improve waste recycling performance by track particular material diversion tonnage and total percentage of recycled material regarding weight or volume.

3.4 Zero emission

The *zero emissions* vision is more extensive than *cleaner production* vision or other related concepts such as *product stewardship* (ZeroWIN, 2010). It is closely related to Eco-design through LCA and carbon footprint. This vision is in line with pollution prevention and *waste prevention* as all focus on reducing wastes and emissions to zero without decreasing productivity. According to (Kuehr, 2007), *zero emission* is the last step toward sustainability whereby a *closed-loop, industrial ecology* (via eco-industrial parks), wastes being used as inputs for other industries. Connection of *zero waste* and *cleaner production* can be found through using of new technologies and analysing material flows (Gravitis, 2007). Various tools are also related to such vision e.g. *GPM* can identify non-productive outputs of processes in term of rest material, waste and emission to air, water and ground (Kurdve et al., 2012).

4 ANALYSIS

The identified set of waste management approaches have similar approaches and strategies to tackle current environmental issues, which cause confusion for industries who want to minimise generation of waste and emission. The approaches can be classified into visions, concepts, tools, and policies; each of these serve the purpose of reducing waste or the effect of the waste that is generated. Visions are generally unattainable, but serve as ultimate targets to strive for. Concepts represent broad ideas and solutions for how to reach a vision; however, each individual concept is generally not sufficient to reach a vision. Tools generally incorporate a specific process that serves a specific goal, and a set of tools with different application might are commonly utilised to pursue each concept. Policies and environmental regulations are either used to hinder development in an undesirable direction or to steer companies towards a more desirable path. Policies and regulations are imposed by local, national or international authorities; however, depending on the policy itself and the market it targets, the effects may exceed its geographical intent or have a more limited effect.

Figure 1 presents the waste management approaches that were most cited in literature with respect to manufacturing industries. The approaches are mapped according to type (vision, concept, tool, or policy), organisational usage level (management or operation), measurement (quantitative or qualitative), improvement action (technology upgrade, management/decision-making, operational improvement, mind-set changes, or raw material substitution) and number of found citations (based on pair key word search).

	Type	Visions				Concepts							Policies			Tools			
	Waste management approach	1. Zero emission	2. Cleaner production	3. Waste prevention	4. Waste Minimization or Zero Waste	5. Eco-efficiency	6. Eco-design	7. Best practice	8. Environmentally Concious Design & Manufacturing (EDCM)	9. Closed-loop	10. Industrial ecology	11. Reverse logistics	12. Material efficiency	13. Product stewardship	14. Environmental management system (EMS)	15. Eco-mapping	16. Green performance map (GPM)	17. Waste hierarchy	18. Waste diversion (planning system)
Organisation level	Management	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓		
	Operational		✓					✓			✓	✓	✓			✓	✓	✓	✓
Measurment	Quality	✓	✓	✓	✓		✓	✓	✓					✓	✓	✓			
	Quantity	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Improvement actions	Technological		✓	✓	✓				✓		✓								
	Managerial	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	
	Operational	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓	✓	✓		✓
	Raw material substitution				✓		✓		✓		✓		✓	✓					
	Mindset			✓	✓			✓					✓					✓	
Citations	"Waste management approach" AND "waste"	40	140	50	434	54	12	70	1	98	76	55	23	12	44	0	0	21	26

Figure 1: The 18 most cited tools, concepts, visions and policies categorised

According to figure 1, most of the approaches are applicable for management, but only one of the visions and two of the concepts are applicable for the operational level. This illustrates a gap where the practical operational processes do not have sufficient background or purpose. The lack of vision and purpose may lead to that hands-on environmental efforts, tools, and policies introduced at the shop-floor are met with distrust and seen as unnecessary work. This inevitably leads to inefficient waste management and non-sustainable production. In order to improve waste management at the operational level, the vision and concept associated with each tool needs to be made clear for the users.

Only half of approaches focus on both a quantitative reduction of waste and a qualitative reduction i.e. reduced toxicity. Treatment of hazardous waste and toxicity disposal is therefore the next major concern in waste management activities. Around 77% of all approaches note that better management and decision making lead to environmental improvement, while 88% of them recommend operational improvement of the actual waste generating processes as well. Technology upgrade, raw material exchange and mind-set change have been addressed by approximately 30%. This indicates that operational improvement and managerial decisions play an important role in environmental improvement.

In figure 2 all chosen waste management approaches are mapped according to product life cycle phase and waste hierarchy steps. The mapping is based on the literature review; however, the specific approaches are not necessarily static and rarely directly linked to life-cycle phases or waste hierarchy. Consequently, the table should be used indicatively for the whole set of approaches, not for drawing conclusions for single approaches.

Product Life Cycle	Landfill	Energy Recovery	Recycling	Reusing	Reduction	Prevention
End of Life	1	1 10	8, 9, 1 10, 11 13	8, 9, 10, 11 12, 13	5, 6, 1 9, 10 12	1 5, 8
Consumption	1	1 8, 9, 11	1, 4 8, 9, 11	4 8, 9, 11 12	1, 4 5, 8, 9 12	1, 4 5, 8
Manufacturing	1 16	1 10 16	8, 9, 1, 4 10, 11 16, 18	8, 9, 2, 4 10, 11 18 12	1, 2, 3, 5, 7, 8, 4 9, 10 16 12, 14	1, 2, 4 5, 7, 8 16
Raw material Processing	1 16	1 10 16	8, 9, 1, 4 10, 11 16	8, 9, 2, 4 10, 11 12	1, 2, 3, 5, 7, 8, 4 9, 10 16 12, 14	1, 2, 4 5, 7, 8 16
Design	1	1	1, 4 6, 8	4 6, 8 12	1, 4 5, 6, 8 12	1, 4 5, 6, 8
	17 - Waste Hierarchy					

Figure 2: Integrated table of waste hierarchy and product life cycle, with numbers from Figure 1

The waste management approaches that cover the most areas in the matrix above are *zero waste*, *eco-design*, *industrial ecology*, *waste prevention*, and *cleaner production*. These are either visions or concepts, which is logical since both tools and policies need to be more detailed and therefore have a more limited scope. The majority of waste management approaches refer to *reduction*, followed by reuse, *recycling*, and *waste prevention*. The dominance of *reduction* approaches is natural since waste reduction has a direct effect on manufacturing activities at the factory, reducing volume, cost and complexity resulting from waste. Therefore, non-environmental benefits might be an incentive for manufacturing companies to more focus on reduction. The limited number of approaches linked to *landfill* and *energy recovery* is a direct result from this study's focus on manufacturing; however, it also shows that these end-of-pipe solutions have a weak connection to a product's life phases and waste management activities in manufacturing. In addition, both *landfill* and *energy recovery* pose primarily technical difficulties, which is not shown in this study.

Approximately 70% of the waste management approaches have impact on the manufacturing phase of the product. 77% of approaches influence raw material processing phase while half of them affect the end of life phase. Moreover, design and consumption phase can be influenced by 44% of the approaches. As the matrix shows, the manufacturing phase and raw material processing phase of product life cycle are often the primary targets of the approaches; however, the evidences of actual use of them among manufacturing companies is not so common.

5 CONCLUSION AND FUTURE RESEARCH

The most frequent barriers toward waste management and sustainable production is according to this study: technical limitation, cultural shifts, lack of EU-level goals on waste prevention and material efficiency, hindrance for waste prevention due to low waste disposal costs and absence of standards for reusable products. Achieving sustainable production therefore, requires a structured approach with best use of existing tools and concepts integrating with environmental policies, and/or developing new ones in order to prevent waste in the first place. Corporate environmental managers should realise that enhancement of waste minimisation is more probable by hands-on approaches at the facility level and consequently integrated methods should be used at shop-floor to motivate companies to formalise and follow their waste minimisation actions. Most of these actions are not technology driven. They constitute material substitution, waste separation, recycling, process improvement, preventing leak and spills, inventory control and better management procedure. Hence, future waste minimisation might not take place on technological changes but on mind-set changes, operational improvement and management techniques in order to reduce the quantity of waste while enhance the quality of waste and residual material. Re-examination of production processes and operations, and redesigning material flow and production system is necessary to identify waste minimisation opportunities and enable remanufacturing, recycling, reusing, refining and recondition of the material. Moreover, taking advantage of other facilities experiences in waste minimisation actions and communicating these among stakeholders, staffs, customers and supplier will facilitate such paths.

The study is an introduction to the research on different approaches regarding waste management, but more data will be needed to describe their specification and interaction in detail. Examples on future research are to study each approach or subset in respect to a more detailed organisation level, improvement processes and direct and indirect effect on product life cycle phases. Moreover, the application of each approach in different manufacturing companies would be essential to see how these concepts are implemented in practice.

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