

Waste Flow Mapping: Improve sustainability and realize waste management values

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ABSTRACT

An efficient Waste Management System creates increased business value contributing to manufacturing industry sustainability and realizes economic opportunities. Previous studies have shown the economic potential of improving material efficiency by climbing the waste hierarchy and turning waste liabilities into assets. World economic forum also identifies innovation for resource efficient solutions and business models as the most strategic option to capture value in industry. The main responsibility for waste lies with the operations owner but since waste management usually is operated by other functions or companies, supportive methods to include material waste in operational development are needed. The main purpose of the research has therefore been to develop a method framework for identifying and analysing potentials for waste management in manufacturing industry, including residual material values of metals, combustible and inert waste, process fluids and other hazardous waste. Case studies were conducted to find economically competitive environmental improvements on team, site and multisite level and to define suitable performance indicators for continuous improvements. A novel approach: waste flow mapping (WFM), combining Value Stream Mapping (VSM), Eco mapping and a waste composition analysis with basic lean principles is used. The material's value flow and the information flow is analysed in a VSM. Eco-mapping is used to give a graphical structure for the analysis of labour and equipment, with subsequent costs. Finally the waste hierarchy and composition analysis is used to imply the potential for business improvements and best practice examples are used. The developed method reveals the potential in an easy way and support integration of waste management in operations and continuous improvement work.

Empirical data from a full scale multi-site study of waste management of material residuals at a global manufacturing company's operations in Sweden are used to exemplify that with the WFM approach the mapping can be done in an efficient and consistent manner, revealing value losses and improvement potentials. Fraction definitions and operational practice standards were essential to realise cost efficiency and reach a more sustainable footprint. Comparisons between sites show that with simple actions, substantial improvements in recycling efficiency can be made, leading to proposed performance indicators and highlighting the need for established standardized implementation solutions. The results further point out the importance of avoiding mixing material with lower quality grade of that material. The experiences prove that Waste Flow Mapping is a suitable method to efficiently identify sustainability improvement potentials.

Keywords: material efficiency, waste flow mapping, waste management services, manufacturing industry, Environmental system analysis

1 Introduction

1.1 Background

Since the concept of sustainable development was defined the awareness of earths limited resources has been in growing focus (UN 1987). With growing demands on material and upcoming shortages of resources, material efficiency is becoming increasingly important in manufacturing companies operational strategies (Julian M. Allwood, Michael F.Ashby et al. 2011). Although environmental management standards like ISO 14001 have made companies focus on improvement of their environmental performance, especially regarding material waste (Zackrisson, Enroth et al. 2000), World economic forum still identifies innovation for resource efficient solutions and business models as the most strategic option to capture value in industry (WEF 2012) and the Swedish foundation for strategic environmental research, Mistra, has pointed out the importance of more circular economy for Swedish industry in a report "Closing the loop: From Waste to Resource" from December 2011.

The importance of the end-of-life phase from an environmental point of view has been shown in several studies (Zackrisson, Enroth et al. 2000; Lundkvist, Andersson et al. 2004) and the economical potential of improving material efficiency by climbing the waste hierarchy has been demonstrated in WASTEnomics-turning waste liabilities into assets (Tang and Yeoh 2008). The intention in this study is to identify these opportunities and show practical ways of realizing them.

Lean manufacturing has been in industrial management focus for the last couple of decades since Toyotas success in the automotive industry. Lean manufacturing principles and tools have proven fruitful in engaging all employees in improvement activities and pick up new challenges. To minimize the environmental impact from production, earlier studies (Florida 1996; EPA 2003; Bergmiller 2006) identify lean and green as a preferred approach for realizing environmental opportunities.

Industrial waste management often involves several actors and personnel from different organizations; this together with the fact that material waste management may be of less operational importance than producing the main product means that even otherwise effective and environmentally aware companies often have large or substantial opportunities in improving waste management (Halme, Anttonen et al. 2007). A major driver of environmental improvements in supply chains are the demands set from customer to supplier (Nawrocka, Brorson et al. 2009). Among the barriers, costs, lack of understanding and

commitment are mentioned as internal barriers and regulations and information flow constraints as external barriers. However, in order to succeed in the waste management business with as good improvements as in the main operation new requirements are raised on the tools and methods to use for improvements. The methods need to be adapted for a supply chain with several actors and with low resources. The methods for analysis thus have to be simple to understand, easy to use and not demand too much personnel time.

1.2 Scope and research questions

The main purpose of the research has been to develop a method framework, Waste Flow Mapping (WFM), for identifying potentials for improving waste management in manufacturing industry. The framework should rely on existing and well proven tools and methods to analyse the current state and find improvement potentials with regards to material losses and inefficiencies in the handling of materials and waste. A secondary aim was to identify and describe the need for adjustment of combined tools and methods in order to be applicable in practical waste management. The results should present the potential in an easy way and supporting integration of waste management in operations.

In order to adjust and validate the developed method framework, two case studies at Swedish manufacturing companies have been conducted. Initially, a smaller pre-study was conducted followed by a full scale multi-site case study. The case studies were used to find economically competitive environmental improvements on team, site and multisite level, through best practice examples, and to define suitable performance indicators to secure continuous improvements.

The study focus on analysis of the material waste management supply chain and especially on the interface between the waste management and the production management since this interface is crucial for the rest of the waste management process

2 Frame of reference: Tools and principles employed for environmental analysis and operational management

There is a multitude of methods and tools for environmental management and environmental engineering. Regarding lean production the toolbox remains, but different interpretation on how to use them for environmental management arise. As the method to develop should rely on existing and well proven tools and methods, this section briefly introduces seven existing fundamental tools and principles for environmental analysis and operation management and comments on their application in this study.

2.2.1 Green Performance map

Environmental management uses an input-output approach in analyzing the environmental aspects of operations (Zackrisson, Enroth et al. 2000; Romvall, Kurdve et al. 2011). In this work we employ a practice of analyzing unwanted material output in order to find efficiency losses upstream, increase the output residual value and ultimately reduce unnecessary input.

A Green Performance Map (GPM) is an input-output visual green-lean tool developed by University of Mälardalen to enhance understanding of environmental aspects in operations (Romvall, Kurdve et al. 2011). This study focus on material input and waste output as shown in Figure 1. In this model the material output of a manufacturing process is divided in; Productive Output (PO) regarded as value adding and Non Productive Output (NPO) such as material residuals or material waste. The input to these processes can be divided into production material that constitutes the product, and process material that are needed for the manufacturing process.

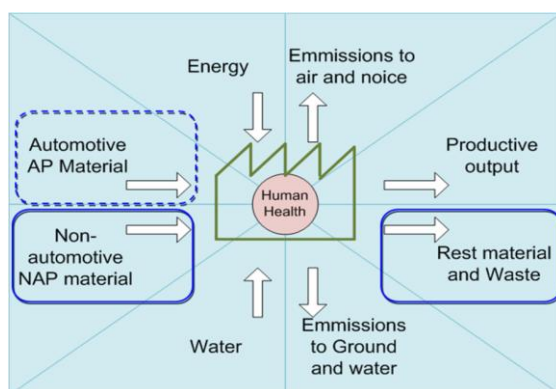


Figure 1 GPM with material focus

2.2.2 Waste hierarchy

Regarding residual material and waste, or NPO, the optimal case is that the disposal of material should be avoided completely. However, some parts of the NPO may still be regarded as necessary (i.e. some type of packaging may be

unavoidable at the time being). In that case, the aim should be that the material value in the NPO material is recovered as an as high grade as possible, e.g. in re-use, material recycling or as energy recovery.

An important principle in increasing material and overall operational efficiency is to use the waste hierarchy (Figure 2). In the waste hierarchy it is generally assumed that from an environmental point of view; reduction of material use is better than reuse of components which in turn is better than material recycling which is better than energy recovery treatment, deposition of waste in landfill and just spreading it out in the environment. The most desirable is, of course, to prevent the waste to occur in the first place. The hierarchy is valid in most cases with exception for some special cases as described by (Kurdve 2008). Although generally accepted this hierarchy is sometimes questioned by practitioners since the different treatment processes' environmental impact are unknown or underestimated further up in the supply chain.



Figure 2 The waste hierarchy (Kurdve, Romvall et al. 2011)

2.2.3 Eco Mapping

One simple and visual tool for working with environmental aspects is Eco-mapping as described by INEM (Engel 2002). Eco-mapping contains several types of environmental aspects but for this study the eco-mapping is limited to waste generation and material waste handling activities. It is simple to use and to understand also by non-experts and is widely used in a variety of industries. The tool is used to identify and visualize the geographical points where the different waste management operations occur, as illustrated in the industrial example in Figure 3.



Figure 3 Eco map of waste points (Kurdve, Romvall et al. 2011)

2.2.4 Waste sorting analysis

In order to analyse the content and composition of waste material, a waste sorting analysis can be performed. For each waste fraction quality criteria are set and during the composition analysis deviations from those criteria are identified; firstly deviations regarding non-wanted materials in this fraction and secondly materials that could have been discarded as another waste fraction with higher material quality (and usually lower cost or higher payment).

2.2.5. Continuous reduction of losses or lean waste

Lean production or lean manufacturing practice focus on reducing “muda”, which means losses or “waste” or rather “waste of time” (rather than material waste). A key issue is to involve all staff in continuous development of their work methods, where a number of lean tools and techniques are used. Successful Continuous Improvements (CI) also demands a mutual trust and that the people involved in operations are also empowered to implement improvements (Moxen and Strachan 1998; Berglund, Karling et al. 2011) This trust will be dependent on an open information flow which becomes more important when several organizational entities are involved (Stoughton and Votta 2003; Kurdve 2010) .

Two fundamentals of lean manufacturing are visualization and go and see – or ‘go to gemba’ (Liker 2004). In order to be able to involve everyone and to make people develop their work in a common direction it is important that it is easy to understand what to do, how to do it and why it should be done. These fundamentals have been leading lights in the development of the use of the employed tools and techniques in this study. Thus the framework prescribes a site visit and the tools and methods have been chosen to be as visual and easy to understand as possible.

2.2.6. Value Stream Mapping

Value stream mapping (VSM) is a tool used to find operational inefficiencies. A VSM can be drawn for the whole supply chain, a process or a single sub-process. When analyzing a single operation cell the VSM analysis will look more like a SOP (Standard Operation Procedure) and inefficiencies may be analysed by drawing spaghetti charts of real movements and comparing them to the SOP. When used in a non-detailed way it can be used to analyse processes with subprocesses in order to focus on improvement potentials. An extension to the regular VSM is to include environmental or resource efficiency losses (EPA 2011) as shown in Figure 4. It can be used to map both product material and process material use for different processes (Qiu and Chen 2009; Zhang 2010; Kurdve, Hanarp et al. 2011).

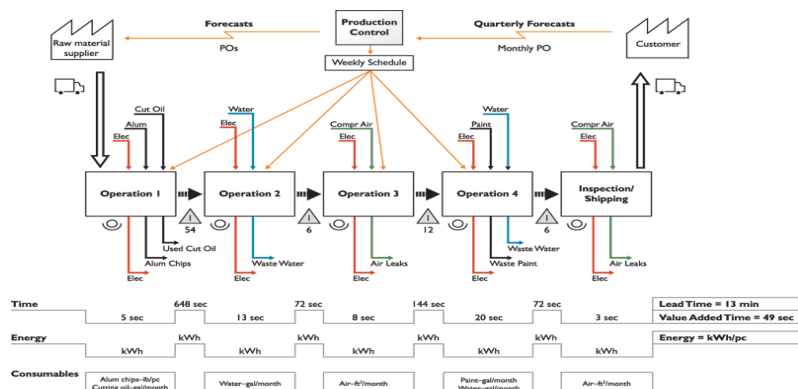


Figure 4 Value Stream Map including environmental aspects (EPA 2011)

2.2.7. Material handling analysis

Material Handling analysis is a tool for analyzing and optimizing internal and external logistics. In its simplest form it is basically a spaghetti chart analysis, but in addition it considers mode of transportation and constraints. There are simulation tools that can support advanced MHA as in Figure 5, but often it may be done by hand drawing and using excel.

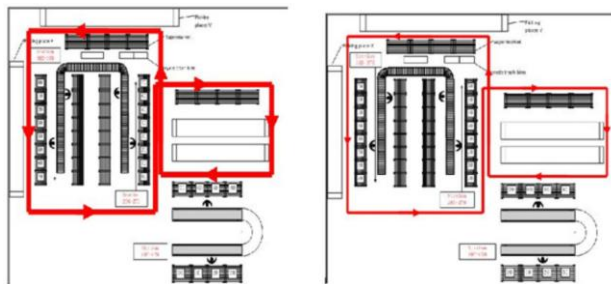


Figure 5 Material Handling Analysis (Qiu and Chen 2009)

3 Research design

The research questions concerned how a framework can be formulated to find practical improvements in industrial waste management, as well as what tools and methods that needs further development in order to be applicable in practice in waste management improvement work.

In order to address these questions, the method development was conducted by a pre-study and a following case study. The multi-site case study was limited to study the wasted material flows and to analyze costs, material efficiency and operational

efficiency in the waste management system at 16 production sites and a number of development and office sites. The method development was performed in order to enable an efficient mapping and analysis with limited resources and time on site, where one main criterion was that the mapping on-site should take at most two working days and the site specific work should be limited to two more days. This meant that the level of detail had to shift somewhat from the prestudy, focusing on team level, to a site or process level.

3.1 Method development procedure

In order to combine tools and techniques into effective and useful methods, the users of the method and the context in which it will be used has to be considered (Lindahl 2005). This means that the criteria, which will make sure that the method is used as intended, has to be in place. In general the method should; support collaboration, promote learning and be easy to learn, be time efficient and support systematic work procedures (Norell 1992)

For environmental work in the automotive industry in Sweden, previous studies have shown that methods need to be based on lean principles, harmonize with ISO 14001, support proactivity, deliver a structured work method/practice and enable performance measure, in order to gain focus on environmental areas in addition to the traditional main productive process focus (Romvall 2012). In addition the multi case study added requirements on usage efficiency and the possibility to conduct a full scale mapping in mere two days on site.

The development followed an iterative loop where the method idea was analyzed, synthesized, simulated or tested, and finally presented. After each simulation/testing, a re-analysis was done in order to change the method to fit to the case. Also the presented results were used to iteratively regenerate new ideas or adapt old ones.

In practice the first methodology approach, simulated in the prestudy, was adapted and analysed in a second loop where an approach better suited for plant level analysis was constructed and synthesized. During the analysis of the first four plants (chosen to be representative regarding size and operations) the method was adapted and time consuming elements (like drawing exact eco-maps) were reduced and a standardized data collection format was used for the rest of the plants. The first four plants were analyzed by all members of the team, but the rest of the plants were analyzed by only one member of the team according to the developed method. This paper can be seen as an analysis phase in order to make a third loop.

3.2 Case study companies

The research has been based on studies from two companies. A pre-study at Concentric AB (formerly Haldex) assembly plant in Sweden was performed in 2009 and a larger multi-site case study was performed on all Swedish sites of the Volvo Group in 2010 and 2011.

Concentric AB Skånes Fagerhult offers applications, product engineering, customer and product service for power packs and pump/motor units for heavy vehicles. The facility operated since 1968 has currently over 110 employees and 31,000 square feet of manufacturing and warehouse space. Concentric AB performed assessment of the packaging waste flows in the pre-study.

The Volvo Group is one of the world's leading manufacturers of trucks, buses, construction equipment, drive systems for marine and industrial applications and aerospace components. Environmental care is a key issue in their vision to become world leader in sustainable transport solutions. Waste management is one prioritized area for environmental improvements regarding industrial infrastructure.

The Volvo group has operations in more than 16 sites in Sweden, illustrated in Figure 6. To support the waste management at all sites, a large multisite project was performed in 2011 focusing waste management and procurement of waste management services. The multisite mapping project was performed by Miljögiraff and Volvo Group Real Estate in cooperation with Martin Kurdve at MDH. The overall mission for Volvo Group Real Estate is to optimize the value of the Volvo Group's real estate facilities and contribute to the Groups' growth through customer cooperation and professional Real Estate and Facility Management.



Figure 6. The location of Volvo Group sites studied.

3.3 Details on prestudy and case study

In the pre-study the Waste Flow Mapping framework (WFM) was synthesized, using Eco-mapping and waste sorting analysis, structured in accordance with the waste hierarchy with the purpose to analyze inefficiencies and material losses in assembly. The pre-study also looked into the incoming bill of material and the material handling system, by material handling analysis (MHA), to find the root causes of the found inefficiencies. The pre-study result was that the initial WFM approach as shown in Figure 7 - to combine modifications of existing lean tools - was an effective way to find potentials. The incoming material handling analysis was perceived as an add-on that could be practiced for some in-depth opportunities for prevention of wasting material. The method developed in the prestudy is further described in (Kurdve, Romvall et al. 2011).



Figure 7 Initial WFM approach

A conclusion from the prestudy was that the approach had to be adapted from usage on team level, to be able to be used on site level and multisite level. The specific characteristics of the team level analysis conducted in the prestudy were that the team conducted sorting analysis of their own wasted material in order to find potential improvements regarding better sorting, sorting into new income generating fractions, minimising unnecessary handling and evaluate placing of bins. This approach requires knowledge of material and waste standards. In the multi site case study, the approach was extended to site and multi site level. The specific characteristics of the site level analysis included overall analysis of the waste fractions volumes and costs on sub segments of waste fractions. Performance measures in order to compare with best practice and process specific analyses of the waste management sub-processes like internal handling and equipment used and type of ownership of equipment was included together with the potentials to improve sorting and minimise costs. The site analysis was finally used for the multisite analysis by finding best practice performance that could be used to find potential quick wins. The multisite analysis also resulted in recommendations for the continuous improvement work and development of waste management services, which however extends outside the scope of this paper. Regarding prevention of the emergence of waste it was concluded that this is a complex issue involving even more actors like suppliers of incoming material and purchasers and adds parameters as logistic, quality and flexibility.

3.4 Data collection

The multisite case study at the Volvo Group aimed to develop the WFM framework for quick site analysis and then to perform this on all Volvos operations in Sweden. The analysis was primarily used as input for procurement of equipment and services, but the method development and analysis was extended to be used as input for operational development on the different sites and on company level. Data on volumes, costs/revenue, transportation mode and final treatment were collected centrally. Complementary data collection and validation were done on each site. The data was gathered through mainly three means:

1. Statistical data logs from existing suppliers.
2. Additional environmental and economic data from each site and electronic order system.
3. On-site visits, interviews, maps and photographs.

The first data category concerned the volumes and costs of treatment of waste fractions and costs of external services. The second category was used to validate and complement the supplier data. Finally the third category of data was used to verify the above data on site, but also to map and understand the internal handling, to estimate internal man time and costs as well as to get an inventory of owned resources.

The multi-site case study was limited in time and resources for each site. The limitation was that each site had to be mapped in two days by aid of one local responsible. In practice the on-site work had to be done in two days by two people of whom one was unfamiliar in the specifics of the method.

4 Results of the framework development: the Waste Flow Mapping framework

Based on the prestudy and the multi site case study, the waste flow mapping (WFM) framework was developed. This section presents the WFM framework by its content and structure, while the following section presents the data results from the extensive multi site case study, the WFM framework consists of three main phases which is detailed in the following. In the final section is the framework concluded into a seven step procedure. The conclusion from the pre study; that it is complex to include prevention of emergence of waste and extend producer responsibility; implies that the prevention opportunities identified by use of the WFM framework are most efficiently treated as separate issues.

4.1 Phase 1: Map waste generation and fractions

In order to achieve the highest material efficiency in an industrial process, material losses need to be minimized. This can be done by minimizing overuse of material input and reduce spill. However, how the wasted material is used in the waste management cycle is not affecting this efficiency measure, but the environmental impact from the waste that is generated mainly depend on at what level of the waste hierarchy it ends up at. The five step waste hierarchy approach, described in detail in (Kurdve 2008) was used in order to grade different types of disposal and recovery operations for material waste (see Figure 2), which is in line with the EU waste hierarchy (EU 2006). One of the main ideas in the WFM framework is that the lower the level in the hierarchy, the lower is the value of the output material. Hence, if *material efficiency* is changed for *material value efficiency* the approach will include also moving the Non productive output material, or material waste, to higher stages in the waste hierarchy.

When studying the waste management process, there is a need to visualize where the actual wasting of material originates. Eco-mapping was used as a tool for where the generation of material waste occurred, and hence where the improvement areas are. All points of generation of Non Productive Output (NPO) and placement of waste handling equipment can be indicated on layouts. For the plant level mapping, the Eco-maps were simplified in the developed framework.

The operations studied in the multi site case study generate over 150 distinguishable different types of waste fractions. In order to understand the material flows ending up as waste and set relevant KPIs for improvements, the study separated the flows into five sub segments:

- Metals
- Combustible material
- Inert materials
- Fluid waste
- Other Hazardous waste

The number of segments depends on the industrial operations and the different materials used. A few of the fractions may be categorized in several of these segments, but for the main volumes the categorization is usually obvious. If it is not obvious the segments chosen may have to be reconsidered.

For each segment of waste in the study, except *Other Hazardous waste*, one or several of the fractions can be considered as a "mixed" fraction (with less value and quality standard than a "pure" or "sorted" fraction in the same segment). In general there is a higher cost of the waste for the mixed fractions compared to the pure ones that often regain a larger portion of the original material value. The value differences usually correspond to the cost of separating or sorting valuable material from the mix.

For hazardous waste legal compliance demand separate flows for certain fractions, with heavy fines for non-compliance, but it is also important from economic reasons not to mix in non-hazardous material into the hazardous fractions.

4.2 Phase 2: Monitoring and comparing performance

The study resulted in a number of performance indicators and monitoring indicators that can be used to control the waste management process. Although data for incoming material is not always collected, the material efficiency can be calculated by the total product weight and the total waste weight which often may be a valid approximation (Kurdve 2008).

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$$\text{Material efficiency (\%)} = \text{product weight} / \text{incoming material weight} \approx \text{product weight} / (\text{waste weight} + \text{product weight})$$

The research has concluded a need of measurements and monitoring of the actual waste and services included in the waste management process. First, there are legal and EMS standard requirements for monitoring of total volumes of hazardous and non-hazardous waste as well as the total (external) cost for handling of these. The plants usually index these per produced unit (P) as in the Table 1 below:

Table 1 Today's requirement on waste monitoring on site

Today's Waste Indexes	calculation	
Weight hazardous per unit	$W_{(haz)}/P$	(ton/#)
Weight non-haz. per unit	$W_{(non\ haz)}/P$	(ton/#)
Waste cost per produced unit	$C_{(total)}/P$	(SEK/#)

However the finding in this study shows that although the overall measures above are important, performance should also be monitored for each segment separately as shown in Table 2. In addition to the weight and cost per produced unit, the average cost (or revenue) per ton for sorted and for mixed waste as well as the sorting degree in each of the segments should be monitored in order to evaluate the efficiency of the waste management.

Table 2 Proposed segment performance measurement

Proposed segment indexes	Calculation	
Sorting degree	$W_{(sorted)}/W_{(segment\ total)}$	(%)
Weight per produced unit	$W_{(segment\ total)}/P$	(ton/#)
Average segment treatment cost	$C_{(segment\ total)}/W_{(segment\ total)}$	(SEK/ton)

4.3 Phase 3: Mapping the waste management process

The waste management process was studied with a Value Stream Mapping approach in a non-detailed way to set the framework for the waste flow mapping method. The waste management system was divided into sub-processes in the value stream of the waste material, where the material value chain was followed together with the information flow. Data was collected in each sub-process, regarding resources inventories, handling and movements.

Taking a systems point of view of waste management is an effective way to gain improved efficiency and effectiveness (Seadon 2010). Seadon further characterises waste management systems as involving collection transportation and storage operations. In this study the Waste management was seen as a process divided into five sub processes within the material flow and two sub processes within the information and knowledge flow. The material flow processes are involving collection and storage or transportation and then the final treatment or recycling process. The full process can be seen as a chain of consecutive storage/collection and transportation links. The study focus is limited to one internal waste handling link and the one external waste handling link. The sub-processes are:

1. Workplace station/bin (internal collection point)
2. Internal logistics/handling
3. External Collection points (internal storage point)
4. External transportation
5. External treatment/recycling
6. Information and data handling
7. Improvement work

The first sub process at the internal collection point was mapped using eco-mapping or tables and layouts including the required data on number of bins (points), what fraction and what type of bin. Man time data for maintaining bins and signs was collected together with cost of ownership or renting cost for the bins. Inefficiencies in the main operation due to waste handling were estimated.

In the second sub process, internal logistics, moving the material from all points in the operations to collection points for external waste handlers was mapped. Man-time data and data on moving equipment and costs were collected. Layouts of containers and equipment to separate or sort waste and maintenance & cost of ownership or renting cost for containers were mapped in the third sub process, which involves internal storage of residual material until external collection of the material.

The fourth sub process was mapped with the type of and cost of external transportation off-site for each material segment. The fifth sub process was analysed on basis on data from the disposal/final treatment operations of the waste and involved what type of disposal or recycling code, cost and location of that process. Full LCA data on final treatment was not available. In addition was data on information management collected by interviews and data records. Finally the improvement process was investigated, by interviews and process efficiency data. This is where all the knowledge from the waste management

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should be used in order to steer the main production process into minimizing material losses (avoid generation and hazardousness of waste). The efficiency of the improvement work was estimated based on the overall efficiency of the process itself (see section 4.2).

When trying to make the overall operation as lean as possible, the focus is on minimizing the use and handling of NVA and NPO material. In practical improvement work, these different inefficiencies are addressed simultaneously. First is the overall efficiency analysed, then the sub process efficiency. In order to evaluate the services supplied internally or externally to each sub process, certain performance measures for each of the services were used, as illustrated in Table 3. These should reflect the effectiveness and quality of the supplied service. However the sub process measurements are subordinated the overall performance measures in order to avoid inefficiencies due to sub-optimisation. One example of this is that if only one large bin is used for all types of waste, the efficiency measure for Bins are good but the costs of final treatment and sorting, as well as internal transportation, will give a non-optimal result. Further development of each of the sub process performance measurements is recommended.

Table 3 Sub process performance measurements

	Bins	Internal handling	Ext Collection points	Ext Transportation	Ext Treatment
Service efficiency	$\#_{\text{(bins)}} / W_{\text{(waste in bins)}}$	Man-h/W	$\#_{\text{(containers)}} / W_{\text{(waste in containers)}}$	$\#_{\text{(trucks)}} / W_{\text{(waste transported)}}$	$W_{\text{(recycled)}} / W_{\text{(sum)}}$ & $W_{\text{(incinerated)}} / W_{\text{(sum)}}$
Cost efficiency	$C_{\text{(bins)}} / W_{\text{(waste in bins)}}$	$C_{\text{(man-h)}} / W$	$C_{\text{(equipment)}} / W_{\text{(waste in equipment)}}$	$C_{\text{(transports)}} / W_{\text{(waste transported)}}$	$C_{\text{(treatment)}} / W_{\text{(sum)}}$
Overall Effectiveness	$C_{\text{(bins)}} / P$	$C_{\text{(man-h)}} / P$	$C_{\text{(equipment)}} / P$	$C_{\text{(trucks)}} / W_{\text{(waste transported)}}$	$C_{\text{(treatment)}} / P$

For plants who operate the waste management with their own people the service efficiency and overall effectiveness were the most useful measurement. When the service was provided from a supplier, the Cost efficiency was the most relevant measure for the supplier delivery. The efficiency of the information system and improvement work was evaluated by analysing the trends for the whole process in accordance with Table 2.

4.4 Concluding the WFM framework in six steps

When operationalizing the finalized WFM method, it can be described in six steps:

- Step 1 Map waste generation points on site (fractions, content in each fraction, bins, type/size, cost of maintenance/rent and operator time, internal and external cost) in addition photographs of the different types of operations and their waste fractions
- Step 2 Map internal logistics on site (mantime, shifts, transportation equipment, external and internal costs)
- Step 3 Map Collection points (fractions, content in each fraction, containers & equipment, cost of maintenance/rent, external/internal costs)
- Step 4 Collect and analyse data on transportation off site (pick up rate/frequency for each fraction, compare to number of containers, mode of transportation and length of transportation)
- Step 5 Collect data on final treatment for each fraction, graphically analyse each segment in accordance to the waste hierarchy.
- Step 6 Identify best practice plants for each segment and each subprocess. Analyze operative differences.

5. Case study results.

In addition to the framework development, the case study resulted in numerous results concerning waste management improvement areas on general and case-specific areas. This section points out an excerpt of the generic waste management findings.

5.1 Waste flows

The multisite case study resulted in a vast amount of detailed data and photos on the waste management within the case company and the waste service supply chain. Diagram 1 shows the overall picture of the amount of waste in the five segments presented as weight%. It is obvious that inert material is of less importance in this case and that the category metals could have been further divided into two or more sub categories in order to refine the results.

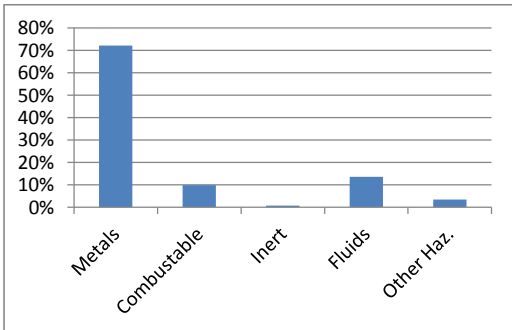


Diagram 1 Waste volumes in different segments

5.2 Overall Waste management performance

The performance measurements of the different plants with regards to the sorting degree and cost or revenue for the waste fraction for each segment as described in Table 2 was used to find potential improvements for each segment in the overall waste management process. At plants with historical data on sorting degree and average price the improvement work could be evaluated. Diagram 2 shows the minimum, maximum and average sorting degree for non hazardous waste (as minimum are only plants with more than 10 ton/year included). It shows clearly that some plants have a large improvement potential especially on metal sorting degree.

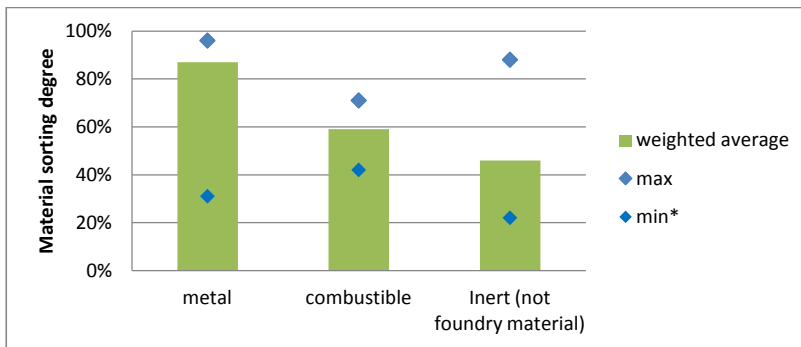
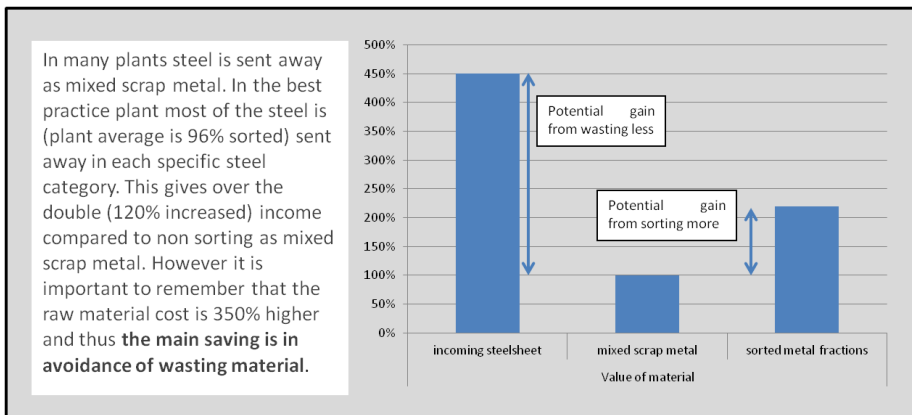


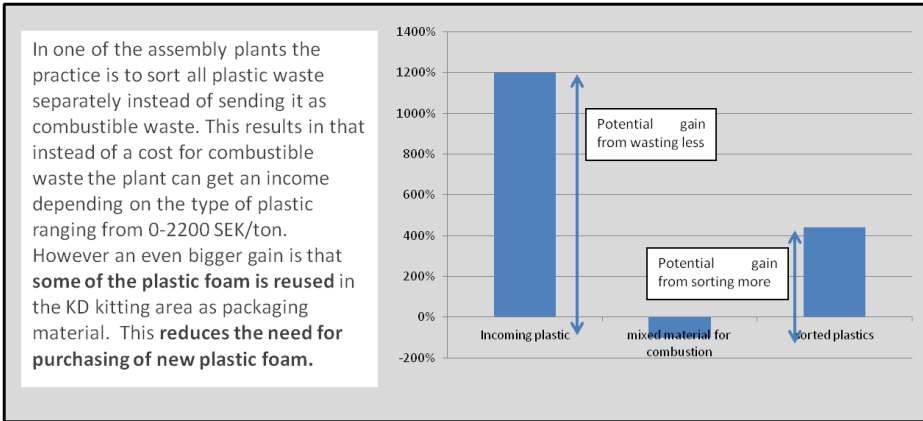
Diagram 2 Sorting degree for non hazardous waste

In this study the cost of incoming material per weight was not generally available. This means there has not been any way to calculate the material loss cost in the waste management. However, to illustrate how big the cost is, the study concluded three examples:

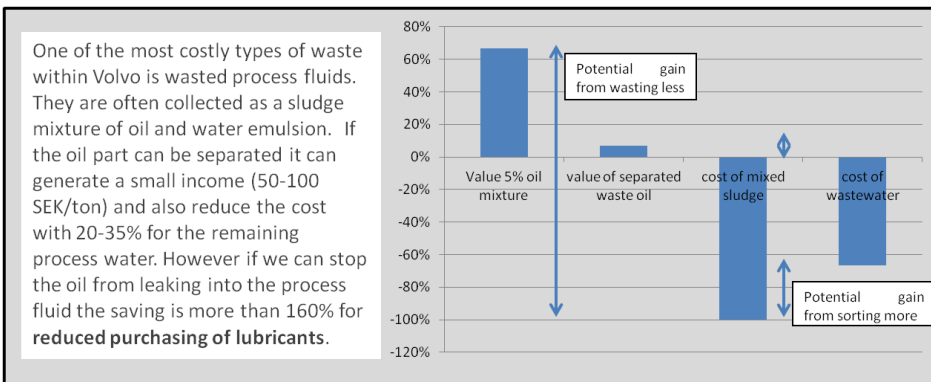
Example 1 Potential for increased revenue and decrease costs by sorting metal scrap



Exempel 2 Potential for increased revenue and decrease costs by sorting plastics



Exempel 3 Potential in process fluids



There are several examples on where material recycling can be seen as one step closer to reduction of unnecessary wasting of the material and saving money. One plant has in collaboration with the chemical supplier arranged for that they operate the process fluids and include the waste fluid management (Kurdve 2010)

5.3 Sub process analysis

The costs in the different sub-processes were analysed, especially the costs of sub-processes and equipment supplied by external suppliers. Cost analyses of the sub-processes clearly show that the majority of costs are generated in final treatment processes and transports. With regards to external supplier costs the treatment process was almost half the cost and transports were a third. Including internal costs shows that also internal handling result in large costs, although not as large as external transports or final treatment. The main saving potentials are in lowering these costs. Another important result is that the cost of buying or renting bins and maintaining these are very low in comparison with other costs. Since savings in final treatment often depend on the initial sorting of the waste this results give a hint that savings may be achieved by making better solutions for sorting in bins at the workplace. Aggregated data from the waste management process in the case study is shown in Figure 8.

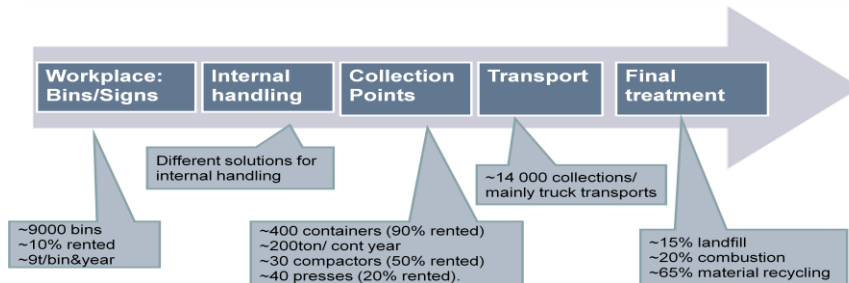


Figure 8 Overall waste management process data

Potential waste management process improvements on plant level were found in all sub-processes;

- underused bins
- lack of bins for some waste fractions
- lack of and poor quality of signs and instructions
- inefficiencies in handling and internal logistics
- poor quality of information management
- container and equipment inefficiency
- inefficiencies and unnecessary costs of external transports
- inefficiencies in choice of final treatment

The improvement process was analysed from a qualitative point of view. In general the improvement work would have benefited from getting a better information support with performance data on production department level. Several inefficiencies could be related to loss of information and/or delay of information indicating bad interface between waste management and operation management. Although proper LCA data was unavailable the economical potentials found could be identified as giving also an environmental improvement potential. E.g. the potentials of shortening transports showed both economic and environmental potential benefits or the potential of sending metals as higher quality grade gave economical as well as environmental potential improvements except for a few special circumstances.

5.4 Best practice comparisons

The multisite mapping enabled identification of best practices for the different segments and for different sub processes. Other plants can be compared with the best practice plants in order to demonstrate the achievable results for that segment.

Since the majority of costs (or loss of value) was connected to the final step of the waste management process, the cost of treatment was used to find best practice management. By analysing each plant and evaluating the sorting degree and average treatment cost in each waste segment, best practice with regards to waste segments could be found. The best practice for each segment was used as comparison for other plants with similar waste. It may be important to break down costs in order to prove that costs of infrastructure and logistics are not increased instead.

One example of how the best practice comparisons were used in the case study was a cost comparison of two sites A and B of similar size and waste structure where waste management was organized in different ways. One of the sites, B, had worked with focused improvement around waste handling on operator level and had invested in smaller bins for sorted material at each workplace as well as team level revisions of performance. The results from the waste mapping showed that the better sorting degree had led to significantly lower cost for combustible waste, mainly thanks to sorting 10% more of the combustible waste into paper and plastic fractions instead. Only a couple of extra metal fractions led to a higher income for metals. The extra investment in bins and internal logistics did still not cost more than the gain, mainly thanks to that also these sub-processes had been optimized when the process had changed. The site A could benefit from the experiences on site B and find improvement targets for their waste management process.

A general analysis of the overall results show that major cost reductions can be made on changes in handling and treating hazardous waste from process fluids, however this often involves investment in equipment. Improved sorting and quality management of scrap metals had a large potential to increase income. Recycling of combustible waste (mainly from packaging material) is a way of turning costs into income by very simple means.

6 Discussion

6.1 Framework context and characteristics: usefulness and applicability

The proposed method proves to support analysis and continuous improvement work for the waste management process. It was perceived to be easy to understand for the practitioners and the critical feature, that site mapping had to be made in a limited time, was solved in a satisfying manner. However, there are certain issues that had to be omitted or simplified due to

this. Especially the identification of logistics inefficiencies were not performed in detail. Inefficiencies were found but the time for root cause analysis was lacking. Also the investigation of alternative treatment processes especially for expensive hazardous waste could not be performed. Further development should clearer connect the framework to opportunities for looping rest materials into recycling, reuse and prevention scenarios as in circular loops such as the cradle-to-cradle concept and similar.

The experience from using the WFM method shows that it is;

- Highly generic with regards to size and level of detail
- Visual and easy to understand
- Supports requirements in ISO14001 such as environmental reporting, prioritization, involvement of everyone and proactiveness.
- Systematic
- Possible to standardise
- Performance can be analysed by easy traceable KPIs
- Supports team efforts and engagement

6.2 Framework content: limitation and specifics

In the prestudy the waste analysed was mainly combustible fractions while the multisite case had five waste segments. The largest segment, metals, could have been further divided into e.g. Iron metals (Steel and Iron) and other metals. Since the potential in this segment was large an additional sorting analysis on each site could give further specific information around the focus areas. For the production material, monitoring of the amount of quality scrap versus design scrap would be beneficial. In the combustible segment, packaging material can be further divided into plastics, paper, wood and other sub segments.

In the sub process cost analysis the cost of area needed for bins is omitted, it may still be of importance to keep down the size of the bins of several reasons. In the transport costs only the direct transports from the site to the treatment company are included. The transport distance has not been part of the collected data in this study, however, the fuel cost is approximately 50% and thus the environmental impact of transports could be calculated. The final treatment process cost may include additional transports since the costs were not always separated. The number of transports and weight of each transport/degree of filling is another area for optimisation with reduction of costs and environmental impact.

In general a lack of on site preparation made it to time consuming to create the complete Waste eco-map although were these were made it was perceived to be of great use for system understanding. Further development and possibly technical aid for the drawing the visual tool communication on operations and team level would be helpful.

6.3. Future development and next step

When the method was applied on the multi site case study, best practices were found for the different segments and sub processes. Though, to establish general best practices requires more analysis and design of waste management sub-processes. The dependence on the amount of waste, complexity and size of the site is something that has to be revealed in further studies. Implementation of best practice has to be done with clear and relevant goals and on all the levels within operations. When internal and external suppliers are involved, the best practice could be designed into the supplied services. This is not included in the methodology but can be seen as a next step.

For the method to be implemented efficiently it is important to integrate waste management and operations management and follow up performance on a regular basis. The information and knowledge has to be saved and presented in a consistent way, available to all involved personnel. It will keep involved people interested in process improvements. It is important to highlight the economic and environmental potential at all levels and establish standardized implementation solutions so that continuous development may be secured. It is suggested for further development of the method, that a tool or system is developed that facilitates updating and monitoring of performance.

However there is also need for further analysis and research on continuous support tools for the management; analysis on which tools that are needed and how to design these as standard solutions. Easy support tools can be used in daily operations and the performance can be monitored at daily and weekly team meetings. Hence there is a need for further studies on how to make waste management more integrated in the operation and one solution could be to design waste management as a service. Since actors have different drivers, (e.g. economic, environmental, use of resources, efficiency), for different levels in the organization, a service concept could be a lean approach to handle waste management. The experience of waste management service design from this study will be presented elsewhere.

7 Conclusions

Realizing that the whole life cycle of materials is important, and that many people are involved, allow for Waste Flow Mapping to facilitate Waste management. Understanding the values of materials and costs for waste handling and treatment, give clear guidance to efficient operations.

The experiences from the study prove that Waste Flow Mapping is a suitable framework, for analysing the waste management process and to efficiently identify sustainability improvement potentials. It showed that it can be beneficial to group different waste fractions into segments and analyse these segments individually. Applying the method on a multiple site case study gave results pointing out the importance of avoiding mixing material with lower quality grade of that material. The proposed performance measurements helped to identify Best Practice for the different segments which gave an indication of possible quick wins. With regards to sub processes these could be analysed and measured and the measurements could be used to monitor sub process efficiency at each plant and compare plants.

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