Improve material efficiency through an assessment and mapping tool

Sasha Shahbazi[1], Pernilla Amprazis[2]

[1]*School of Innovation, Design and Engineering, Mälardalen University, 63220, Eskilstuna, Sweden, sasha.shahbazi@mdh.se*
[2,] *IVL Swedish Environmental Research Institute, 41133, Göteborg, Sweden, e-mail addresses*

Abstract

Material efficiency in manufacturing results directly in cost and energy savings in fabrication, transformation, transportation and disposal, as well as reduced greenhouse gas emissions through increases success rates of waste management initiatives. Previous sustainability related studies on manufacturing companies indicated several barriers towards material efficiency and circular economy, including lack of a suitable tool for environmental initiatives, limited environmental motivation and engagement, lack of effective measures to evaluate sustainability, poor visualization and limited intra-organisational interaction. This paper aims to adjoin this functional gap via simplified Environmental Value Stream Maps (EVSM) to evaluate, measure and visualize material/waste flows of a limited operation in manufacturing. Two case studies were performed on (1) productive material flow (2) auxiliary material flows. Applying EVSM proved to be a practical solution to engage different organizational functions in material efficiency improvement, to visualize material and waste streams, to realize the value of wasted material and costs associated to waste handling and treatment, to define or update relevant KPIs and to support lean principles such as "go to gemba". This paper contributes to the area of lean and green and circular economy through aiding manufacturing companies to better manage, measure and visualize industrial waste and material consumption in order to go up the waste hierarchy, reduce waste and material consumption.

Keywords: Environmental value stream mapping, Material efficiency, Lean and green

1. Introduction

To achieve *Sustainable Development* goals (Brundtland, 1987), it is essential to include current industrial system which has helped to increase living standards and has also contributed to negative environmental impacts. According to Garetti and Taisch (2011) *Sustainable Manufacturing* can be defined as "the ability to smartly use natural resources for manufacturing, by creating products and solutions that, thanks to new technology, regulatory measures and coherent social behaviours, are able to satisfy economic, environmental and social objectives, thus preserving the environment while continuing to improve the quality of human life". With publication of Our Common Future report (Brundtland, 1987), sustainability objectives gradually commenced in business strategies (Möller and Schaltegger, 2005), environmental performance indicators were considered in managerial decision makings (Bai and Sarkis, 2014), and externally communicated in form of environmental reports (Azapagic and Perdan, 2000). However, the environmental considerations in production and performance management systems are still top-down approaches, aggregated for the whole manufacturing plant and often related to a separated department. Despite the main core areas of old-school production systems such as productivity, quality, delivery precision and cost efficiency, environmental improvement and sustainability has not yet received satisfactory attention. Although there are sufficient practical tools for lowest operational level (shop floor) to measure and evaluate quality, productivity and efficiency, the number of practical tools for environmental initiatives on shop floor is fairly low (Bey et al., 2013). *Lean and Green* studies have been trying to fill this gap to some extent (Kurdve et al., 2012, Zokaei et al., 2013), but the lack of detailed methodologies or practical tools for manufacturing improvement in terms of environmental sustainability and operational performance is still evident (Smith and Ball, 2012).

Material efficiency is an important area to achieve sustainable manufacturing (Allwood et al., 2012) and circular economy (European Commission, 2011) by capturing wasted values in industry. Material efficiency in manufacturing can be related to improved manufacturing practices using less materials per product and/or generating less waste per product (Shahbazi et al., 2016). Nevertheless, material efficiency in manufacturing has not received to its full potentials, while improvement opportunities are high (Smith and Ball, 2012, Worrell et al., 2016), particularly with regards to using appropriate tools on shop floor (bottom-up approach). There is also a requirement from environmental management to effectively evaluate and measure processes, make decisions and implement improvements (Kurdve and Wiktorsson, 2013). This is where that Lean and Green concept and tools can integrate environmental goals within the production system with continues improvement tools. Perhaps the most known lean tool is Value Stream Mapping (VSM) that identifies time inefficiencies within a manufacturing process. United States Environmental Protection Agency - EPA (2015) has introduced Environmental Value Stream Mapping (EVSM) to take environmental aspects of a process into consideration for improvement, but less has been published on using EVSM on material flow and waste generation only. Therefore, this paper aims to help material efficiency management to map, measure and assess material and waste flows through simplified EVSM. This paper also adjoin the gap between environmental studies (here material efficiency) and operation management via presenting empirical data on application of EVSM on material efficiency in manufacturing. This study considered two flows of input material (1) productive and (2) auxiliary, each investigated in separate case studies.

2. Theoretical background

Looking to different sustainability definitions associated to an industrial system such as *sustainable manufacturing* (Garetti and Taisch, 2011), *sustainable production* (Veleva et al., 2001) or *corporate sustainability* (IISD, 1992), the importance of manufacturing process can be perceived. However, previous research has indicated several barriers towards sustainability in manufacturing including: lack of suitable tools for environmental initiatives (Bey et al., 2013, Shahbazi et al., 2016), limited environmental motivation and engagement (Ammenberg and Sundin, 2005, Murillo-Luna et al., 2011) and lack of detailed methodologies for manufacturing improvement in terms of environmental and operational performances to measure and evaluate environmental sustainability (Al Zaabi et al., 2013, Zhu et al., 2011) and limited intra-organizational cooperation and interaction (Simpson, 2010, Sarkis et al., 2007). Several researches have tried to fill this gap by lean integration and introducing tools and methods to measure sustainability in manufacturing. Here we present a snapshot of literature on lean and green studies aiming to fill this gap.

Tóth (2003) evaluated the environmental performance of companies via analytical explanation and evaluation of different methods and classification of them. He concluded his research with a set of application and benefits of his environmental performance evaluation tool. Arina and Viktoria (2007) introduced and tested Eco-mapping as a visual, simple and practical tool to integrate environmental management systems at SMEs in Estonia. They concluded increase of environmental awareness via understanding the environmental and economic benefits that eco-mapping brings which can be used for upcoming sustainability regulations. Furthermore, Torres and Gati (2009) used EVSM as a managerial tool for sustainability to align the economic and environmental aspects of a production process in Alcohol and Sugar manufacturing industry. However, the main focus remained on raw water usage. Dadashzadeh and Wharton (2012) used Green-VSM for information technology function area of organizations with different indicators such as materials, energy, water, emission, garbage, biodiversity and transport. Faulkner and Badurdeen (2014) developed Sustainable-VSM to include different indicators of environmental and social sustainability. In addition, Müller et al. (2014), and Posselt et al. (2014) focused on energy saving and efficiency, without including any other environmental impact like waste or material consumption.

Even within limited studies on material efficiency in manufacturing, the main focus has been lied on the higher levels of a manufacturing i.e. national, sectorial and supply chain, for example see Worrell et al. (2016) and Pajunen et al. (2013) for national level, and Milford et al. (2011) for supply chain level. Among few studies on an operation level, Smith and Ball (2012) investigated material, energy and waste flow modelling to support the pursuit of sustainable manufacturing. Their qualitative model helps identification and selection of environmental efficiency improvements through a guideline. Liao et al. (2015) used a high-resolution waste input-output table to trace waste flows into corresponding waste treatments. The result included identification of deriving forces of waste in an economic system as well as consumption patterns via categorizing final demand.

3. Methods

This paper is mainly based on empirical studies at manufacturing companies, although a structured literature review on material efficiency and waste stream mapping has been carried out. The literature selection incorporated the keywords search in scientific data bases along with qualitative up-stream and down-stream search for references. Keywords include "material efficiency" and "waste stream", "material flow", as well as their combination with "tool" and "manufacturing". The literature search focused on papers addressing a situation similar to the defined problem in automotive industry; even though papers outside of this area tackling relevant issues (e.g. other sorts of material or in different industry) have been also included. The empirical study included two single case studies at large automotive manufacturing companies located in Sweden. With a limited understanding, the adopted case study methodology was appropriate to comprehend the phenomenon (here the material efficiency performance assessment and measurement) and to fulfil the research aim. Case studies were performed during the period of 2016 – 2017, as parts of two Swedish research projects, here called CIM and SPM. The research area of each project directly contributes to different aspects and material flows. CIM project aims to develop Life Cycle Cost (LCC) and Life Cycle Assessment (LCA) models for extended recycling loops, to develop collaboration and explore opportunities for cooperation in recycling loops. SPM project focuses on developing a performance measurement systems to support companies in development and redesign of performance measurement systems taking sustainability into consideration (Sustainable Performance Measurements). Table 1 indicates a brief description of involved companies.

Table 1. *Company description.*

	Company description	Total No. of employees	Studied operation	Projects
Company I	Manufacturer and assembler of trucks	1,500	Fabrication	SPM
Company II	Manufacturer of trucks and buses	10,000	Assembly line	CIM

The first author had an active role as “participants as observers” (Saunders et al., 2009) with access to different sorts of data from both operation and waste management. The empirical data were collected via multiple sources of evidence as suggested by Yin (2014), including observations and site-visits for two weeks in company I and a week in company II, meetings and also document reviews of internal environmental and operational reports. The document reviews helped to get a basic insight about companies, their overall strategy and environmental target and current improvement projects. For better understanding and validating the empirical findings, collected data, thoughts, suggestions and mapped material/waste flows were compounded with discussions with different organizational functions such as environmental manager, team manager, production manager, waste management entrepreneur, production planner and production technicians. On an overall level, the empirical data analysis followed the process suggested by Miles and Huberman (1994), including data reduction, data display, and conclusion drawing and verification. Therefore, the empirical collected data were simplified, organized and interpreted. The results, were thereafter compared and analysed via an interactive back and forth process between cases and literature to increase understanding and generalizability of empirical findings.

4. Empirical findings

The main idea behind two single case studies were to test and validate EVSM with focus on material in two different flows. The first flow is *Productive material* that includes any type of material or semi-final product that usually end up in the primary product i.e. adding value to the primary end product. An example of wasted productive material is metal scarp or quality-failed products. The second flow is *Auxiliary material* that includes any type of material or semi-final product that is used in the production of the primary product, but usually is not a part of the primary product and does not add value to the final product; the term is synonymous with non-value added material, non-productive material, or process material. An example of auxiliary material ending up as products is necessary lubricants used in engine assembly line. In our case studies in automotive industry, metal was the main productive material, whereas common types of auxiliary materials included packaging material, plastics, wood, paper, maintenance tools, personal protection equipment, as well as chemicals and lubricants. Both productive material and auxiliary material can end up as *Residual material*, which is defined as any remnant or leftover material or product derived from a manufacturing process i.e. almost any material excluding the primary product. Residual material is synonymous with rest material and by-product, waste, co-products, intermediate products, non-core products or sub-products. The value of these materials is almost always neglected, particularly packaging and plastics. Figure 1 illustrates a simplified version of different material flows within an operation in a factory.

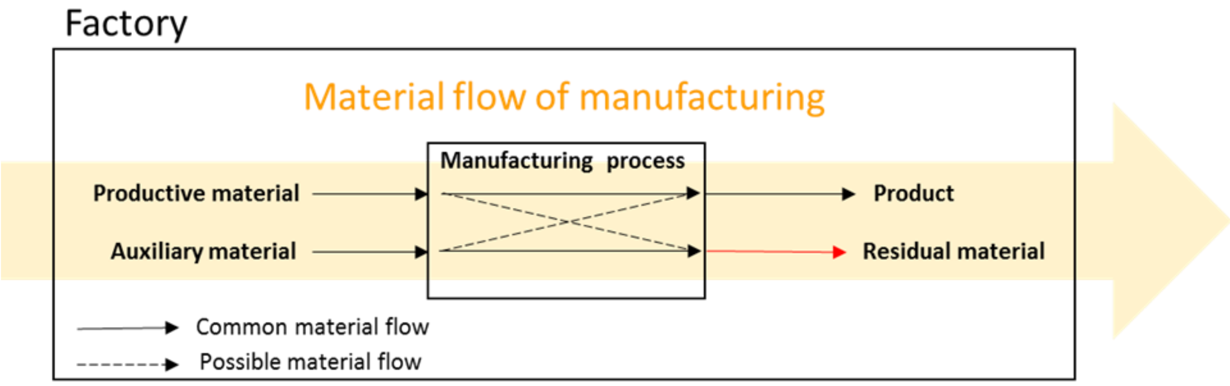

Figure 1. Material flows in operation.

Case study 1 at company I focused on productive material flow where a great amount of them were wasted as metal scrap (residual material). On the other hand, case study 2 at company II focused on great amount of auxiliary material consumption which were ended up as combustible waste. So the ultimate goal is to decrease transition of "productive materials to residual material" and reduce "the consumption of auxiliary materials that end up as residual material". Empirical findings are presented here separately based on the explained material flows and will be discussed in next chapter to draw conclusions.

4.1 Productive material flow

This study was performed on a manufacturing process of a key component in truck's chassis made of steel. The manufacturing process together with scrap generation were mapped based on EVSM, but simplified for the defined purpose. The process in short starts with steel coil transported to the factory, followed by metal sheet forming, punching, plasma cutting, blasting, phosphating, painting, heat treatment and shipping to different customers. To ease the understanding and analysis, the manufacturing process was divided into seven sub-processes to be studied individually and in details. The data collection in each sub-process included type and amount of steel being used, scrap generation and the causes i.e. when, where, how much and why scraps are generated? The additional aggregated information on scrap costs/revenue and volume, final treatment, transportation mode etc. from waste management company were also collected. Figure 2 depicts the process with scrap generation in each sub-process. Based on our investigations, causes of scarp generation could be categorized into three areas: (1) *design*, (2) *set up/process* (3) *quality*. The numbers in the boxes underneath each sub-process associates to the weight given to the tonnes of generated metal scraps within each sub-process in a limited period of time. For instance, quality scrap generation from sub-process P were 4 times bigger than design scraps produced in sub-process R.

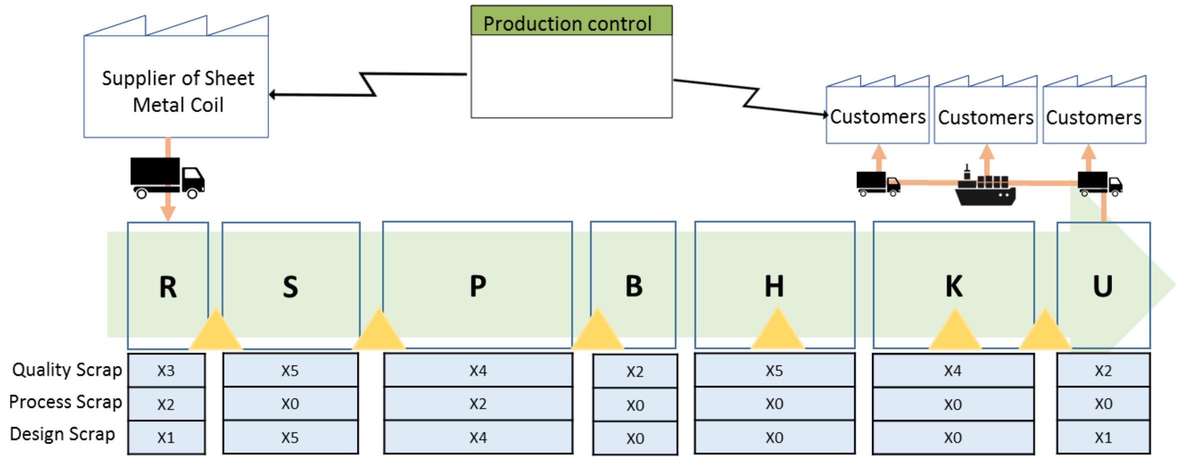

Figure 2. Environmental value stream mapping for wasted productive material.

Scrap generation due to design: this included the wasted metal pieces which were designed to be produced and were inevitable to avoid e.g. coin-form steel pieces generated in punching machine. Although design could be improved in a long term to waste less material, this type of scrap were usually product related and very difficult to be improved by manufacturing engineers within the factory because of the distinct specification of products. Moving from conventional design process to sustainable product development and eco-design (Gagnon et al., 2012) was suggested for future developments to include manufacturing processes and capabilities in the design phase.

Scrap generation due to process or set up issues: this included the scraps which were generated because of the machine set up or the manufacturing process (technology). An example was scrap generation in plasma cutting machine and steel forming machine in the first round of changing products' specification. The avoidance of this kind of scrap was difficult and expensive as it needed changes in process layout, equipment and technology, however it was an essential aspect for a long-term improvement vision. Nevertheless, there were also less expensive possible changes that could be made to improve and avoid this sort of scrap e.g. optimization of production planning with a right sequence of products i.e. production levelling or Heijunka. Another example could be related to upgrading the IT system to log in the scraps and production data, not only for reporting purposes, but also for improvement analysis.

Scrap generation due to quality issues: this included the scraps generated because of quality deviations, insufficient inspections and human errors, for example cutting metal sheets with wrong lengths or scraps owing to unremoved dross on products. In some cases the quality-failed product were going through a number of sub-processes before being identified as a scrap; which was wasting material, energy and production time. In addition, scrap generation statistics among production shifts were indicating the role of human errors in waste generation, which could be owing to oversight and reluctance of operators because of indolence, weariness and exhaustion. All in all, prompt scraps from this category could be considered as the "low-hanging fruit" with big environmental impact (number of scraps) and high associated cost, which had to be targeted first.

4.2 Auxiliary material flow

This study was performed on a truck's engine assembly line where several components e.g. pipes and pumps came with several plastic plugs on them to be assembled on an engine. These plastic plugs were then removed and disposed as combustible waste in small bins located in different stations. The combustible waste are considered as a cost for the company to discard by contracted waste management entrepreneur. To start with, a limited part of the assembly line with nine stations was selected for detail analysis. Different components were assembled in each station and each component had different sort of plastic plugs in terms of shape, colour and material. The assembly line and disposal of plastic plugs were mapped based on EVSM, but simplified for the defined purpose. Data collection in this study included information on the amount of disposed plastic plugs, types of them, as well as functionality and possibility to avoid using them in the first place. Soon, it was understood that engine is a very sensible product and cleanness and protection of equipment are extremely essential for the customer and the manufacturing company itself. As a consequence, avoidance of using plugs or reducing the amount was impossible. Figure 3 depicts the assembly line along with the number of plastic plugs disposed at each station. According to the analysis, plastic plugs were made of three different materials including EVA (Ethylene Vinyl Acetate), PE (Polyethylene) and PVC (Polyvinyl Chloride), and in different colours including red, blue, black, yellow, green and transparent.

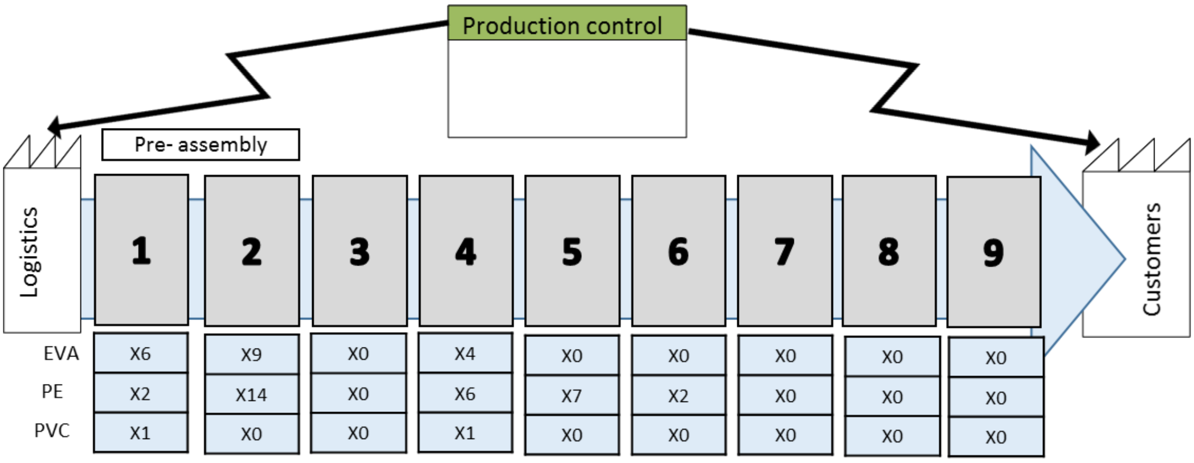

Figure 3. Environmental value stream mapping for auxiliary material.

Taking waste hierarchy into account, *prevention* and *reduction* of plastic plugs were inevitable under any circumstances. Therefore, the *reusing* option was investigated. This option was also not possible with current circumstances, as it required washing of plastic plugs before reusing them due to cleanness requirement of engines. With the current equipment, in-house washing was not possible either, and external washing was neither economically beneficial for the company, although the discussion and investigations were initiated for future improvement activities. Moving to the next option on waste hierarchy, *recycling* found to be highly possible and profitable, particularly for PE plastic plugs, which comprised around 50% of total plastic plugs. It was also feasible to mix PE and EVA (comprise 40%) for recycling, although less environmental and economic benefit were associated. As a result, there was a possible to recycle around 90% of plastic plugs, although the colour of plugs might be a limited barrier for high quality recycling. According to the preliminary investigations, there was not any color-coding associated with plugs on assembly line which imply feasibility of colour harmonization (through discussion with plastic plugs' suppliers) to ease recycling.

5. Discussion

EVSM proved to be a useful tool to map material and waste flow depending on the manufacturing company's requirements or environmental goals. The main criteria for EVSM was simplicity and visualization. Since these two studied involved different organizational functions to assess and measure material flows and waste generation, and scrutinize possibilities or limitations, simplicity and visualization of EVSM were the key factors to create a common platform. In this way everyone could understand and engage in the improvement process of daily operation. Involved organizational functions included waste handling entrepreneur, on-site and central-enterprise environmental management, operators and production technicians, production planner and management, quality assurance and purchasing department. These studies with the help of EVSM, aided the manufacturing companies to engage these functions into a practical improvement project through "go to gemba" approach, which in lean principles referring to going to the location where the actual production (here also include material consumption and waste generation) is taking place and value is created (here also include wasting of material value). Therefore we can conclude that EVSM used for material efficiency improvement in manufacturing, eradicated some barriers mentioned in literature such as limited environmental engagement and intra-organisational interaction (Simpson, 2010, Sarkis et al., 2007), and effective measurement to evaluate sustainability (Al Zaabi et al., 2013, Zhu et al., 2011); here material efficiency aspect.

As it shown in figure 2, there majority of generated metal scraps are due to *quality scrap*. Therefore, quality assurance and production technicians related to that specific problem were consulted to come up with solutions. Although the scrap metals, products and steel sheets are now sold to the waste handling entrepreneur for mixed recycling, the better option (both in terms of environment and economy) is to prevent or reduce scrap generation in the first place. These options help avoiding the unnecessary consumption of productive materials and even auxiliary materials, since in several cases, the scrapped product moved on in the process consuming energy, material (for instance for painting and heat treatment) and production time, while it would be scrapped eventually. Another environmental and economical option was to send the pure steel sheets (*set up or process scarp*, before being fabricated) to the original supplier to be recycled to the original clean unalloyed steel (avoiding downgrading). As a consequence, new Key Performance Indicators (KPIs) related to material consumption and waste generation were defined to measure and monitor scrap generations and track products. The EVSM in the second case study also helped to define new KPIs to measure plastic plugs consumption in total and also per engine. These KPIs were also broken down to different plastic types. As shown in figure 3, PE plugs have the biggest volume to be segregated separately, followed by EVA.

When the EVSM was applied in the case studies with different material streams, it was perceived that the amount of wasted material, type of waste, complexity of process and size of the selected operation might be problematic. Including different materials in the EVSM is not suggested as it brings confusion among different functions. One aggregated EVSM it can be informative to visualize the process and provide a clear picture of material consumption and waste generation, but for detail analysis of material flow and waste streams it is necessary to study one material/waste stream at a time. Another reason for this is the fact that different materials have to be defined separately with different KPIs and with different measurement units. It is usually easier to use EVSM with focus on energy or water as both have a single unit of measurement (e.g. kWh for energy consumption) while different materials have different unit of measurements. Study on one material/waste flow at a time can also help concentrating on a clear and relevant goal on different levels of operation, either vertically or horizontally (Kurdve et al., 2015).

It is vital for environmental improvements to include operation management and follow the performance (both operational and environmental) on a regular basis, and provide data availability, and easy communication within the organization. From our industrial experiences we can conclude that improvement potentials should be highlighted in not only environmental improvement potentials, but also in cost saving/revenues to attract different function to engage, since different functions have different drivers.

6. Conclusions

Improving material efficiency is aligned with *sustainable manufacturing* and *sustainable development* goals, as industry greatly contribute to energy and material consumption, waste and emissions generation. Material efficiency embrace both environmental benefits and economic advantages (even in short-term) through recycling, reusing, reduction and prevention of wasted materials. This paper contributes to the area of lean and green and circular economy through aiding manufacturing companies to better manage, measure and visualize industrial waste and material consumption in order to go up the waste hierarchy i.e. from waste incineration to recycling, reusing, reduction and prevention. This in turn will lead to reduction of solid industrial waste, the demand for virgin raw material and correlated total energy consumption and carbon emissions. Applying EVSM to map the material flow and waste stream proved to be a practical solution to engage different organizational functions in environmental (here material efficiency) improvement via visualizing a detailed insight. Using EVSM for both productive material (case study 1) and auxiliary material (case study 2) flows helped realizing the value of wasted material and costs associated to waste handling and treatment, promoting the waste segregation to different fraction both in metal (pure steel vs mixed metal scrap) and plastic (combustible waste vs pure PE plastics) and providing environmental and economic benefits to the manufacturing company. All in all, material efficiency at studied companies could be improved as the applied EVSM on material/waste flows provided (1) visualization of process, material consumption and waste streams, (2) easy to understand by different functions in organization, (3) engaging different functions into environmental improvement activities, (4) adjoin the gap between material efficiency management and operation management, (5) defining/updating KPIs, (6) supporting lean principle like go to gemba, and (7) standardize way to work in future. However, some difficulties were associated to the tools when using different material/waste streams, which brought some confusion among involved functions. Beside further validation of proposed tool for material/waste flows, future studies will pursue extension of application to other type of manufacturing industry or SMEs.

References

Al Zaabi, S., Al Dhaheri, N. & Diabat, A. 2013. Analysis of interaction between the barriers for the implementation of sustainable supply chain management. The International Journal of Advanced Manufacturing Technology, 68, 895-905.

Allwood, J. M., Cullen, J. M. & Carruth, M. A. 2012. Sustainable Materials with Both Eyes Open, UIT Cambridge Limited.

Ammenberg, J. & Sundin, E. 2005. Products in environmental management systems: drivers, barriers and experiences. Journal of Cleaner Production, 13, 405-415.

Arina, K. & Viktoria, V. 2007. Eco-mapping as a basis for environmental management systems integration at small and medium enterprises. Management of Environmental Quality: An International Journal, 18, 542-555.

Azapagic, A. & Perdan, S. 2000. Indicators of Sustainable Development for Industry: A General Framework. Process Safety and Environmental Protection, 78, 243-261.

Bai, C. & Sarkis, J. 2014. Determining and applying sustainable supplier key performance indicators. Supply Chain Management: An International Journal, 19, 275-291.

Bey, N., Hauschild, M. Z. & Mcaloone, T. C. 2013. Drivers and barriers for implementation of environmental strategies in manufacturing companies. CIRP Annals - Manufacturing Technology, 62, 43-46.

Brundtland, G. 1987. World Commission on Environment and Development, Our Common Future. Oxford University Press, Oxford, UK.

Dadashzadeh, M. D. & Wharton, T. J. 2012. A Value Stream Approach For Greening The IT Department. 2012, 16, 12.

Epa 2015. Lean and Clean Value Stream Mapping. Available at: www.epa.gov/e3.

European Commission 2011. A resource-efficient Europe – Flagship initiative under the Europe 2020 Strategy (EN). EUROPEAN COMMISSION. Brussels.

Faulkner, W. & Badurdeen, F. 2014. Sustainable Value Stream Mapping (Sus-VSM): methodology to visualize and assess manufacturing sustainability performance. Journal of Cleaner Production, 85, 8-18.

Gagnon, B., Leduc, R. & Savard, L. 2012. From a conventional to a sustainable engineering design process: different shades of sustainability. Journal of Engineering Design, 23, 49-74.

Garetti, M. & Taisch, M. 2011. Sustainable manufacturing: trends and research challenges. Production Planning & Control, 23, 83-104.

Iisd, I. I. F. S. D. 1992. Business Strategies for Sustainable Development. Winnipeg, Canada.

Kurdve, M., Shahbazi, S., Wendin, M., Bengtsson, C. & Wiktorsson, M. 2015. Waste flow mapping to improve sustainability of waste management: a case study approach. Journal of Cleaner Production, Vol. 98, P. 304–315.

Kurdve, M. & Wiktorsson, M. Green performance map: visualizing environmental KPI's. European Operations Management Association (EurOMA), 2013.

Kurdve, M., Zackrisson, M., Wiktorsson, M. & Harlin, U. 2012. Lean and Green integration into production system models – Experiences from Swedish industry. Swedish Production Symposium, SPS12. Linköping, Sweden: Swedish Production Symposium, SPS12.

Liao, M.-I., Chen, P.-C., Ma, H.-W. & Nakamura, S. 2015. Identification of the driving force of waste generation using a high-resolution waste input–output table. Journal of Cleaner Production, 94, 294-303.

Miles, M. B. & Huberman, A. M. 1994. Qualitative Data Analysis: An Expanded Sourcebook, SAGE Publications.

Milford, R. L., Allwood, J. M. & Cullen, J. M. 2011. Assessing the potential of yield improvements, through process scrap reduction, for energy and CO2 abatement in the steel and aluminium sectors. Resources, Conservation and Recycling, 55, 1185-1195.

Murillo-Luna, J. L., Garcés-Ayerbe, C. & Rivera-Torres, P. 2011. Barriers to the adoption of proactive environmental strategies. Journal of Cleaner Production, 19, 1417-1425.

Müller, E., Schillig, R., Stock, T. & Schmeiler, M. 2014. Improvement of Injection Moulding Processes by Using Dual Energy Signatures. Procedia CIRP, 17, 704-709.

Möller, A. & Schaltegger, S. 2005. The Sustainability Balanced Scorecard as a Framework for Eco-efficiency Analysis. Journal of Industrial Ecology, 9, 73-83.

Pajunen, N., Watkins, G., Husgafvel, R., Heiskanen, K. & Dahl, O. 2013. The challenge to overcome institutional barriers in the development of industrial residue based novel symbiosis products – Experiences from Finnish process industry. Minerals Engineering, 46–47, 144-156.

Posselt, G., Fischer, J., Heinemann, T., Thiede, S., Alvandi, S., Weinert, N., Kara, S. & Herrmann, C. 2014. Extending Energy Value Stream Models by the TBS Dimension – Applied on a Multi Product Process Chain in the Railway Industry. Procedia CIRP, 15, 80-85.

Sarkis, J., Hasan, M. A. & Shankar, R. 2007. Evaluating Environmentally Conscious Manufacturing Barriers With Interpretive Structural Modeling. Optics East International Society for Optics and Photonics

Saunders, M., Lewis, P. & Thornhill, A. 2009. Research Methods for Business Students, Financial Times Prentice Hall.

Shahbazi, S., Wiktorsson, M., Kurdve, M., Jönsson, C. & Bjelkemyr, M. 2016. Material efficiency in manufacturing: swedish evidence on potential, barriers and strategies. Journal of Cleaner Production, 127, 438-450.

Simpson, D. 2010. Use of supply relationships to recycle secondary materials. International Journal of Production Research, 48, 227-249.

Smith, L. & Ball, P. 2012. Steps towards sustainable manufacturing through modelling material, energy and waste flows. International Journal of Production Economics, 140, 227-238.

Torres, A. S. & Gati, A. M. Environmental Value Stream Mapping (EVSM) as sustainability management tool. Management of Engineering & Technology, 2009. PICMET 2009. Portland International Conference on, 2-6 Aug. 2009 2009. 1689-1698.

Tóth, G. 2003. Evaluation of Environmental Performance of Companies. Society and Economy, 25, 383-402.

Veleva, V., Bailey, J. & Jurczyk, N. 2001. Using Sustainable Production Indicators to Measure Progress in ISO 14001, EHS System and EPA Achievement Track. Corporate Environmental Strategy, 8, 326-338.

Worrell, E., Allwood, J. & Gutowski, T. 2016. The Role of Material Efficiency in Environmental Stewardship. Annual Review of Environment and Resources, 41, 575-598.

Yin, R. K. 2014. Case Study Research: Design and Methods, SAGE Publications, Inc; fifth Edition edition

Zhu, Q., Sarkis, J. & Geng, Y. 2011. Barriers to environmentally-friendly clothing production among Chinese apparel companies. Asian Business & Management, 10, 425-452.

Zokaei, K., Lovins, H., Wood, A. & Hines, P. 2013. Creating a Lean and Green Business System: Techniques for Improving Profits and Sustainability, CRC Press,Taylor and francis group.