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Procedia CIRP 41 (2016) 289 – 294

www.elsevier.com/locate/procedia

48th CIRP Conference on MANUFACTURING SYSTEMS - CIRP CMS 2015

An Approach to integrate Parameters and Indicators of Sustainability Management into Value Stream Mapping

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Abstract

In production research, sustainability is discussed in various forms and often combined with Value Stream Mapping (VSM), a highly accepted method in practice for improving production systems using lean principles. In scientific literature, most authors present frameworks for scoring production processes (e.g. ratios, benchmarks). These approaches aim to reduce (material) input for producing a specific amount of goods. Hence, improved target-conditions of value streams can be designed to increase ecological efficiency and therefore decrease costs. However, the main aim of this contribution is to present an approach to combine generally accepted parameters and indicators of sustainability and VSM. This approach is based on process-oriented accounting of resource consumption along buffers, transports and processes along value streams. This model of integrating sustainability into VSM goes conform with international accepted guidelines to prevent disposals of input resources by reuse, recycle and recovery. On the one hand, following international guidelines and frameworks, this approach can be used for sustainability reporting; e.g. calculating emitted solvents per produced part, kilogram carbon dioxide equivalents per produced part (with units [kgCDE] or [kgCO_2eq]), kilogram disposals per produced part, etc. On the other hand, companies will be able to calculate costs and revenues of sustainable value streams; i.e. to quantify their efforts and benefits monetary. Hence, it is necessary to immerse into material flows in value stream, material consumptions at processes, energy consumption of transports, buffers and processes in value stream, linkage of processes with scrap rates, creation of waste, etc. New data lines in VSM need to be created to represent the parameters and indicators of sustainability. The research findings will be presented by an use case from automotive industry.

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Peer-review under responsibility of the scientific committee of 48th CIRP Conference on MANUFACTURING SYSTEMS - CIRP CMS 2015

Keywords: Manufacturing; Sustainable development; Value Stream Mapping

1. Introduction

For sustainability several definitions are existing [1]. Most important are from the (a) Brundtland Report: "*Development that meets the needs of the present without compromising the ability of future generation to meet their own needs*" [2]; and the (b) United States Department of Commerce (US DOC): "*sustainable manufacturing is defined as the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound*" [3]. The European Union represents a Life Cycle Approach with the goal to minimize environmental impacts as well as usage of resources across all life cycle stages [4]. Improvements in areas regarding environmental, health and safety issues have been in demand from public and their political representatives [5]. Various authors argue that in manufacturing processes cost saving potentials arise after application of sustainability management [5,6,7,8]. The concept and measurement of sustainability are known in natural systems as well as in socio-technical systems [9]. For effective reporting, classical indicators have been widely used; e.g. energy, material and water consumption as well as emissions [10,11]. The work of Jayal et al. has shown that further development of sustainable manufacturing increases stakeholders' value and engagement [12]. The General Reporting Initiative (GRI) therefore provides a standard format for sustainability performance

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Peer-review under responsibility of the scientific committee of 48th CIRP Conference on MANUFACTURING SYSTEMS - CIRP CMS 2015
doi:10.1016/j.procir.2015.08.037

reporting which can be used by manufacturers to benchmark processes [13]. To ensure usage across all manufacturing processes water, raw material, and energy consumption indicators should be included [14]. In lean production, developed in the 1950s and 1960s by Eiji Toyoda and Taiichi Ohno for Toyota [15], conventional/traditional methods in manufacturing and service industries are replaced by lean methods [16]. The focus of lean is the reduction and elimination of waste with a strong focus on the costumer. Methods like Value Stream Mapping (VSM), 5S and Kaizen, last one popularized in the western industry mainly through the published work of Imai, are used to accomplish a lean condition/process [17].

The book "*The Machine That Changed the World*" by Womack et al. made the concept of "lean production" known popular outside of Japan due to arising significant potentials for decreasing manufacturing costs by organizational aspects [15]. The additional inclusion of sustainability in lean can be seen as a development of the traditional short-term (e.g. yearly base) perspective. This combination of lean manufacturing and sustainable development is documented to increase quality, customer satisfaction, decreasing costs and reducing lead time [18]. The practical application of lean principles and scientific discussion became very popular, indicated through the rising number of published papers about lean management and sustainability [19]. But, several studies indicate that lean practices do not necessarily improve environmental performance [16,20].

2. Fundamentals

The approach presented in this paper is based on the fundamentals of value stream and the so far published, diverged approaches and practices in sustainability management.

2.1. Value Stream Mapping

Value Stream Mapping was originally developed as a method within the Toyota Production System [21,22] and introduced as a distinct methodology by Rother & Shook [23]. Value Stream Mapping is a simple, yet very effective, method to gain a holistic overview of the conditions of the value streams within an organization. Based on the analysis of the current-condition, flow-oriented target value streams (target-conditions) are planned and implemented [23,24,25].

A value stream includes all activities, i.e. value adding, non-value adding and supporting activities that are necessary to create a product (or to render a service) and to make it available to the customer. This includes the operational processes, the flow of material between the processes, all control and steering activities and also the flow of information [23]. In order to assess possible improvement potential, Value Stream Mapping considers, in particular, the entire operating time compared with the overall lead time. The greater the distinction between operating time and lead time the higher the improvement potential [24]. According to a previous published approach in which we combined Value Stream Mapping with Methods-Time Measurement (MTM), this approach again immerses into detailed consideration of processes in a value stream regarding sustainability management. The interaction of Value Stream Mapping and MTM at different levels of detail consideration contributes to the identification, elimination and avoidance of waste and thus leads to the design of efficient and effective processes.

2.2. Combined sustainability management and Value Stream Mapping approaches in literature

In the literature, there exist several approaches for sustainability in the value stream:

(a) Green VSM (GVSM) [26] with the focus on office operations and the indicators energy, water, materials, waste, transport, emissions and biodiversity. The possible visual representation is limited [14]. (b) Environmental VSM (E-VSM) [27] with the primary focus on water consumption. The visual identification of wasting water is not very clear. A detailed analysis is only available for the water resource [14]. (c) Energy Value Stream [28] with the focus on energy savings, examines each production step for energy waste. The work of Erlach is practicable, but the analysis of other resources (e.g. waste) is missing. (d) Energy and Environment VSM (EE-VSM) [29] considers process energy consumption. Energy usage due to transport or storage are, however, neglected [14]. (e) Lean Sustainable Production Assessment Tool [30] a further development of EE-VSM, with the metrics: energy-, water-, material usage and CO_2-emissions. Social indicators or visual representation of several indicators are not discussed [14]. (f) Sustainable Manufacturing Mapping (SMM) [31] considers selected sustainability indicators based on VSM, Life Cycle Assessment (LCA) and Discrete Event Simulation (DES). VSM is used as a basis, a detailed visualization of the data is missing. (g) Sustainable VSM (SVSM) [32] which analyzes Greenhouse gas (GHG) emissions It is assumed that the social indicators are incorporated indirectly through the positive effects on the economy and the environment [14]. (h) U.S. Environmental Protection Agency's (EPA) lean and environmental toolkit is used to highlight potentials for considering waste [33]. It helps lean users to identify waste of energy and to improve/reduce the environmental impact.

2.3. Sustainability parameters and indicators

Several organizations and researchers described sustainability indicators in their works but, however, there is no universal standard published yet [32]. Further development of sustainability reporting in the production practice can be identified [11]. This made it important to define criteria that help to develop strategies for the evaluation and improvement of sustainability [10]. Paju et al. list a compilation of indicators, which can be used in a Sustainable Manufacturing Mapping [31]. In the following widely used indicators, like used i.e. in the GRI standard [34], are explained. These indicators can also be found in this approach. (a) Waste due to use of resource "material": Here, the legal EU definition of waste *"(…)means any substance or object which the holder discards or intends or is required to discard"* [35]. Material

waste means all non-productive output (NPO) including solid and fluid waste [36]. An established categorization for produced waste is taken from the "DIRECTIVE 2008/98/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL" [35], which orders the "R" strategies reuse, recycle, recovery and disposal descending by importance [37]. The reduction of waste therefore begins with prevention, followed by reuse or recycle and thermal recovery. The efficiency of a manufacturing system is defined with the ratio of output in comparison with the input. Despeisse et al. explain that a system which utilizes generated waste internally and views it as a resource is more efficient than a system that does not. Additional approaches such as redesign and remanufacture [14] are not considered in this paper, since they are not applied in VSM. (b) Solvents: Depending on the manufacturing process solvents are used in paints or adhesives. In the literature solvents are used as sustainability indicators [34]. (c) Water: often used for cooling, heating or cleaning in a production process [11]. E-VSM primarily focusses on water [27]. (d) Energy: Since non-renewable energy has a direct impact on greenhouse gas, energy must be seen as an important indicator for sustainability [14]. Common energy and material forms in production which are used as sustainability indicators are electricity, natural gas and compressed air [31]. Furthermore diesel or district heating can be included [38]. (e) CO_2: The EPA eGrid supplies emission factors in the USA with whom [kWh] can be converted in [kg] of CO_2 [11]. Products with a known CO_2 balance are subject to steadily growing demand by consumers [39]. In the method "carbon footprint analysis" the total greenhouse gas (GHG) emissions are estimated in terms of carbon equivalence (i.e. as tons of carbon dioxide equivalent [tCO_2e] or grams of CO_2 equivalent per kilowatt hour of generation [gCO_2eq/kWh] from a specific product [40].

3. Identification of challenges in sustainable value streams

The described approaches from the literature deal with sustainability in value streams – but only very superficially and without detailed consideration of resource use and cycle and especially without an underlying, universal model for the calculation of sustainability indicators.

Moreover neither the categories of the waste pyramid reuse, recycle, recovery and disposal nor their monetary values are considered. This paper describes an approach to close this gap. Similar to a previously published approach (Value Stream and MTM [41]) the value stream perspective is used to look at the whole thing, while the process evaluation looks and measures the specific and thus it can be improved subsequently. Since a comprehensive Sus-VSM needs to have methods for visualization of the selected metrics [14], this is also taken into account in this approach. Documented approaches with a focus on savings in regards to waste, mainly waste prevention [40], are not considered. In spite of already published "case studies" which describe the development of the current state of Sustainable Value Streams (i.e. Sus-VSM) further research is needed [42].

4. Model-based Sustainable Value Stream Mapping

In this paper an "ideal-typical re-utilization cycle" is introduced. It is the basis for evaluation of sustainability indicators. In each process of the value stream an ideal-typical re-utilization cycle is underlained; and all ideal-typical re-utilization cycles themselves virtually include the categories reuse, recycle, recovery and disposal.

However, generally additional material is required in production. Waste of material resources is assigned to each ideal-typical re-utilization cycle of a process. Waste occurs depending on process technology. This waste can be – partial – reused, recycled, recovered or brought to the disposal site. But before immersing into the ideal-typical re-utilization cycle and the calculation of sustainability indicators, the connection of processes in a value stream need to be discussed.

4.1. Cumulated scrap rate

With a serial sequence of processes of a value stream and the occurring scrap rates at processes, each upstream process has to produce more to finally provide the required amount to the customer. Contrary to the direction of material flow the cumulated scrap rate increases for each process of the value stream accordingly. As a result, the calculation of cumulated scrap rate for each process in a serial sequence is:

$$s_{cum}(i) = 1 - \prod_{i=n}^{1} (1 - s_i) \tag{1}$$

- s_{cum} … cumulated scrap rate along a value stream [%]
- s_i … scrap rate of a process I [%]

Starting from the actual costumer demand D_{net}, the customer demand per process (i) results in:

$$D_{net.p}(i) = \frac{D_{net}}{1 - s_{cum}(i)} \tag{2}$$

- $D_{net.p}$ (i) … … increased net demand per process due to cumulated scrap rate process i [parts per time period]
- D_{net} … net demand of customer [parts per time period]
- $s_{cum.}$ … cumulated scrap rate [%]

This formula is essential for the calculation of total waste along a value stream.

Another effect of the cumulated scrap rate is not considered in this paper, but should be mentioned because of practical relevance in Value Stream Mapping: The cumulated scrap rate causes an increase of the required net demand per process upstream the considered value stream. Therefore, the customer tact time is not assumed to be constant for each process. Strictly speaking, the specific tact time of each process has to be reduced due to an increased required net demand while keeping available net working time constant.

4.2. Calculation of waste at single processes

The waste of material resources for each process in the value stream is, as described above, associated with the ideal-typical re-utilization cycle. This waste can generally occur in three ways; see Formulas 3, 4 and 5.

$$W_{nok} = (D_{net.p} - D_{net}) \cdot d_n \tag{3}$$

- W_{nok} … waste due to cumulated scrap rate [kg per time period]
- $D_{net.p}$ … increased net demand of customer [parts per time period]
- $D_{net.}$ … net demand of customer [parts per time period]
- d_n … net weight of input resource [kg per part]

W_{nok} is the waste because of not fulfilling quality requirements such as damaged or improperly manufactured parts. The gross material input is d_g. Due to the chosen manufacturing process additional resource input W_{ok} is often necessary and calculated as follows:

$$W_{ok} = D_{net.p} \cdot (d_g - d_n) \tag{4}$$

- W_{ok} … waste due to material input difference [kg per time period]
- $D_{net.p}$ … increased net demand of customer [parts per time period]
- $d_{g.}$ … gross weight of input resource [kg per part]
- d_n … net weight of input resource [kg per part]

The net material input is d_n e.g. the material input differences between gross and net is sprue in injection moulding or paint sludge in the painting processes.

As a third category waste because of set-ups $W_b(i)$ is introduced. This waste is usually produced in batch production or discontinuous shift models. The above proportions of all waste depend on the considered time period. The waste proportion because of set-up is usually not in the same observation period as the required amount of the customer D_{net}. For this reason, the following proportionality is presented:

$$\frac{W_{set-up}(i)}{D_{net.p}} \square \frac{W_b(i)}{b(i)} \tag{5}$$

- W_{set-up} … waste due to set-ups [kg per time period]
- $D_{net.p}$ … increased net demand per process due to cumulated scrap rate [parts per time period]
- W_b … waste per batch [kg per batch]
- b … batch size [parts per batch]

W_b presents the average waste per batch. B is referred to as batch-size. The sum of waste per observation period – e.g. shift – is calculated as follows:

$$W = W_{nok} + W_{ok} + W_{set-up} \tag{6}$$

- W … total waste [kg per time period]
- W_{nok} … waste due to cum. scrap rate [kg per time period]
- W_{ok} … waste due to material input difference [kg per time period]
- W_{set-up} … waste due to set-ups [kg per time period]

To convert the waste per unit the calculated waste per observation period must be divided by the observation period. Thus, the waste per part w_i for each process i is:

$$w(i) = \frac{d_g(i)}{1 - s_{cum}(i)} - d_n(i) + \frac{W_b(i)}{b(i)} \tag{7}$$

- w(i) … total waste per ok part [kg per ok part]
- $d_{g.}$ … gross weight of input resource [kg per part]
- $s_{cum.}$ … cumulated scrap rate [%]
- d_n … net weight of input resource [kg per part]
- W_b … waste per batch [kg per batch]
- b … batch size [parts per batch]

The waste per unit can be calculated for each process and each resource which is used. This waste of material resources are supplied to the ideal-typical utilization process and rated. Simplifying the mathematical model, only the primary resource is considered, which excludes process water, solvents or packaging.

4.3. Ideal-typical re-utilization cycles for each process

In this chapter, the ideal-typical re-utilization cycle gets introduced. The three types of waste of each process get assigned to the introduced categories reuse, recycle, recovery and disposal. In all categories but disposal, material gets used somehow else again, whereas disposals get transported to landfill.

Each process of a value stream gets layers for the re-utilization categories (see Figure 1). One specific re-utilization cycle then consists of five transport activities, three buffers and the re-utilization process itself to become an ideal-typical re-utilization cycle. This ideal-typical re-utilization cycle is applicable for all kinds of production/assembling processes. An example to illustrate is an injection moulding process. Due to set-ups, sprue and scrap rate waste is created to produce customer demand; 80% of total waste is recycled to produce other products (e.g. a linoleum covered floor) and 20% is disposal so we have two layers. The machine operator puts all types of waste into one or more containers, which get transported by forklift to a silo for shreddering. After shreddering, the ready-to-recycle material waits in bags on a pallet. All efforts like space, transport distance and time for re-utilization can be assessed similar to classic VSM approach.

Furthermore, one can separate between several resource types in value stream to distinguish types of disposals. On the one hand, this modelling of resource flows at processes seems not replicable when drawing value streams with paper and pen, but on the other hand it is representable in a VSM software tool. Figure 1 shows system boundaries and layers of an ideal-typical re-utilization cycle of a process in a value stream.

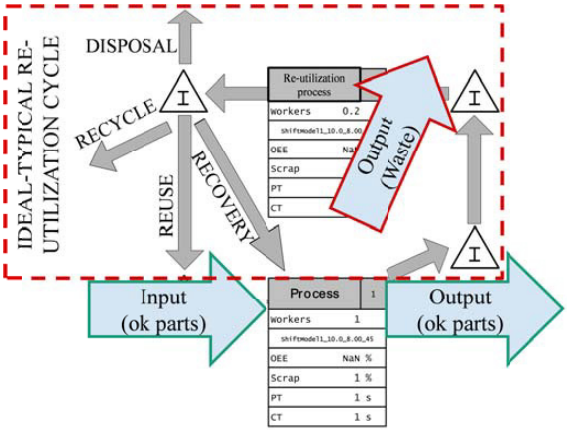

Fig. 1. Principle of an ideal-typical re-utilization cycle.

4.4. Calculation of sustainability indicators and disposals data line

Applying ideal-typical re-utilization cycles at processes of a value stream enables the calculation of sustainability indicators such as disposals by the presented model. This model can then be applied to calculate waste and disposal for all resource types in the same way. Practical examples next to primary input resources are solvents, drinking water, process water and packaging materials. Finally, all criteria needed for sustainability and/or customer reporting can be calculated in the same way with the presented model.

When calculating total lead time of a value stream, all waiting times in buffers are added; same when calculating total process time with adding up all process times in processes. These two values are represented in the time data line at the very end of a value stream. We use the same approach for the disposals data line. All types of resource disposals are summed up to calculate the total disposals value. As an example to illustrate, a specific value stream consists of four serial processes and the process technologies are injection moulding, painting, assembling and sequencing. Types of disposals of primary input resources are therefore synthetics, coating and parts from bill-of-material in unit kilogram per part. Other resources may be solvents and process water at coating process as well as cardboard and synthetics of packaging material at assembly process. All categories of disposals can be summed up apart from each other and/or altogether to represent the disposals of a whole value stream. The final disposals data line of a value stream is shown in Figure 2; sustainability indicators are calculated per part to be comparable.

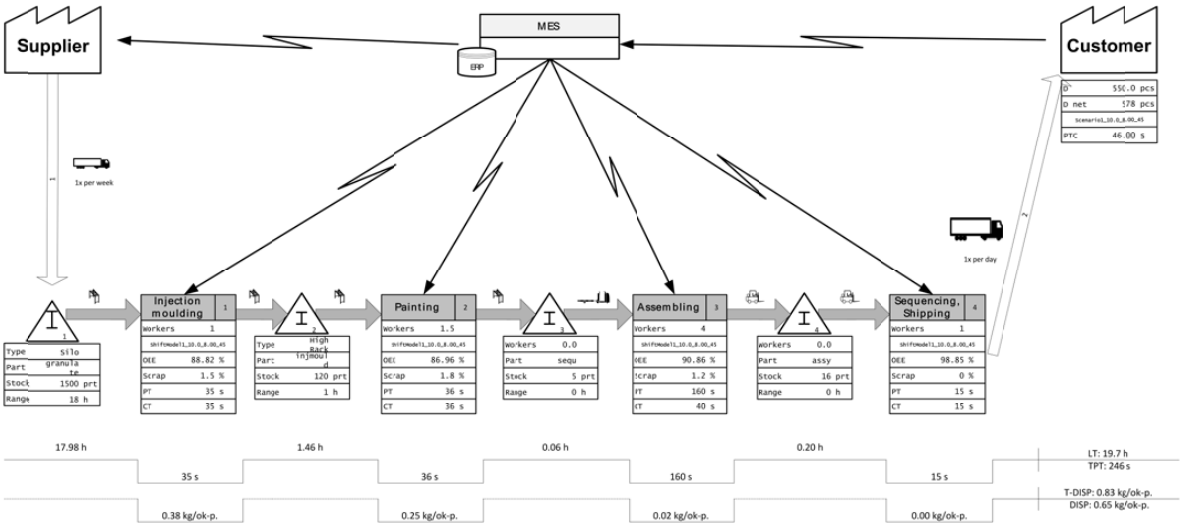

Fig. 2. Use case, disposals data line.

5. Conclusion and outlook

The presented process-oriented accounting of resource consumption combined with Value Stream Mapping to calculate sustainability indicators enables a value stream manager to immerse into improving resource efficiency when improving value streams. The presented calculation of waste and disposals of a value stream is the first step of our work when combining sustainability management and value stream mapping. In future works, we will present how to asses re-utilization cycles accordingly to classic value streams with both monetary and quantitative parameters/indicators; i.e. costs and revenues of sustainability actions in value streams as well as process-oriented accounting of energy used and kilogram carbon dioxide equivalents generated when producing customer demand.

References

[1] Manufacturing Skills Australia, 2008. Sustainable manufacturing. [Online]

[2] WCED, 1987. Our Common Future (World Commission on Environment and Development, Brundtland Commission). Oxford: Oxford University Press.

[3] US DOC, 2014. How the DOC Defines Sustainable Manufacturing. [Online]

[4] European Commission, 2014. EPLCA | European Platform on LCA. [Online] Available at: http://eplca.jrc.ec.europa.eu/ (05.11.2014).

[5] Kleindorfer, P., Singhal, K. & Van Wassenhove, L., 2005. Sustainable operations management. Production & Operations Management, 4(14), pp. 482-492.

[6] Bevilacqua, M., E., C. F. & Giacchetta, G., 2007. Development of a Sustainable Product Lifecycle in Manufacturing Firms: A Case Study. International Journal of Production Research, 45(18-19), pp. 4073-4098.

[7] Dou, Y. & Sarkis, J., 2010. A joint location and outsourcing sustainability analysis for a strategic offshoring decision. International Journal of Production Research, 48(2), pp. 567-592.

[8] Seuring, S. & Müller, M., 2008. From a literature review to a conceptual framework for sustainable supply chain management. Journal of Cleaner Production, 16(15), pp. 1699-1710.

[9] Diaz-Balteiro, L. & Romerio, C., 2004. In search of a natural systems sustainability index. Ecological Economics, 49(3), pp. 401-405.

[10] Jasch, C., 2000. Environmental performance evaluation and indicators. Journal of Cleaner Productions, 8

[11] Mani, M. et al., 2014. Sustainability characterisation for manufacturing processes. International Journal of Production Research, 52(20), pp. 5895-5912. (1), pp. 79-88.

[12] Jayal, A., Bodurdeen, F., Dillon, J. O. & Jawahir, I., 2010. Sustainable Manufacturing: Modeling and Optimization Challenges at the Product, Process and System Level. CIRP Journal of Manufacturing Science and Technology, 2(3), pp. 144-152.

[13] Feng, S. & Joung, C., 2009. An Overview of a Proposed Measurement Infrastructure for Sustainable Manufacturing. Gaithersburg, Maryland, USA: s.n.

[14] Faulkner, W. & Badurdeen, F., 2013. Sustainable Value Stream Mapping (Sus-VSM): methodology to visualize and assess manufacturing sustainability performance. Journal of Cleaner Production

[15] Womack, J., Jones, D. & Roos, D., 1991. The Machine That Changed the World: The Story of Lean Production. s.l.:Harper Perennial.

[16] Venkat, K. & Wakeland, W., 2006. Is Lean Necessarily Green.

[17] Masaaki, I., 1986. Kaizen: The Key To Japan's Competitive Success. 1. Hrsg. New York: McGraw-Hill/Irwin.

[18] Nitin, U., Deshmukh, S. & Suresh, G., 2010. Lean Manufacturing for Sustainable Development. Global Business and Management Research: An International Journal, 2(1), pp. 125-137.

[19] Martínez-Jurado, P. & Moyano-Fuentes, J., 2013. Lean Management, Supply Chain Management and Sustainability: A Literature Review. Journal of Cleaner Production.

[20] Yang, C., Lin, S., Chan, Y. & Sheu, C., 2010. Mediated effect of environmental management on manufacturing competitiveness: an empirical study.. International Journal of Production Economics, 123(1), pp. 210-220.

[21] Ohno, T., 1998. Toyota Production System beyond Large Scale Production. In: Ohno, T. (1978) Toyota seisan höshiki. Tokyo, Japan Diamand, Inc.. Portland USA: Productivity Press.

[22] Liker, J., 2009. Der Toyota-Weg: 14 Managementprinzipien des weltweit erfolgreichsten Automobilkonzerns. 6, slightly different version ed. München: FinanzBuch.

[23] Rother, M. & Shook, J., 2006. Learning to see (Sehen lernen - Mit Wertstromdesign die Wertschöpfung erhöhen und Verschwendung beseitigen). Aachen: Lean Management Institut.

[24]Erlach, K., 2007. Wertstromdesign - Der Weg zur schlanken Fabrik. Berlin Heidelberg: Springer Verlag.

[25]Klevers, T., 2007. Wertstrom-Mapping und Wertstrom-Design: Verschwendung vermeiden - Wertschöpfung steigern. Landsberg am Lech: mi-Fachverlag.

[26] Dadashzadeh, M. & Wharton, T., 2012. A Value Stream Approach for Greening the IT Department. International Journal of Management & Information Systems, 16(2), pp. 125-136.

[27] Torres, A. & Gati, A., 2009. Environmental Value Stream Mapping (EVSM) as Sustainability Management Tool In. Portland, OR, IEEE.

[28] Erlach, K. & Westkämper, E., 2009. Energiewertstrom - Der Weg zur energieeffizienten Fabrik. Stuttgart: Fraunhofer Verlag.

[29] Kuriger, G. & Chen, F., 2010. Lean and Green: A Current State View. Cancun, Mexico, Industrial Engineering Research Conference.

[30] Kuriger, G., Huang, Y. & Chen, F., 2011. A lean sustainable production assessment tool. Madison, Wisconsin, Proceedings of the 44th CIRP Conference on Manufacturing Systems.

[31] Paju, M. et al., 2010. Framework and indicators for a sustainable manufacturing mapping methodology. Baltimore, Maryland, Proceedings of the 2010 Winter Simulations Conference.

[32] Simons, D. & Mason, R., 2002. Environmental and transport supply chain evaluation with sustainable value stream mapping. Birmingham, UK, 7th Logistics Research Network Conference.

[33] US EPA, 2014. The Lean, Energy and Climate Toolkit. [Online] Available at: http://www.epa.gov/lean/environment/toolkits/energy/index.htm (06.11.2014).

[34] Global Reporting Initiative, 2014. Global Reporting Initiative. [Online] Available at: https://www.globalreporting.org/Pages/default.aspx (30.12.2014).

[35] European Commission, 2008. Directive 2008/98/EC on waste (Waste Framework Directive). [Online] Available at: http://ec.europa.eu/environment/waste/framework/ (06.11.2014).

[36] Kurdve, M. et al., 2014. Waste flow mapping to improve sustainability of waste management: a case study approach. Journal of Cleaner Production xxx, pp. 1-12.

[37] Despeisse, M., Oates, M. & Ball, P., 2013. Sustainable manufacturing tactics and cross-functional factory modelling. Journal of Cleaner Production 42, pp. 31-41.

[38] Lourenço, E., Baptista, A. & J.P. Pereira, C. D.-F., 2013. Multi-Layer Stream Mapping: a new approach to assess production system's overall efficiency & eco-efficiency. Singapore, Proceedings of the 20th CIRP International Conference on Life Cycle Engineering.

[39] Erlach, K. et al., 2012. CO_2-Wertstrom - Integrierte ökologische und ökonomische Bewertung und Optimierung. wt Werkstatttechnik online Jahrgang 102 (2012) H.7/8, wt Werkstatttechnik online.

[40] Roosen, T. & Pons, D., 2013. Environmentally Lean Production: The Development and Incorporation of an Environmental Impact Index into Value Stream Mapping. Hindawi Publishing Corporation Journal of Industrial Engineering Volume 2013.

[41] Kuhlang, P., Edtmayr, T. & Sihn, W., 2011. Methodical approach to increase productivity and reduce lead time in assembly and production-logistic processes. CIRP Journal of Manufacturing Science and Technology, 4(1), pp. 24-32.

[42] Brown, A., Amundson, J. & Badurdeen, F., 2014. Sustainable value stream mapping (Sus-VSM) in different manufacturing system configurations: application case studies. Journal of Cleaner Production xxx, pp. 1-16.