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► To cite this version:

Jeff Mangers, Meysam Minoufekar, Peter Plapper. Value Stream Mapping (VSM) to Evaluate and Visualize Interrelated Process-Chains Regarding Circular Economy. IFIP International Conference on Advances in Production Management Systems (APMS), Sep 2021, Nantes, France. pp.534-542, 10.1007/978-3-030-85910-7_56 . hal-03806494

HAL Id: hal-03806494

<https://inria.hal.science/hal-03806494>

Submitted on 7 Oct 2022

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Value stream mapping (VSM) to evaluate and visualize interrelated process-chains regarding Circular Economy

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Abstract. The concept of circular economy (CE) aims to close and slow resource loops without neglecting the goals of sustainable development. Recently, the concept received encouraging attention among researchers and business experts to be a convenient solution to move away from the finite linear economy concept to a more sustainable solution. However, this change of paradigm is only possible if we consider systems in a holistic manner and can see and localize the preventing hurdles.

Value stream mapping (VSM) is a commonly known lean method, which is used to develop current state visualization of product and information flows within organization, helping to seek weaknesses and improve process flows. The motivation of this paper is a new C-VSM model, which enables its users to evaluate and visualize connected process-chains regarding CE on different levels in a holistic manner. For this purpose, the traditional VSM model was adapted towards the needs and requirements of CE through the application of a new representation method, additional indicators, and an appropriated evaluation system. C-VSM is in line with the current political and industrial objectives to apply CE principles by enabling a holistic reflection and consideration of supply-chains (SCs) on different levels. The model itself is validated through an extensive cross-company case study.

Keywords: Value stream mapping (VSM), circular-economy, process-chains, supply-chain, company

1 Introduction

The concept of circular economy is attracting more and more attention and is currently a highly debated topic within scientific, political, and industrial communities. CE promotes the responsible and cyclical use of resources [1], the longevity of products [2], the minimization of waste [3] and this without neglecting sustainability [4]. CE is seen as a way to overcome the current dominant economic development model, the so called ‘take, make and dispose’ [5] model, by promoting the adoption of closed and slowed resource loops [1]. A major critique of CE is the missing uniformly accepted definition [6], which may lead to the concept ultimately collapsing or remaining in a deadlock [7]. Furthermore, it complicates the circularity assessment and measurement of products or process-chains, resulting in a wide range of circularity indicators [8], which may lead to different or even incoherent conclusions [1].

The change in production systems leads to new logistical needs related to resources and waste, as well as to the distribution and recovery of products, thus influencing the current SCs [9]. A SC consists of all parties involved, directly or indirectly, fulfilling a customer request [10]. The change towards circular supply chain management (CSCM) comes up with new challenges, concerning resource efficiency, life management strategies, reverse network management and sustainability [11]. One possibility to visualize and map supply-chains is VSM [12], even with regard to sustainability [13] and CE [14]. The VSM method was made popular by Rother & Shook [15] and was standardized due to a variety of different approaches leading to misunderstanding and conflicts within supply networks [16] within ISO 22468 [17]. VSM is one of the more common lean methods, which is used to develop current state visualizations of product and information flows within organizations [18].

This paper extends the VSM application towards the evaluation and visualization of process-chains regarding CE on macro (supply-chain) and micro (company) level. In doing so, it is possible to analyze SCs in a top-down manner regarding CE with the help of VSM. The macro level allows for a holistic view and evaluation, and the micro level provides a more detailed perspective on the individual resource flows. The different micro VSMs are added up to one overall macro level VSM.

2 Literature review

This chapter reviews the current applicability of VSM within the scientific literature. In this research, ‘value’ refers to the 9R-framework and the waste hierarchy [6], [19].

Typically, VSM visualizes material and information flows within companies and focuses on time. Over time, this has been extended by further applications. The integration of CE aspects into VSM has already been done recently by other researchers. Edtmayer et al. [20] included three re-utilization cycles for waste material into VSM. Galvão et al. [21] mainly focused on connecting value streams within circular business models and their ecosystems and not on measuring the circularity of value streams. Hedlund et al. [14] investigated how companies and industrial systems and networks might use value stream mapping as a tool to enhance sustainability and accelerate change towards an eco-friendly, circular economy.

In addition, a lot of focus lately lay on combining VSM with sustainability [20], [22]–[27]. In this context, additional assessment ladders with new indicators were added to the time assessment. The added indicators are related to materials [22], environment [28], energy [29], water [24], emissions [22], transport [26], waste [13], efficiency (OEE) [30], physical work index [24], noise level [25] and life-cycle-assessment [25]. Other interesting fields of application for VSM are discrete event simulation [31], industry 4.0 with dynamic value streams [32], information flows [18], [33] and multi-layer VSMs [34].

As shown, a research gap concerning the holistic applicability of VSM within inter-related SCs based on CE is missing. None of the listed studies can evaluate the circularity of related process-chains and visualize the connection between different partners. This essential gap is filled by the results presented in the following sections.

3 Research methodology & Findings

This chapter explains the research methodology and discusses the findings, so the new C-VSM evaluation and visualization for macro- (Figure 1) and micro-level (Figure 2).

The research methodology is analytical and the case study structure is based on the Yin methodology [35]. The data collection was done during 10 different company visits, which are all part of PET-bottle SC-network in Luxembourg. The logic behind C-VSM is to first map the overall resource flow throughout the SC, by starting at the OEM on a macro level with as main information the determination of the resource flow value. This helps to get a general overview and understanding of the SC. Afterwards, the different SC-partners are analyzed more in detail on a micro-level and the respective data for each process are collected. This implies the information exchange as well between different SC partners. The visualization itself is based on ISO 22468:2020 and on other mentioned VSM use cases. The evaluation with the respective indicators is taken either from a list of indicators already integrated in sustainable VSMs or from a systematic literature review coming up with 181 circularity measurement indicators (not yet published). The indicators are divided into direct (related to circularity, so the resource flow) and indirect indicators (related to sustainability, so environmental, economic, and social aspects). In another study (not yet published), three main CE goals (close & slow loops [1], minimized waste [36] and sustainability [6]) and two areas with a need for action (identifying the needed collection, sorting and R-infrastructure & developing circular product guidelines) were determined on which the indicators are dependent.

The C-VSM model uncovers overarching problems within SCs, which are only visible through the holistic applicability. The practical application was validated by the PET-bottle case study, which highlighted the close dependencies between the end-of-life (EOL) and the beginning-of-life (BOL). In the future, the study should be extended to other products and sectors.

3.1 Macro-level

The macro C-VSM visualization differs significantly from traditional VSMs. The main questions were how to depict a circular flow of resources and how to add a value depiction into the framework. Both were achieved by referring to the swim lane alternative [17] and the inclusion of the 9R-framework [6]. Each level of the swim lane diagram represents a certain CE value, whereas the lowest level defines the overall value of a SC. The 9R-framework is included as a vertical value-hill on the right side of the diagram, ranging from R0 (highest) to R9 (lowest). Since the three highest Rs (refuse, rethink, and reduce) are only reachable through an adapted design, they are depicted collectively on the design level. The second value is the actual use-phase, during which the product has its highest value. All other Rs are subsequently included except for the last one, namely 'disposal' which has no CE value and should be avoided.

Each SC-partner is visualized as a process-box with a respective data-box, which contains information from the micro analysis. The OEM is visualized as ISO 22468 customer and the direct (e.g., PET-bottle, HDPE-cap) and indirect (e.g., additional packaging foil) supplier are visualized as ISO 22468 supplier. The user has a

completely new symbol. Depending on the respective stage, different information is shown within the data-boxes (see fig. 1 & 2). Since the overall value is defined during the collection and sorting process (compare a glass and PET-single use bottle), this process is ranging from R3 to disposal. The resource flows between two SC-partners are color coded and completed by a respective transportation symbol. A last addition is the inclusion of two information flows, D- (active in the product/ process design) and R-info flow (active in the resource retake), and the inclusion of certain basic product-characteristics (e.g., material, fu, etc.), defining the product in question.

3.2 Micro-level

The micro C-VSM differs slightly from traditional VSM. Main differences are the newly included indicators and the visualization of additional material flows. The material flows, the same as the suppliers are divided into 4 different groups, which are color coded. The first group represents the actual product (e.g., water; green), the second group represents direct inputs (e.g., bottle, cap, and label; blue), the third indirect inputs (e.g., additional foil packaging; red) and auxiliary materials (e.g., glue; black). The output flows and customers are similarly divided into three groups, resources staying in the same loop (e.g., packed bottles; black), resources going to other loops (e.g., PET-scrap; blue) and waste (e.g., foil wraps; red). The traditional information flow is kept and the D- and R-info flow are added to see if a link between both exists.

The used indicators are shown in [Figure 1](#) and [Figure 2](#) and the meaning of the abbreviations can be found in the appendix. Relations between micro- and macro data exist and the indicators are mostly based on a functional unit. The CO₂-equivalents are calculated with national conversion factors and serve as rough indication. The data itself and the names are fictive to avoid sharing any critical information from companies.

4 Discussion & Conclusion

This paper introduces a new VSM visualization and evaluation on macro and micro level regarding CE. This is of importance for other researchers and industrials, who benefit from the holistic applicability of C-VSM and the insights of the case study. Thus, the results not only help to advance the applicability of VSM but are interesting for everyone interested in better understanding the connections and dependencies within SCs and economic systems in general.

Currently, C-VSM was only applied within one extensive packaging use case, focusing on the main resource flow. In the future, it needs to be verified in further use cases. At present, MS-Visio is used to draw the VSM and a connection to MS-Excel is included for the data handling. Since this is not an ideal solution, mainly regarding the analysis (potential improvement VSM) and optimization (future state VSM [37]) as well as the short-, medium, and long-term perspectives for sustainability, this should be made more interactive, allowing for the simulation of different scenarios.

A valuable extension of the current VSM applicability was presented in this paper, which highlighted the necessity of holistic approaches to solve current CE problems.

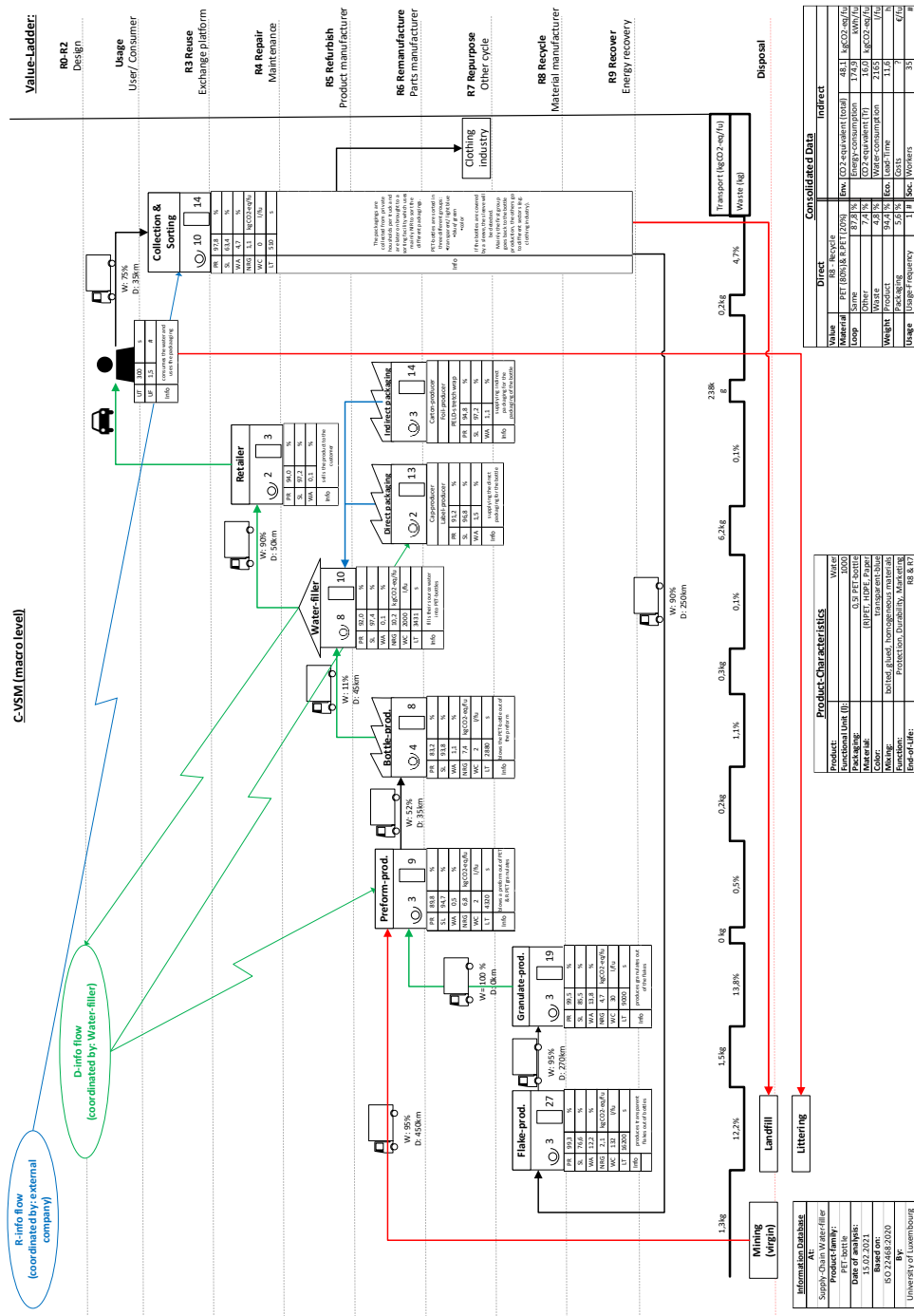
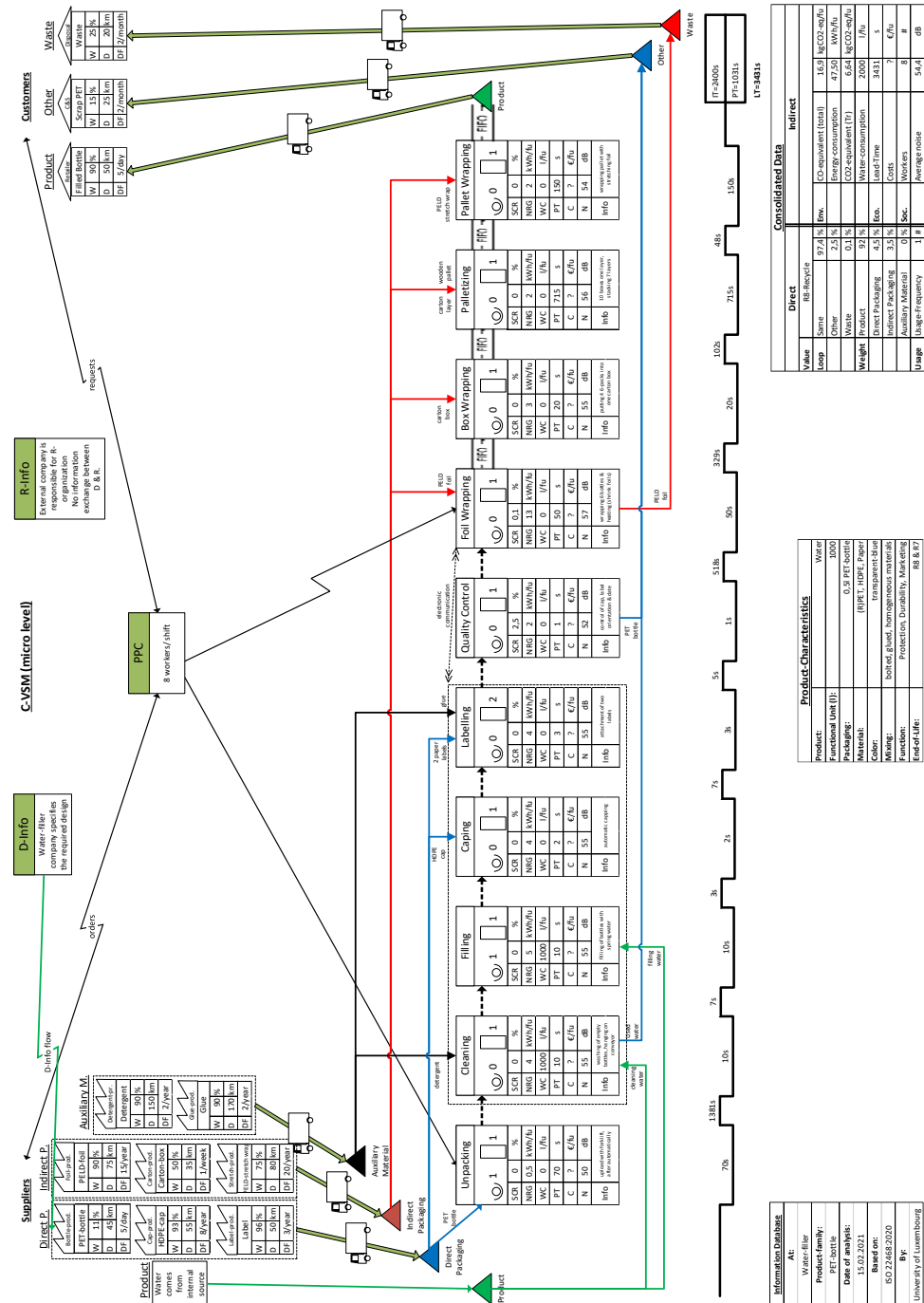


Figure 1. C-VSM, macro level



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Annex

Table 1. Abbreviations of the different indicators

Abbreviation:	Meaning:
C	costs
D	distance
DF	deliver frequency
fu	functional unit
IT	idle time
LT	lead time
N	noise
NRG	energy-consumption
PR	product-weight
PT	process-time
SCR	scrap-rate
SL	same-loop
W	weight
WA	waste
WC	water-consumption
	number of operators
	macro: number of process, micro: number of machines

Funding: This research was funded by the Di-Plast project, which is supported by Interreg NWE. The project aims to improve the uptake of recycled plastic material (rPM) within the packaging and building sectors. Di-Plast aims to improve processes for a more stable rPM material supply and quality. Find more details about Di-Plast at <https://www.nweurope.eu/projects/project-search/di-plast-digital-circular-economy-for-the-plastics-industry/>