21ST INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED17
21-25 AUGUST 2017, THE UNIVERSITY OF BRITISH COLUMBIA, VANCOUVER, CANADA

A PROCESS FOR DESIGNING LEAN- AND SUSTAINABLE PRODUCTION

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Abstract

Today's trends such as globalization, increased customer demands, and increased sustainability challenges have caused a paradigm shift, where the importance of designing lean- and sustainable modern manufacturing systems is realized by many companies. This study proposes a process of action steps using Value Stream Mapping method integrated with sustainability life cycle analysis and sustainability compliance index to assist in designing lean- and sustainable production systems. The developed process was validated through a case study to test the adopted tools and how they can capture and improve the lean- and sustainability levels. The current sustainability and lean levels were explored first, followed by analyzing and developing the future improved state. A roadmap of about 40 actions was suggested to the case company distributed on a one year time plan. The key contribution of this study is an applicable and generic process of action steps including several adopted tools from the lean- and sustainable product development fields to help manufacturing companies in creating roadmaps for more lean- and sustainable production systems.

Keywords: Lean production systems, Sustainability, Value Stream Mapping, Lean design, Case study

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Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 21st International Conference on Engineering Design (ICED17), Vol. 1: Resource-Sensitive Design | Design Research Applications and Case Studies, Vancouver, Canada, 21.-25.08.2017.

1 INTRODUCTION

The lean philosophy has been a major concept for increasing efficiency in the manufacturing industry for many years (Forrester et al., 2010; Bhamu and Singh Sangwan, 2014). Lately, the trends of globalization, increased customer demands, and the increased sustainability challenges (Charpentier, 2007) have moved lean and sustainable production from being a competitive advantage into an expected feature. Many companies realized the benefits of designing lean and sustainable manufacturing systems at an early stage, in order to optimize their production processes in terms of time, cost, quality (Hoppmann et al., 2011), and to increase stakeholder value (Morgan and Liker, 2006).

Several approaches and tools have emerged in the sustainable product development field to assess the environmental impacts of products throughout its life cycle and enhance the development of more sustainable products. For example Cleaner production (Aloisi de Larderel 1998), Framework for Strategic Sustainable Development (FSSD) (Broman and Robèrt, 2015), Life Cycle Assessment (LCA) (ISO, 2006) in addition to various eco-design tools, such as the ABC-Analysis, the MECO Method, LiDS-Wheel, and the Strategy List, in forms of matrices, guidelines etc, see, e.g., Byggeth and Hochschorner (2006) and Poulikidou (2016). However, most of these eco-design tools lack empirical studies to facilitate their diffusion as support tools (Simboli et al., 2014). Furthermore, they do not always fall within the capabilities of small and medium-sized enterprises (SME), due to their complexity, required resources and time consumption factors (Simboli et al., 2014). In a recent review study, Zetterlund et al. (2016) concluded that there are several decision support methods and tools with the purpose to support sustainability consideration in product development. But the implementation and generic applicability levels of the support tools are low. Also, several support tools do not cover all three dimensions of sustainability; ecological, economic and social.

For companies to achieve goals like being competitive, responsive to the increased customer demands and the rising sustainability challenge, it is important for them to be provided with suitable and applicable methods to design lean-and sustainable production systems. A natural starting point is to investigate best practices, and how these practices can be adapted to include ecological, economic and social sustainability. Effective interaction between lean and sustainable efforts leads organizations to avoid risks from noncompliance with regulatory requirements, and investigate new methods of improving operational and sustainable performances by supporting lean on aspects where it is considered weak (Herron and Braiden, 2006; Roosen and Pons, 2013). Using lean tools to account for sustainability performances is widely discussed in the literature (Mollenkopf et al., 2010; Dues et al., 2013). In this regard, the use of Value Stream Mapping (VSM), which is a powerful methodology to improve production performances and optimize product development processes (Rother and Shook, 2009; Morgan, 2002), has received attention. A number of studies proposes the extension of VSM to incorporate sustainability measures, by utilizing some ad hoc sustainability indicators. The problem with these studies is the generalizability and the complexity of collecting sustainability data on the process level. Furthermore, only a single effort was proposed by Vinodh et al. (2016) to construct a future production state that is more environmentally sustainable using a software package. This raises the need for more general and applicable methods to assess the current lean and sustainability levels, and to design a future improved manufacturing system.

1.1 Purpose and scope

The overall purpose of this paper is to investigate how manufacturers can design manufacturing systems to increase production and sustainability performances, by using applicable and adopted tools from the literature of lean manufacturing and sustainable product development. A process of action steps was developed to aid the design of a lean and sustainable production system. A case company in the roller blind industry was selected to validate the developed process, the company was preparing to introduce lean production into its operations, and aiming towards higher sustainability levels, which made it a suitable candidate for the research purpose.

In section 1.2, the research approach is presented. Section 2 provides a literature review of the existing efforts to extend VSM to include sustainability aspects. Section 3 presents a detailed description of the developed process consisting of ten steps for developing a roadmap towards lean and sustainable production systems. Section 4 presents the results from the case company, where the developed concept of adopted tools was tested. The final section 5 is a concluding discussion about the developed process, its benefits, and further validation and development of the approach.

1.2 Research approach

The following research question has been formulated in order to explore the area of combining lean and sustainability on the operational level: "How could a lean and sustainable production roadmap be created for manufacturers with respect to the lean and overarching sustainability principles?"

The sustainability definition used in this paper is based on a framework for strategic sustainable development (FSSD), which has been developed, used, tested, and refined for over 20 years by a peer-reviewed academic and scientific community (Ny et al., 2006; Broman and Robèrt 2015). It is defined by a set of sustainability principles (SPs), which state that "organizations who want to move into a sustainable society should not contribute to systematically increasing: …(SP1) concentrations of substances extracted from the Earth´s crust, (SP2) …concentrations of substances produced by society, (SP3) ... degradation by physical means, and, in that society (SP4) people are not subject to conditions that systematically undermine their capacity to meet their needs." The social sustainability principle has been recently developed into five distinct principles (SP4-SP8): "people are not subject to structural obstacles to: health; influence; competence; impartiality; and, meaning-making" (Missimer, 2013).

As a first step in developing the process of actions steps, existing literature with a focus on "environmental value stream mapping," "sustainable value stream mapping", and "sustainable lean production" was explored. The literature search included up-to-date peer-reviewed journals, most searched databases were Science Direct, Emerald, Ebrary and Academic Search Elite. Existing tools and methodologies for extending VSM to account for sustainability aspects were explored to evaluate the degree of sustainability inclusion. A prescriptive approach resulted in the developed process, based on the findings from the literature review. Furthermore, some tools and methods from literature were adopted to fit the purpose of the study.

The developed process was validated through a case company, which is a medium-sized manufacturerin the roller blind industry. The company is preparing to introduce lean production into its operations with the aim of increasing production efficiency, and has an open eye for sustainability improvements in order to comply with their customer demand. However, the management has rough ideas about problem areas in their production and how to design the future lean and sustainable system. Thus, there is a need for a more structured view inside production and for what can be improved from both a lean and sustainability point of view, which makes the company a suitable candidate for the research purpose.

According to Yin (2013), six sources of evidence are used in performing case studies. The research at the case company relied heavily on the primary data collected through, firstly, eight semi-structured interviews with the management, production, product development teams and the customer to understand production processes and assess sustainability. Secondly, direct observations for collecting VSM data and lean metrics were undertaken. Finally, participant observations which involved conversations and dialogues with operators were utilized. In addition, secondary data was collected in terms of literature review, archival data, and internal documents to grasp a full understanding of the products and to cross-check the accuracy of some collected data.

2 VSM EXTENSION

The conventional VSM methodology is well documented in the literature (Rother and Shook, 2009) with a wide variety of industrial applications to distinguish value-added and non-value added activities and hence improve efficiency. However, the focus of this paper is on the efforts to extend the VSM capabilities of capturing solely lean metrics to also include sustainability aspects to validate the sustainability performances in the production phase.

Simons and Mason (2002) proposed a method called the Sustainable Value Stream Mapping (SVSM). In this method the greenhouse gas emissions, CO_2 and the value-adding time across the value stream are captured. Fearne and Norton (2009) built on the developed tool (SVSM) by Simons and Mason (2002), by combining it with additional metrics such as water, waste, and other industry-based indicators to create a sustainable value chain map (SVCM). Another effort was done by the United States Environmental Protection Agency (EPA) who proposed the lean and environment toolkit (US EPA 2007a). This toolkit detects environmental wastes in addition to health, and safety (EHS) measures, EHS efforts would require the presence of a company EHS expert. Later the EPA introduced the lean and

energy toolkit (US EPA, 2007b) with focus on assessing energy consumption on the process level. In 2009, Torris and Gati extended the EPA lean and environment toolkit and presented the environmental VSM (E-VSM) tool with emphasize on detailed water consumption.
In 2010, Paju et al. introduced a methodology called the Sustainable Manufacturing Mapping (SMM) by combining discrete event simulation (DES), conventional VSM and life-cycle analysis.in order to assess energy, materials, and emissions. In the same year, Kuriger and Chen (2010) introduced the Energy and Environment VSM (EEVSM) with focus on energy. In 2011, Kuriger et al. presented the lean sustainable production tool, taking energy, materials, CO_2 and water as metrics. This was followed by Dadashzadeh and Wharton (2012) who created the Green VSM (GVSM) taking energy garbage, transportation, emissions, materials and biodiversity into account. Two years later, Faulkner and Badurdeen (2014) presented a tool called the Sustainable Value Stream Map (Sus-VSM) which holds a variety of sustainability metrics to choose from. The aim was to measure the energy and raw materials at the process level, eventually these were measured per piece due to difficulties in measuring on a process level. Furthermore, the values only represent the current state; to classify it as good or bad it needs to be benchmarked with other similar situations (Faulkner and Badurdeen, 2014). Vinodh et al. (2016) proposed an LCA integrated with VSM framework using SimaPro 8.1 LCA software package including four environmental indicators, being water eutrophication, air acidification, carbon footprint, and energy, and a future sustainability state was proposed. It is important to note that almost all of the identified tools labelled *sustainable* focus on environmental sustainability metrics only, leaving the social metrics behind. Furthermore, they do not comply with the overarching sustainability principles presented earlier.

3 ROADMAP DEVELOPMENT PROCESS

Based on the findings and gaps from the literature review, a process of ten action steps was developed, including some adopted tools for lean manufacturing and sustainable product development. The process takes into account socio-ecological sustainability aspects, according to the sustainability principles, and proposes a future improved state. The purpose with the developed process is to support the design of lean and sustainable production through a suggested roadmap that ultimately results in improvements of the production and sustainability performances. To develop the lean and sustainable production roadmap, it is suggested to follow the ten distinct action steps presented in Figure 1.

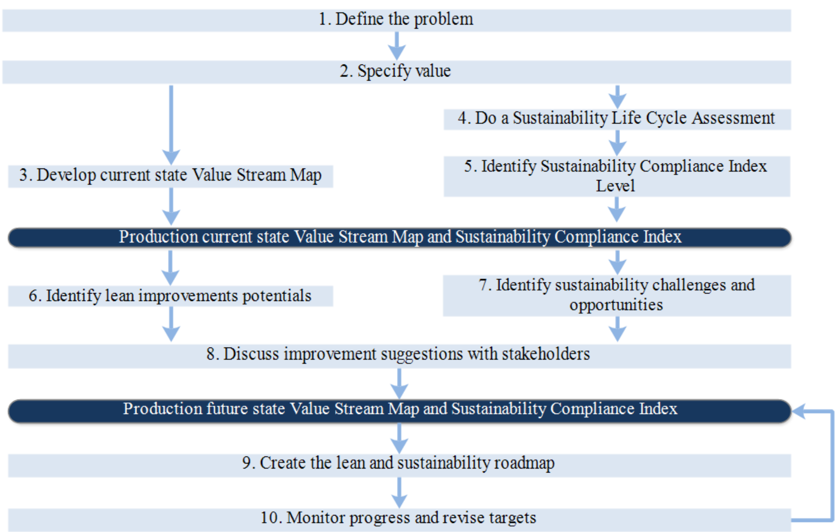

Figure 1. Process of action steps for creating a lean and sustainable production roadmap

The sequence of the action steps is based on recommendations from the VSM literature starting from problem definition to creating a future lean state (Rother and Shook, 2009). Adopted sustainability tools were added to the VSM steps to provide a current sustainability assessment and a future sustainability state. The Sustainability Life Cycle Assessment (SLCA) method (Hallstedt et al. 2013) is firstly used to explore the company's contributions towards sustainability, and afterwards the Sustainability

Compliance Index (SCI) matrix developed by Hallstedt (2015) is used to measure the current levels of sustainability. The action steps are illustrated below with key references added to the different steps.

3.1 Define the problem – Step 1

The first step in improving the lean and sustainability status is to get a profound understanding of the problems and improvement areas in the organization. Before commencing the lean and sustainable transformation, the management needs to involve internal and external stakeholders such as the production and product development teams, in addition to customers in the problem definition process (Jaghbeer and Motyka, 2016).

3.2 Specify value – Step 2

Creating value for the customer is a major concern; this value definition from the customer's perspective allows for decreased lead times, costs, and the achievement of better quality and flexibility (Melton, 2005). This is reinforced by Garza-Reyes (2015) and Broman and Robert (2015), confirming that lean and sustainability lead organizations to goals such as profitability, efficiency, customer satisfaction, quality and responsiveness.

3.3 Develop current state VSM – Step 3

To visualize the current production and product development process, the VSM method is to be used, including both information and material flows on a door-to-door level. It is important to emphasize the fact that the VSM gives as much information as the data put into it; the more parameters added, the more beneficial the results become (Rother and Shook, 2009).

3.4 Do a Sustainability Life Cycle Assessment – Step 4

The Life Cycle Analysis (LCA) is one of the most rigorous methods in the field of evaluating the environmental impacts of a product, process or activity throughout its life cycle (Simboli et al., 2014). Anyhow, LCA often introduces trade-offs between specificity and depth on one hand, and applicability and comprehension on the other hand (Ny et al., 2006). The Sustainability Life Cycle Assessment (SLCA) method (Hallstedt et al. 2013) is an overarching method to assess social and ecological sustainability aspects. It allows for a strategic sustainability assessment of a product life cycle using backcasting from the socio-ecological sustainability principles included in the FSSD. The SLCA has several advantages over traditional LCA and other assessment tools, as it allows for an easier and less confusional business decision making, a more user-friendly tool, and a more embedded sustainability perspective, however, it includes less details and information than LCA (Ny et al., 2006). The SLCA starts with a quick identification of the most important high-level sustainability challenges over the different life-cycle phases and then a detailed analysis can be performed as required with the overall objective of identifying strategic pathways towards sustainability (Boren, 2016). In this work, a detailed SLCA was created with specific guided questions based on each sustainability principle. The template of the detailed SLCA question/ answer form was developed by the Forum for the Future and The Natural Step using sustainability principles (see https://www.forumforthefuture.org/project/streamlined-life-cycle-analysis/overview).

The template developed for this step includes seven to nine questions for each sustainability principle such as: asking about the use of fossil fuels for production and internal transportation (SP1), the generation of hazardous wastes from the operations (SP2), the wastes going to landfill (SP3), and work-related fatalities and occupational diseases (SP4-8) (for the full template see Jaghbeer and Motyka, 2016).

3.5 Identify Sustainability Compliance Index level – Step 5

To allocate the current sustainability compliance level for each principle, and identify improvement opportunities, the SLCA results are further analysed using a Sustainability Compliance Index (SCI) matrix developed by Hallstedt (2015). The SCI can be used to evaluate and communicate a development of a concept and visualize the progress towards a more sustainable solution. It can also be used in concepts ranking and comparison between different alternatives, e.g., valuable material ranking (Hallstedt et al., 2016). The results indicate the current level of compliance which later can be utilized to create a sustainability roadmap with the suggested SCI levels to be targeted in the future (Hallstedt, 2015). SCI includes five colour coded levels of compliance, namely 0/grey, 1/red, 3/orange, 6/yellow and 9/green, where 0 indicates the worst condition and 9 indicates the best condition of sustainability compliance.

3.6 Identify lean improvement potentials – Step 6

The previously illustrated steps provide a full lean and sustainability overview of the current production and product development state, which would facilitate further analysis. To identify lean improvements, VSM is analysed according to the lean principles in production- and product development, by detecting wastes through observations and by interviews with the different teams. The lean production principles are well established in the literature with extensive empirical base, while the lean product development is still not widely discovered nor applied in empirical cases other than by, mainly, Toyota (Hoppmann, et al., 2011). Mcmanus (2005) presents a comparison between the five traditional lean principles in manufacturing and product development context, shown in Table 1.

Table 1. Traditional lean principles in manufacturing and product development (Mcmanus, 2005)

Lean principles	Manufacturing	Product development
Value	Visible at each step, defined goal	Harder to see, emergent goals
Value stream	Parts and materials	Information and knowledge
Flow	Iterations are waste	Planned iterations must be efficient
Pull	Driven by Takt time	Driven by needs of the enterprise
Perfection	Process repeatable without errors	The process enables enterprise improvement

3.7 Identify sustainability challenges and opportunities – Step 7

Identify the positive and negative contributions of the organization towards both ecological and social sustainability principles (Broman and Robèrt 2015) indicated by the different compliance levels. Apply more attention to the low-scoring SCI levels (Hallstedt, 2015) and investigate what could be improved there to achieve a higher SCI level.

3.8 Discuss improvement suggestions with stakeholders – Step 8

Discuss improvement suggestions with the different stakeholders and set the future lean and sustainability targets. It is essential to include the management, production and development teams in the outcome discussion of the analysis, in addition to proposing and assessing the feasibility of actions to be taken before translating these into reality.

3.9 Create the lean and sustainable production roadmap – Step 9

The previous lean and sustainability analysis highlight the improvement potentials and provides a full picture of the future VSM and SCI levels to be achieved. In order to reach these defined targets, a set of actions coupled with clear milestones need to be defined, assigned and distributed on a timeline presenting the lean and sustainable production roadmap for a leaner and more sustainable state.

3.10 Monitor progress and revise targets – Step 10

The improvement process should be seen as continuous, and the progress towards a lean and sustainable production and product development system is to be monitored. The results are to be communicated internally and externally to all stakeholders, and targets are to be revised once current targets are achieved.

4 PROCESS VALIDATION IN THE CASE COMPANY

The developed process was tested on the case company's high volume roller blind production line. It started with problem and value definition. The VSM analysis (Step 6) highlighted the areas to be targeted for lean efforts and, consequently, which lean tools, e.g. 5S Kanban to apply; the future state VSM can be seen in Appendix A. In addition, the SLCA template (Step 4) provided a holistic understanding of the company´s current positive and negative contributions towards socio-ecological sustainability. The SCI facilitated communication of results with the company's different teams, and helped target higher sustainability levels (Steps 5 and 8). A schematic representation of the current and future SCI levels at the case company is shown in Figure 2. The current SCI level was found to be excellent regarding the low contribution of chemical substances to nature from the manufacturing site, and good regarding low degradation of nature by physical means, representing the SP2 and SP3 respectively. However, a low compliance level was revealed for the first principle related to an increase of concentration of substances extracted from the earth crust. Furthermore, low compliance with the social sustainability principles was detected

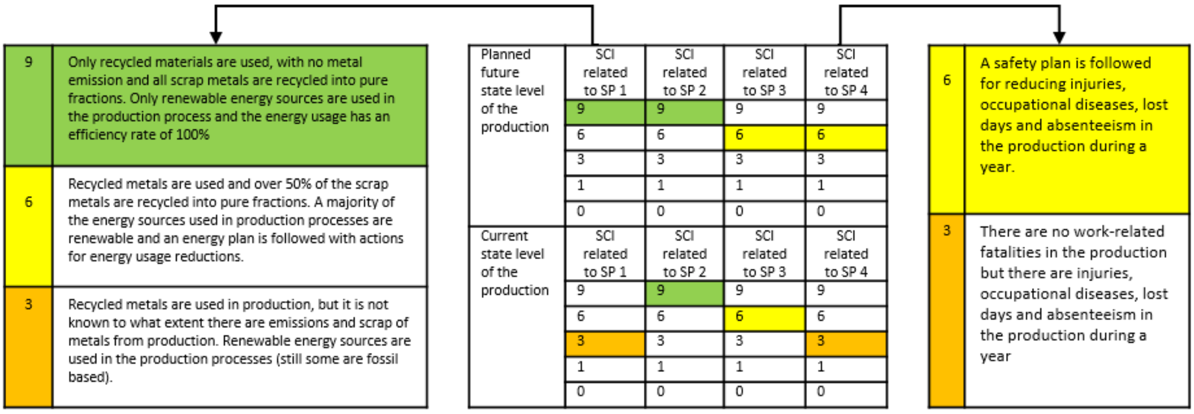

Figure 2. Schematic illustration of current and future SCI for production life cycle phase

Based on the analysis, a lean and sustainable production roadmap was developed with 40 actions distributed on a one-year plan; the short timeframe was urgent to cope with customer demands. An example of the suggested actions can be seen in Table 2 (For a full roadmap see Jaghbeer and Motyka, 2016).

Table 2. Example of suggested lean and sustainable actions

Time	Lean action	Sustainability action (relevant SP)
Immediately	Clear labelling of batches, materials and pallets	A rotation program for operators between cells (SP4)
1 month	Replace current trolleys with self adjusted trolleys	Replace carton boxes with durable packages (SP1)
3 months	Apply 5S at labelling workstations	Precise documentation of injuries to set guidelines for the safety plan (SP4)
6 months	Install a communication system between production floor and warehouse	Start tracing noise level in and surrounding the facility (SP3)
1 year	Invest in a multi-packing automated packaging	Replace the Acrylic plastic coated Polyester fabric with recyclable Polyester (SP1)

The improvements expected from the roadmap in key production and sustainability performances are summarized in Figure 3, with the current state values indicated in dark blue to the left, future state values indicated in medium blue, and the third column to the right presenting the percentage of increase or decrease between current and future values. From the VSM, the lead time was found to be 228 hours with only 3.2 hours as value-added time, which is a massive waste of time and resources. The suggested improvements have the potentials to decrease the lead time by around 63% through the use of supermarket pull systems, Kanban boards, visual boards and redesigning of some manual processes.

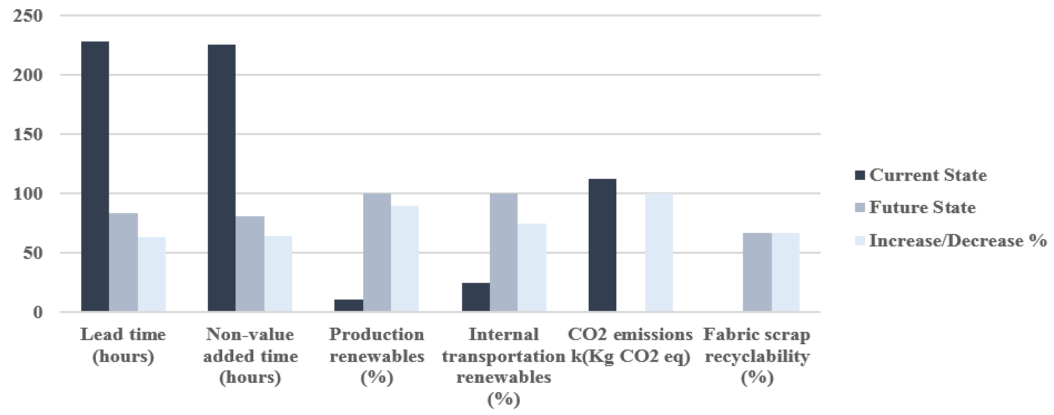

Figure 3. Key lean and sustainability improvements

Furthermore, the switching to renewable energies for production and internal transportation purposes will be done to keep with the increased sustainability customer demands and avoid any upcoming legislations. The recyclability of the materials was investigated, with 67% increase in fabric recyclability due to the switching from acrylic plastic-coated polyester to recyclable polyester. Finally, a safety plan will be created with sufficient operators training to avoid accidents and injuries in the production.

The amount of wastes found in the processes was surprising to the management, while the improvement potentials exceeded both the company and the customer expectations. The questions in the SLCA were easy to understand and did not require any specific competence or extra resources such as data bases or computer software to answer. Combining the SLCA with the SCI facilitated the understanding of the current and future sustainability levels, especially through the colour-coded levels. The roadmap was found applicable and useful to the case company, that already applied several actions during the research period.

5 CONCLUDING DISCUSSIONS

Increasing global competition and sustainability challenges are forcing companies to shift from traditional efficiency improvement techniques to techniques that also account for environmental and societal metrics in the design. The integration of existing techniques with sustainability efforts would develop innovative methods for designing lean and sustainable production and product development systems. VSM is widely used in lean manufacturing and product development to identify wastes, and several efforts are being made to extend it to include environmental metrics. However, its extension to cover all sustainability aspects is lacking in literature (Faulkner and Badurdeen, 2014).

This paper proposes a process including action steps for creating a lean and sustainable production roadmap that meets the capabilities of SMEs. This process enhances lean and sustainability performances in accordance with lean and sustainability principles. Comparing the suggested approach to other available methods in the literature, several gaps are addressed. For example, the adopted sustainability tools, e.g., the SLCA and the SCI, put emphasis on both environmental and social metrics. In this way, a proactive approach is taken to mitigate environmental regulations changes, health risks issues and assure employee safety and good working conditions, thus raising employee satisfaction and efficiency. All this ultimately results in cost savings and a more secure supply chain.

Other advantages with this approach include easy communication of results and quick consensus on future improvements, due to the qualitative approach used to assess sustainability. The suggested process provided the manufacturer with some simple and hands-on action steps that result in a concrete roadmap and time plan for changes. The general, yet sufficient, SLCA questions comply with the overarching sustainability principles, far from selecting arbitrary indicators that fit a specific case or manufacturing sector. Furthermore, the SCI levels, in addition to the short-time demand of few days to collect and analyse the lean and sustainability data, with no particular need for a specific competence in the field or extra resources, lead us to the assumption that the process is generic with high probability for implementation in other manufacturing companies. Furthermore, a future research direction suggested by Faulkner and Badurdeen (2014) of representing a future sustainability state is fulfilled by this paper, which takes into account both social and environmental aspects with no extra resources in terms of software or specialists, making the proposed process more applicable and general than the approach suggested by Vinodh et al. (2016).

Improvement potentials for the approach include the economical sustainability dimension. In this approach, it is considered to be a result of the value definition by the different stakeholders at the case company. However, further investigation of economical aspects by including different methods such as accounting analysis tools needs to be considered in future research. The process suggested here can be used for assessing and improving the lean and sustainability performances in production and product development contexts. Further testing of the developed action steps is needed to validate the process in a product development context, where the investigation of all product life-cycle phases from the raw materials extraction to the end of life, using SCLA and SCI, should be done. This is essential as most violations to the sustainability principles usually happen early in the design phase and could be avoided already in the early phase of the product innovation process (Hallstedt, 2015) .

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APPENDIX A: FUTURE STATE VSM