Sustainability Performance Measurement and Management Model

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ABSTRACT

This paper proposes an initial process model for designing and implementing a sustainability performance measurement and management system for manufacturing companies. The process model follows the DMAIC (Define, Measure, Analyse, Improve, Control) approach that is widely used in performance improvement projects. The phases of the process cover selecting and implementing relevant sustainability key performance indicators (KPIs) and linking measurement to sustainability performance improvement, management and control. This paper presents the initial process model and the associated tools and guidelines that assist companies in developing and implementing a sustainability performance measurement, improvement and management system. The use of the process model is demonstrated by a virtual case study, which provides an example of sustainability performance measurement and management system for a shop floor level.

1. INTRODUCTION

"Meeting the needs of the present without compromising the ability of future generations to meet their own needs"[1] is the often presented definition of sustainable development. This requires a balancing of humanity's demand for natural resources and the planet Earth's supply of such resources. The current situation, however, is far from this objective. In 2014, the Earth Overshoot Day, which marks when humanity has exhausted the Earth's annual resource budget, was the 19th of August. This means we already demand the resources of more than 1.5 planets, and the "business as usual" projection indicates that the resources of more than two planets will be needed by 2030. [2][3]

To realise sustainable development, a radical change is needed both on a global level and in the manufacturing industry, which has an important role in reducing resource use, waste and emissions (see e.g. [4]). For example, the European Commission [5] states that although progress has been made in addressing environmental issues of production and consumption, fundamental changes and significant improvements are needed in the ways and practices of extracting natural resources, and producing, distributing, using and disposing of products. The trend of increasing demand and increasing manufacturing activities adds to the need for reducing the environmental impact of manufacturing and the need for "doing more with less" [4].

Several organisations and researchers have developed tools and guidelines for enabling companies to make the required change and move towards sustainable development. For example, the World Business Council for Sustainable Development [6], the Global Reporting Initiative [7] and the Organisation for Economic Cooperation and Development [8] have developed standards and guidelines for sustainability reporting and development. Others, e.g. Jovane et al. [9] and Jawahir et al. [10], have provided reference models and frameworks to assist in achieving sustainability in manufacturing. The authors have studied the sustainability practices in Finnish manufacturing industry and observed that regardless of the wide variety of available tools and assistance, the path towards sustainability is proving a struggle for Finnish manufacturing companies [11]. To provide these companies with support for realising sustainable development, the authors have focused on the development of sustainability performance measurement.

This paper reports results from the VS-KPI project (Visualization of Sustainability Key Performance Indicators), which is one of the six sub-projects of FIMECC's MANU program [12]. The aim of the project is to develop a process

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model for identifying and implementing relevant sustainability KPIs, and linking the measurement results to performance improvement and management. The initial version of this process model is introduced in this paper. The objective is to provide an overview of the process model and tools included in it, and to demonstrate the use of the model with a case study. The paper is structured as follows. Section 2 presents the background on sustainable development and sustainability performance measurement. Section 3 briefly describes the objectives and approach of the ongoing research project. The initial version of the process model and related tools are presented in Section 4, while in Section 5 the proposed model is applied in a case study. Section 6 concludes the paper.

2. BACKGROUND

2.1. SUSTAINABLE DEVELOPMENT

To concretise the concept and the general-level definition, i.e. "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [1], sustainable development is typically further divided into three pillars: environmental, social and economic sustainability. These are often referred to as "the triple bottom line" or "the 3 Ps": planet, people and profit (e.g. [13][14]). The economic aspect focuses on securing both short- and long-range profitability and economic viability. Social sustainability entails that people feel they can have a fair share of wealth, safety and influence [9][15]. Issues such as safety and well-being, employment and human rights are central to this aspect. Environmental sustainability "seeks to improve human welfare by protecting the sources of raw material used for human needs and ensuring that the sink for human wastes are not exceeded, in order to prevent any harm caused to human beings" [16].

Sustainability can also be divided to the perspectives of consumption and production. Sustainable consumption is "the use of goods and services that respond to basic needs and bring a better quality of life, while minimising the use of natural resources, toxic materials and emissions of waste and pollutants over the life cycle, so as not jeopardise the needs of future generations" [17]. Sustainable production has been defined by the Lowell Centre for Sustainable Production as "the creation of goods and services using processes and systems which are non-polluting, conserving of energy and natural resources, economically viable, safe and healthful for employees, communities and consumers and socially and creatively rewarding for all working people" [18]. Jovane et al. [15] link sustainability of production with the three pillars of sustainability and state that sustainable production must respond to:

- economic challenges, by producing wealth and new services ensuring development and competitiveness through time;
- environmental challenges, by promoting minimal use of natural resources (in particular non-renewable) and managing them in the best possible way while reducing environmental impact;
- social challenges, by promoting social development and improved quality of life through renewed quality of wealth and jobs.

2.2. SUSTAINABILITY PERFORMANCE MEASUREMENT AND INDICATORS

Several authors and organizations regard sustainability performance measurement and indicators as important enablers of realizing sustainable development and sustainable production in industry (e.g. [19][20][22][23]). As a result of research and development work in this field, a variety of sustainability performance indicators, as well as guidelines for measuring and reporting sustainability, are available. The Global Reporting Initiative (GRI) provides guidelines for sustainability measurement and reporting, and presents 91 sustainability indicators [7], OECD presents 18 Sustainable Manufacturing Indicators [8], and EUROSTAT has identified and proposed 15 Sustainable Consumption and Production Indicators [21].

Although a variety of indicators, tools and guidelines are available, the authors argue that further research and development related to sustainability performance measurement and improvement is needed. A review of available indicators, guidelines and companies' practices indicates that sustainability performance measurement and reporting are mainly carried out at company level, with only limited influence on decisions related to production and product design. Examples of this are annual sustainability or corporate social responsibility (CSR) reports, which provide high-level, aggregated data, but insufficient assistance for decision-making in production and product design. Hence, performance indicators that better support sustainability-related decision-making and improvement need to be developed. This argument is supported e.g. by Winroth et al. [24], Feng et al. [19] and Lu et al. [23].

3. OBJECTIVES AND APPROACH

The objective of the VS-KPI research project is to support Finnish manufacturing companies in realising sustainable production and achieving sustainable development. A more concrete aim is to develop a process model that assists the companies in measuring and improving sustainability performance, and developing a system for managing and controlling sustainable production. With regard to research approach and methodology, the project aims at developing a concept for improving the current situation, and can be categorised as an innovation-building design science study [25]. The research project consists of the following phases, which are typical for a design science study (e.g. [26]):

1. Clarifying the situation and challenges related to sustainable development and production in Finnish manufacturing industry;
2. Developing a concept or model that assists Finnish manufacturing companies in improving sustainability performance and in realising and managing sustainable manufacturing;
3. Testing, evaluating and further improving the developed concept or model;
4. Finalising the concept or model and concluding the research work.

In the first phase, questionnaire surveys, workshops and interviews were used to clarify the current situation and challenges of sustainable development in Finnish manufacturing industry. This was performed partly in an earlier KEKE-project. The progress, content and results of the first phase are described in more detail in [11]. This paper describes the second phase, which focused on developing the process model and assisting tools for identifying and implementing relevant sustainability KPIs, and linking the measurement results to performance improvement and management. Results of the first phase provided the basis for the development work. The general structure of the process model, as well as the content, that consists of tools that assist in conducting the different phases of the process, have been developed with help of literature reviews and observation in companies. The initial version of the process model is presented in Section 4. In the third phase, case studies are used to test, evaluate and validate the process model. First case study is reported in this paper (Section 5). Further case studies and finalization of the model are part of the planned future work of the on-going research project.

4. PROCESS MODEL FOR DEVELOPING AND IMPLEMENTING A SUSTAINABILITY PERFORMANCE MEASUREMENT AND MANAGEMENT SYSTEM

The process model for developing and implementing a sustainability performance measurement and management system follows the well-known DMAIC approach (e.g. [27]) that is widely used to structure performance improvement projects. The phases of the process are: Define, Measure, Analyse, Improve and Control. The DMAIC structure and approach were seen to be suitable as they emphasise measurement as a basis of improvement, and include the key elements of an improvement project and management. In the Figure 1, and in the following sections, the key objectives, content and the assisting tools of each phase are presented. This is an initial version of the model and it will be later analysed, improved and detailed based on the case studies.

4.1. DEFINE

The define phase focuses on defining and identifying appropriate and useful sustainability performance indicators for a company. This requires clarification within the company and among the stakeholders, e.g. customers, investors, and legislators, of the objectives of improvement and the measurement needs. Sustainability performance indicators relevant to the identified needs are subsequently selected and defined. Hence, this phase focuses on "What should be measured?" and "How should it be measured?". The aim is to identify sustainability performance indicators that provide real-time data at factory, process and machine level, and support decision-making related to production and product design.

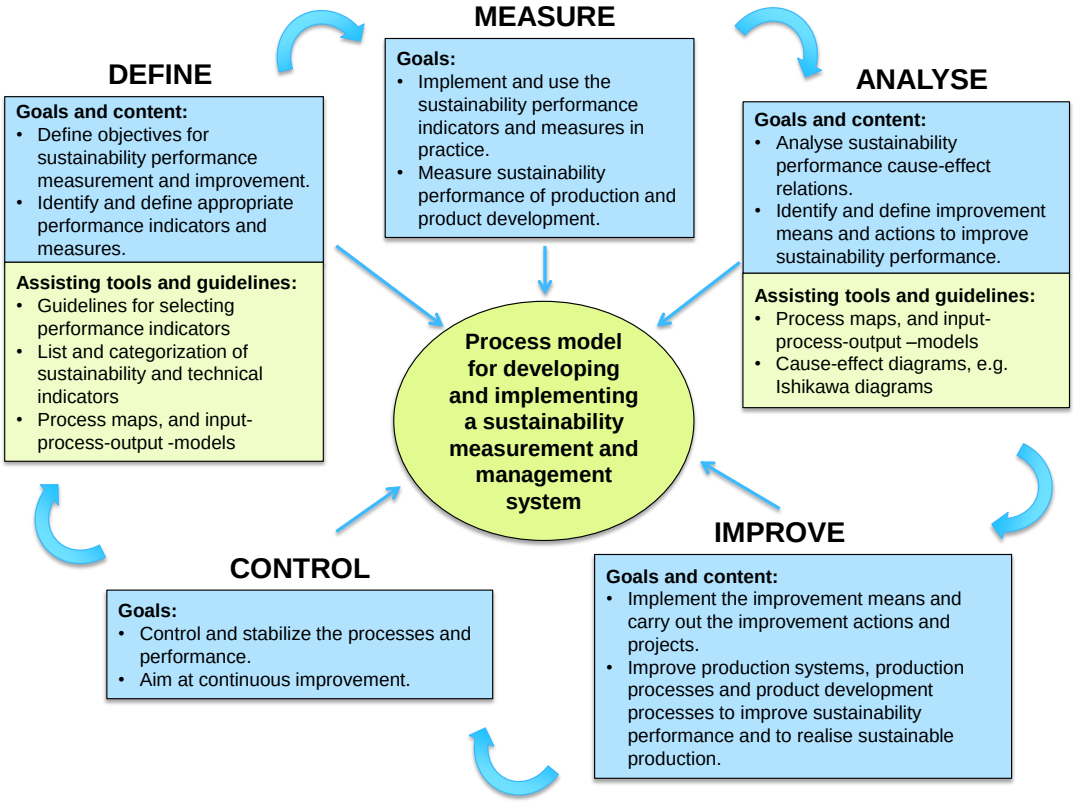

Figure 1: Process model for developing and implementing a sustainability measurement and management system.

Guidelines and tools assisting in this phase have been identified from the literature and developed by the authors. Literature provides guidelines and requirements for selecting performance measures for a company. For example, Feng et al. [19] state that the indicators should be measurable, relevant and comprehensive, understandable and meaningful, manageable, reliable, cost-effective, and timely. For more practical assistance, the authors [28] have listed over 200 sustainability and technical indicators and categorised these based on three dimensions: level of measurement within a company, measurability and temporal focus. These are intended to assist companies in identifying indicators that are relevant to their objectives and measurement needs. Furthermore, process mapping and models (Figure 2) are seen to be useful in considering what and how should be measured within production.

4.2. MEASURE

In the measure phase, the sustainability performance indicators selected in the previous phase are implemented and used in practice. This includes collecting the required data and carrying out the required calculations. Further research and development work is needed to define and describe an approach and process for implementing the sustainability performance measurement system efficiently and effectively within a company. Methods also need to be developed for collecting the required data at factory or machine level in real time.

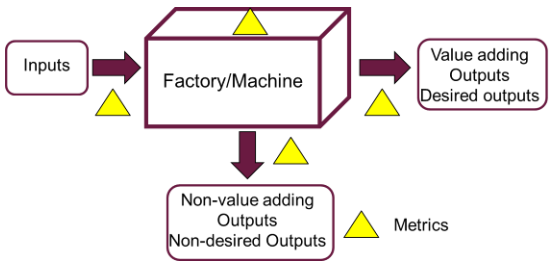

Figure 2: Generic model of the inputs and outputs relating to the metrics.

4.3. ANALYSE

The analyse phase aims to facilitate the reporting of relevant and useful information both within the company and to external stakeholders, and to enable performance improvement and management. With regard to reporting, the measurement data must be analyzed and summarized to provide useful information for stakeholders. To enable performance improvement, the cause–effect relationships between measurement results and decisions, related to production and product development, must then be identified and described. This should enable practical performance improvement actions and projects based on the measurement results and current sustainability performance to be determined. Hence, the phase aims at answering the question "How can sustainability performance be improved?" For this, the use of cause-effect tools and diagrams, such as Ishikawa or fishbone diagrams, is recommended. Also process maps and models (e.g. Figure 2) will be useful in identifying how the outputs and performance can be affected and improved.

4.4. IMPROVE

In the improve phase, the planned improvement actions and projects are executed. Changes and improvements are made to product development processes, products, production systems and production processes in order to achieve higher levels of sustainability performance.

4.5. CONTROL

In the control phase, the aim is to stabilize, standardize and control the new processes and improved sustainability performance. Processes and sustainability performance are monitored using the performance indicators and analysis systems developed in the previous phases. Aim is to identify deviations from the standardised processes and performance, and opportunities for further performance improvements. Hence, the control phase contributes to a sustainable production management system that aims to standardise the processes and sustainability performance, and to enable continuous improvement.

5. CASE EXAMPLE

The proposed process model for developing and implementing a sustainability performance measurement and management system is used in a virtual case environment, named as LeanMES Concept Factory. The LeanMES Concept Factory is being developed in the LeanMES project, which is another sub-project of FIMECC's MANU research program [12]. LeanMES aims to develop a concept of a new type of MES (Manufacturing Execution System), which is lean, scalable and extendable, and supports human operator in a dynamically changing environment. The aim with the LeanMES Concept Factory is to act as a virtual environment, where different concepts developed during the project can be tested and visualized. As the measurement of production sustainability indicators is strongly related to collecting data from the factory floor, LeanMES-project is especially interested in what the sustainability reporting and optimization will require from the future MES and other manufacturing IT-systems. It is seen, that customers are becoming more and more interested in the ecological footprint of the products they buy. Therefore the product manufacturers need to be supported by proper IT-tools, which can assist in providing reliable information, relating to the product and production sustainability, to the customers. Furthermore, this information is needed to support sustainable production planning and scheduling. The focus and objective of the case study is to introduce sustainability performance indicators and measurement to the LeanMES Concept Factory. This section presents the ongoing work and its initial results.

The DMAIC model served as the basis and guideline for developing the sustainability measurement concept model for the LeanMES Concept Factory, targeting at the shop floor level. The define phase, i.e. identifying and selecting relevant sustainability performance indicators, was carried out in workshops with the case study participants from the LeanMES-project, including both academic and industrial representatives. Initially, a plethora of sustainability metrics, relating to environmental, social, economic and technical aspects (see [28]), were introduced to the participants. The performance indicators to be implemented to the LeanMES Concept Factory were then selected in two workshops. As the LeanMES project focuses on Manufacturing Execution Systems, the objective was to identify especially those aspects and indicators of sustainability performance that can be affected by production planning, scheduling and control decisions. Additionally, indicators of sustainability that are not directly linked to such decisions, but were considered important to be reported, were also included. The economic and technical metrics were left out intentionally, because they are already commonly measured in the industry, and the manufacturing IT-systems provide

support for them. The selected metrics were then categorized into metrics that could be optimized by operative production decisions, and general reportable metrics. The selected metrics are presented in Table 1.

Table 1: Metrics to be optimised and general reportable metrics for the LeanMES Concept Factory.

Metrics to be optimized	**General reportable metrics**
Energy consumption within the whole organization Energy consumption of individual resources Energy Cost Energy Efficiency Materials used by weight or volume Material Efficiency (used material/waste material) Waste (total weight of waste by type and disposal method)	Percentage of materials used that are recycled input materials Direct greenhouse gas emissions Emissions of ozone-depleting substances (ODS) NOx, SOx, and other significant air emissions Total water withdrawal by source Percentage and total volume of water recycled and reused Injury rate (number of injuries in a given time period) and type of injury Lost days (number of days lost due to injuries, occupational diseases, absenteeism etc. in a time period) Number and rate of near misses and hazards Lost time injury frequency rate Number of work-related fatalities (by region and gender) Job Satisfaction and motivation Average hour of training per year per employee Percentage of employees receiving regular performance and career development reviews Job-related experience and skills

One motivation of LeanMES for this exercise is to define the requirements for the future manufacturing IT-systems, such as MES. What information they need to collect and handle, in order to assist the companies in their sustainability measurement and management activities? What needs to be collected and from where? Therefore, in the second phase (measure) the measuring was made more concrete by visualizing the inputs and outputs that relate to certain processes accomplished with the resources included into the LeanMES Concept Factory simulation. Two examples of such input-output analysis are shown in Figure 3. The actual measurement and indicator calculations has not yet been implemented to the Concept Factory simulation model.

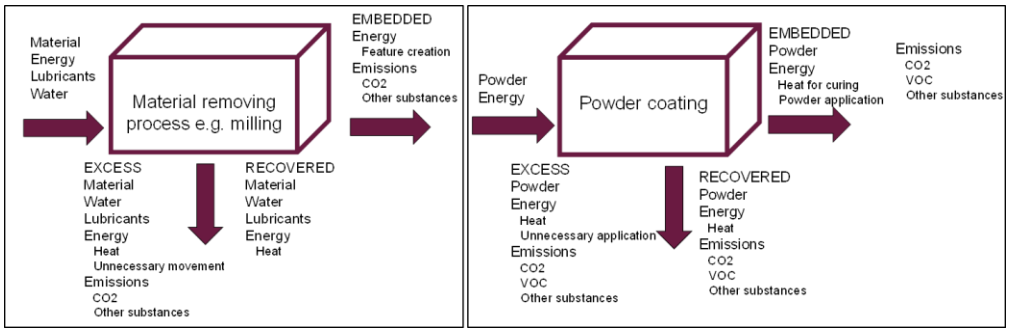

Figure 3: Example input-process-output graphs for material removing and powder coating processes.

In the analysis phase, an evaluation was done on how the production planning, scheduling and control decisions can affect to the selected metrics, especially how they could improve the sustainability performance. Such an analysis involves identifying the cause-effect relationships between the production decisions and sustainability metrics. In general, as discussed in [11], the decisions done in product development and production system design phases have a significant impact on the sustainability of the production. The actual operative decisions have a small role in the overall sustainability performance of production. However, for instance, the energy consumption can be reduced by turning off the machines, when there are no jobs to be performed in near future. This could be implemented by building a link between the MES and the individual resources on the factory floor so that the machines would know their own job list and would be programmed to turn themselves off if the production plan shows idle time of certain duration. However, the practice has shown, that machine tools' accuracy declines when its temperature decreases below the optimal

processing temperature. Also, if machine is long in an idle state, bacteria may start to grow in cooling fluid, which may corrode the sealants of the machine. Therefore, it has to be remembered, that sustainable manufacturing can not concentrate on partial optimization, but should be taken as a comprehensive development. Compromising product quality for the sake of reduction in energy consumption may not be a very sustainable and wise move.

Few other ways to affect to the sustainability of production by production planning decisions were also identified. For instance smart energy grids could be utilized to optimize production plan based on the fluctuating energy availability and changing energy prices, e.g. by optimizing the order scheduling and utilization of resources based on their energy consumption and current energy prices. The allocation of resources could also be optimized based on their energy consumption. In order to do this, the planning system should know the energy consumption of each machine for producing a specific feature of a specific material. By using this information the scheduling system could allocate the orders to certain resources, simultaneously respecting the given delivery dates and trying to minimize the overall energy consumption. For the material efficiency and waste generation especially the nesting and billet material selection, which relate to production planning, has a big role.

6. CONCLUSIONS

The presented research work aimed at clarifying the situation and challenges of sustainable development in manufacturing industry and at developing a concept that supports the realisation of sustainability in industry. Key challenges in realising sustainability in manufacturing industry can be summarised as the lack of metrics on the factory floor level, a lack of clarity about improvement means, and a lack of demand, understanding and awareness. To overcome the challenges, and to support manufacturing companies in realising sustainability, development of a concept that assists in measuring, improving and managing sustainability performance has been started. The initial version of the concept was discussed in this paper. The concept is based on a DMAIC (define, measure, analyse, improve, control) structure that is seen to be well-suited for the purpose and objectives. The first phases of the concept assist companies in defining and implementing sustainability performance indicators, while the latter phases link the measurement results to improvement and management. Additionally, a preliminary case study was introduced in adapting sustainability metrics to a virtual factory environment. Once completed, the concept is expected to provide useful assistance and support for manufacturing companies in measuring, improving and managing their sustainability performance. The paper and the results pave the way towards sustainability, as they assist both industry and academia in identifying the actions required to improve sustainability performance and realise sustainable production. Furthermore, the discussed case study is expected to provide ideas for the manufacturing IT-system developers to design new features to their systems, especially regarding the data collection and subsequent reasoning relating to sustainability performance.

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