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The Sustainability Cone – A holistic framework to integrate sustainability thinking into manufacturing

Jan-Markus Rödger *, Niki Bey, Leo Alting (1)

Department of Management Engineering, Division for Quantitative Sustainability Assessment (QSA), Technical University of Denmark (DTU), Kgs. Lyngby, Denmark

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ABSTRACT

Integrating sustainability into manufacturing is a multifaceted endeavour. Global sustainability aspects and specific manufacturing success factors have to be combined with life cycle thinking in order to get the holistic view on manufacturing which is needed to make truly sustainability-oriented decisions in manufacturing. Industry, at the same time, is always deterred by possible high cost and time constraints related to implementing new approaches. Using examples from car manufacturing, this paper introduces and explains a new sustainable manufacturing framework – the Sustainability Cone – as the missing link which closes these gaps by providing necessary holistic and consistent overview while being aligned with established stage-gate project execution models, thus ensuring practical applicability as shown for a highly automated production cell. The paper shows how to apply life cycle target thinking, as essential part of the Sustainability Cone, derived from customer-demanded functionality down to a production system.

1. Introduction

Manufacturing is more than production – it comprises the pathway from the idea and design, over raw materials transformation into finished goods that meet customers' expectations [1]. Sustainability can be assessed by using the holistic approach oflife cycle thinking (LCT) which follows a similar pathway like manufacturing. Thus, a good basis to align both and achieve *sustainable manufacturing* exists. But why should manufacturing strive for sustainability? The sector contributes significantly to the global carbon dioxide emissions (CO_2), and plays a substantial role for the labour market and economy (GDP). And, although evermore efficient *technology* (T, e.g. [2]) is developed, the foreseeable developments of *population size* (P) and *affluence* (A, the value created or consumed per capita) overcompensate the technology improvements, leading to overall increase in carbon dioxide emissions [3], i.e. increasing *impact on environment* (I). This relation has been described by Commoner [4] as the "IPAT Equation". The above underlines the fundamental challenge towards the manufacturing field and thenecessity for it to respond. Hauschild [5] points out, that the three variables cannot be seen independently since increased eco-efficiency of products and technologies not always leads to less environmental impact, and that, rather, eco-effectiveness should be strived for instead. This may be achieved by broadening the term "technology" in the IPAT Equation to "manufacturing" in order to emphasize the lever effect of the sector. In order to achieve this, a transparent, quantitative and – most importantly – industrially applicable method for assessing sustainability impacts must be derived based on a new framework that encompasses external and internal requirements, and addresses the upcoming challenges – all in support of being able to move towards a more sustainable future (see Fig. 1).

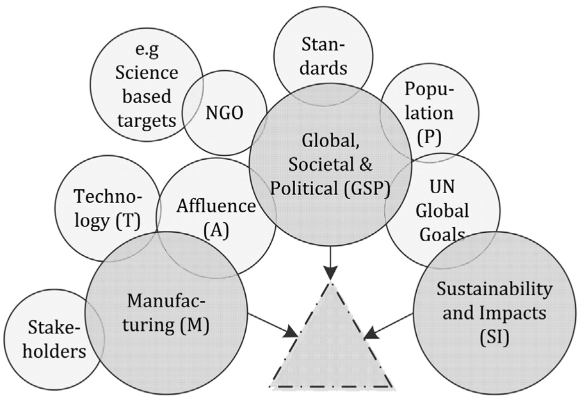

Fig. 1. Stakeholders of and requirements towards sustainable manufacturing. Shown as triangle the missing link between Global, Societal and Political requirements (GSP), Manufacturing requirements (M) and Sustainability and Impacts-related requirements (SI).

1.1. Global, societal and political motivation

Recognized by external stakeholders, sustainability has become an import criterion [6] and manufacturers report today their environmental performance to several non-governmental organizations (NGOs, e.g. [7]). EFFRA [8] states that Sustainability can

* Corresponding author.
E-mail address: januw@dtu.dk (J.-M. Rödger).

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underpin Europe's competitiveness, thus factories have to be environmentally friendly and socially sustainable.

Standardization organizations like ISO support environmental sustainability work with their ISO 14000 series. The latest version of ISO 14001 on Environmental Management Systems includes taking a life cycle perspective on production activities [9]. Many automotive Original Equipment Manufacturers (OEMs, e.g. [10–12]), have published Life Cycle Assessments (LCAs) according to ISO 14040 [13] in order to transparently show impacts of their products. In the automotive sector, specific fuel consumption of the manufactured vehicles has been reduced continuously [2]. Meanwhile, companies are exploring new markets and are exposed to new technological trends, and higher numbers of product variants and shorter product life cycles are expected [14] which likely leads to roughly 57% more sales in 2025 compared to 2010 [15]. Additionally, total light duty vehicle (LDV) travel distance will continue to grow [16], and thus an increase in total fuel consumption is projected [2]. To tackle this, companies are already providing electrified cars potentially powered by renewable energy or hydrogen. This, however, may result in so-called burden shifting – from one life cycle stage to another or from one impact category to another [10]. Increased product variety leads to more complex production systems [14] and most likely increases the environmental impact and economic efforts per vehicle. However, regarding total transportation by LDV, the foreseeably increasing worldwide sales suggest that all product-related environmental improvements will be eliminated by the so-called "rebound effect" – a higher overall impact due to higher sales figures of improved products. To avoid rebound effects, thresholds for environmental impacts from entire sectors can be defined or even thresholds for concrete product categories, like suggested for Greenhouse gases by "Science Based Targets" [17]. Those absolute and concrete targets can be used in planning processes of both product and production. However, any new framework needs to address companies' reservations towards implementing new approaches (for high cost and time constraints [18]).

1.2. Objectives for a new framework

In this context, three key objectives for a new framework can be formulated: (1) Address the full scope of sustainable manufacturing, incl. all key drivers and obstacles. (2) Reflect the relation between manufacturing and global environmental contexts (ideally following the Planetary Boundaries concept [19]), interpreted in a way that sustainability is understood as a relation between the three factors *demand for functionality* (i.e. manufactured products that fulfil customers' functional requirements), the *product* and the *production system*, while always taking a life cycle perspective. (3) Ultimately allocate absolute targets, e.g. a maximum number of tons of greenhouse gas emissions of the entire transport sector for a given period, broken down to the very last production station in a feasible and operational way. Since commonly agreed planetary boundary-based targets do not exist today for manufacturing, a company adopting the Planetary Boundaries concept today could develop and implement self-defined absolute targets. Still, current definitions of sustainable manufacturing [20,21] do not incorporate such predetermined objectives, and henceforth a new definition is suggested:

> "Sustainable Manufacturing satisfies the (societal) demand for functionality while adhering to environmental, economic and social targets over the entire life cycle of products and services."

This definition encompasses targets for both products and for productions and internationally agreed targets as well as company self-defined targets.

2. Requirements towards an applicable framework

Prerequisites for profitable and sustainable business are the integration of economic, environmental and social requirements, the development of innovative products and services, and the comprehensive usage of available knowledge [22] as well as "planning efficiency", in particular in high-wage countries [23]. Results of the industry-focussed EU FP7 project AREUS (see acknowledgement) underline that any industry-applicable sustainability framework needs to be aligned with existing decision-making processes (i.e. stage-gate models) in companies (top-down applicability) and fit to existing product development processes (PDP) and production planning processes (PPP). It should also consider the workflow with external companies as well as the workflow of internal planners, and it should be transparent in order to support gathering of sustainability-related data at all levels of manufacturing (bottom-up applicability). Incorporation of the life cycle approach is also required, e.g. in response to latest developments in standardization [9] and European policy [24]. Applicability would be given by designing a modular framework and related assessment method that allows each designer, product manager or other decision-maker to easily "find" himself or herself in the framework.

Accurate and correctly specified requirements are extremely important in manufacturing to clearly document expectations and to prevent any failure (incl. potentially its far-reaching consequences). Therefore, the assessment method has to incorporate existing company specific critical *success factors* like annual output and cycle time, in order to provide data for well-established key result indicators (in retrospect) and performance indicators (in advance) for all different stages in the PDP and PPP. The method must also entail *manufacturing-specific* success factors, e.g. shift-system, jobs per hour (jph) or engineering hours per product (ehp) and be linked to social, economic and environmental thresholds. Furthermore, the method should account for prospective trends (e.g. secondary use of manufacturing infrastructure) and reflect global and local requirements, to ensure its applicability. It should consider (potential) trends, like increasing modularity of production lines, increasing product variety and software-controlled processes as well as companies' interest in always employing newest production technologies. The developed method is meant to be used as planning tool in the PDP and PPP to gain highest improvement potentials and guide the *developers* and *planners* through the different alternative options during the project by providing the most relevant data in an understandable way.

Applicability and minimal additional workload in companies-when transferring solutions from digital environments to the real production [14] can be assured by building upon existing software and databases that are integrated in their individual *IT-Infrastructure* (e.g. PLM software). The assessment method needs also to be designed to support an intuitive graphical user interface and to operate stable (enabled, e.g. via less complex algorithms). Usability of data for up- and downstream stakeholders must be guaranteed, e.g. by data preparation in transparent formats ready for possible audits and documentation. Finally, the whole implementation and use of the method need to have a positive economic cost–benefit ratio.

3. Gaps in currently suggested frameworks

Several publications have dealt with, e.g. "sustainable manufacturing", "sustainable production" and "green manufacturing" over the last decade, and the authors identified several frameworks and methods which all, to varying extent, aim at enhancing sustainability performance of manufacturing from different perspectives. In general, the existing frameworks are lacking alignment with stage-gate models used in industry. Compared to the derived requirements from manufacturing in Section 2, there are several gaps. Generally, all three *Sustainability* dimensions are acknowledged, but the majority of frameworks deal in detail with the environmental dimension and only with a substantially lower level of detail with the economic and social dimensions. In regards to the *life cycle* perspective, the product level is in focus, but facilities and production systems are