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A Methodology to Align Core Manufacturing Capabilities with Sustainable Manufacturing Strategies

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Abstract

How do core business and manufacturing capabilities enable strategies for sustainable manufacturing, and what are those capabilities? This paper proposes a Capability Methodology for Sustainable Manufacturing (CMSM) for allowing top management of manufacturing companies to address these questions. A diagnostic tool was developed from three case studies based on a set of interview questions aimed at identifying core capabilities and sustainability issues in manufacturing companies. Interview data was coded and mapped through a relational matrix formulation that describes four archetypes for the development of sustainability strategies. The matrix maps the degree of complexity of the sustainability concept as understood by the company, and the scope of the product life cycle being considered. It is argued that the methodology helps bring awareness to managers of any gaps or mismatches between their actual core capabilities and the desired outcomes for sustainable manufacturing.

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Keywords: Sustainable Manufacturing; Triple Bottom Line; Capabilities; Complexity; Product Life Cycle.

1. Introduction

1.1. Background

In 2015, the United Nations (UN) invoked a universal call to action to protect the planet and ensure peace and prosperity by issuing seventeen Sustainable Development Goals (SDGs) [1].The study presented in this paper addresses the 12th SDG: *responsible production and consumption*. It does so by proposing a methodology to support top management of manufacturing companies on the journey towards more responsible production of products and services.

The use of specific terms in this paper is hereby clarified:

- *Production and manufacturing* are sometimes used interchangeably, especially in a non-academic context; in this paper we consider the former to have a systemic, functional connotation, and the latter a technological and sectoral one.
- The SDG concept of *responsible* production is defined as equivalent to *sustainable* production.
- In turn, *sustainable production* is defined as the production of goods in a way that is aligned with sustainable development goals.
- *Sustainable manufacturing* (SM) is specifically defined as a set of "processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities and consumers and are economically sound" based on [2].
- An *SM strategy* is business strategy, formulated by a manufacturing company, with the aim to embed SM in its corporate and operational goals.

An increasing pressure for sustainable practices is put not only on organizations, but also on their stakeholders, such as customers, suppliers, shareholders, governments, non-governmental organizations (NGOs) and public authorities [3].

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Therefore, we also add that such processes described in [2] must take place both inside and outside the physical system boundaries of factories and consider the whole product life cycle [4].

In 1994 the disillusionment from the failures of improvement programs such as Total Quality Management and Just in Time that were implemented in Western factories was criticized by Hayes and Pisano in their Harvard Business Review article [5]. The authors advocated for the integration of manufacturing strategy with core competences and learning organizations to ensure the long-term success and consistency of improvement programs. In corporate language, an organizational *core competence*, or *core capability*, is a business activity that "must provide a benefit to the consumer, should not be easily replicated or imitated by competitors and should be widely leveraged across various markets and products" [6]. For instance, process understanding, waste reduction and volume flexibility are manufacturing capabilities [7] because they are prerequisites for running a manufacturing operation, whereas pollution prevention and product stewardships are core capabilities derived from a natural resource-based view of the firm [8]. We believe that Hayes and Pisano's argument also applies to the success and failure of sustainability programs and projects in manufacturing. Hence, the focus of this study is on core capabilities addressing the 12th SDG, by looking at how management itself formulates core capabilities to realize the vision of SM.

Capability management, aka the formulation, visualization and alignment of business capabilities, is traditionally part of the key expertise of management consultancies. Researchers have reviewed and proposed a wealth of methods to advance capability management, such as [9-14]. In particular, researchers differentiated static and dynamic capabilities for sustainable production [15] and modelled strategic capabilities for manufacturing Small and Medium Enterprises (SMEs) [16].

Pigosso et al. [17] created a maturity model to support eco-design implementation in manufacturing companies, and Subic et al. [18] developed a framework for capability assessment for SM in sports apparel companies. We assert that none of the reviewed methods directly probe how the capabilities are formulated and framed by management, despite their novelty and wide degree of applicability. As a result, these methods may not generate a credible discussion around the complexity of sustainability issues, or whether the operations stemming from these capabilities effectively contribute to a more sustainable production. The study presented in this paper proposes a methodology to address this gap.

1.2. Research Objectives

The purpose of this study is to develop a methodology that helps manufacturing companies align their manufacturing capabilities to the desired strategy for SM. In particular, based on the definition of SM presented in the introduction, this alignment must adopt a holistic view of sustainability [19-21] and raise awareness of the entire product life cycle for the realization of an effective SM strategy [22-24].

The following two research questions (RQs) summarize the purpose of the study:

RQ1: How can a company's core capabilities be analyzed to raise top management's awareness about its SM strategy?

And, in relation to the findings that propose to answer RQ1:

RQ2: How can these findings be used to help the company bridge gaps between its current and desired SM strategy?

2. Research Design

The Capability Methodology for Sustainable Manufacturing (CMSM) was designed to tackle these two research questions.

It was developed from the synthesis of two datasets: data from three case studies and interview data from three experts.

The characteristics of the case studies are listed in Table 1. Each case study was based on a manufacturing company located in Sydney, Australia. The cases were conducted sequentially, starting with A, then B and finally C. This enabled increased clarity and possibilities to generalize the CMSM as the study progressed. Three experts in industrial sustainability were interviewed. These experts were not affiliated with the companies involved in the case studies. Their expertise covered sustainable procurement, sustainability education in engineering and the concept of circular economy. The aim of these interviews was to get feedback on the CMSM and ensure its applicability across a wide range of manufacturing companies.

Table 1: Characteristics of the case studies used to develop the CMSM.

	Case study A	Case study B	Case study C
Manufacturing sector	Materials Handling	Confectionery	Optics
Number of employees in the company	500 employees	50 employees (excluding the mother company)	35 employees
Product family analyzed	Heavy trucks	Starch molding equipment	Prescription glasses
Number of interviewees: Role/position of each interviewee	Five: CEO, Production manager, Engineering design manager, Accounting manager, HR manager.	Three: General Manager, Sales Manager Asia Pacific, Production Manager	One: R&D and operations manager (cross-functional role)
Data collection format	Focus group	In-depth interview	In-depth interview

3. Development of the Capability Methodology for Sustainable Manufacturing (CMSM)

The analysis of each case study consists of three consecutive stages: elicitation, interpretation and alignment.

The first stage aims to elicit relevant primary data from the interviewees. In the second stage, the data is interpreted and synthesized. Interpretation depends on the construct of SM built in this study and synthesis occurs inductively. In the third stage, gaps between the current and the desired SM are outlined and a roadmap to tackle them is envisioned if needed. Due to space limits, only the data from one case study is detailed in this paper.

Case study A provides a concrete example of the approach proposed, along with the type of data collected and the information offered to the company at each stage.

3.1. Elicitation

The purpose of the first stage – *elicitation* – is to produce the capability statement, which is a list of the core capabilities of the company that the top management agrees upon. This list contains the competencies that the company sees as a must-have in order to succeed in its market. Information to build such a list is collected by means of a semi-structured interview. The interview questions have been designed to capture external factors (e.g., market trends) and factors internal to the company (e.g., underlying values and norms) that shape the concept of sustainability within the company Ten interview questions have been classified in six groups, per thematic area. Three interview questions are shown below. The full list of interview questions is available at [25].

Thematic area 2: Company's Value Proposition. Question 2.1*: How does the company provide value to its customers?* Question 2.2: *What guarantees its competitiveness?* Thematic area 3: Core capabilities. Question 3.1: *From a business and operations standpoint, what are the critical success factors and capabilities that allow the company to provide such value?*

Case study A focused on a company that produces equipment for materials handling (trucks) mainly in ports, mines, and construction sites. The management people involved in case study A were introduced to the concept of the triple bottom line (economy, environment and society) before the interview took place. The following list of core capabilities was produced by this management group (reported verbatim):

- Targeting correct markets
- Marketing the company's unique value in the market
- Truck customization/flexibility
- Transparency and awareness of parts network
- Guaranteeing engineering support
- Keeping up with new technologies for machines, in and outside the factory
- Improving internal efficiency and quality
- Training of customers in effective use and maintenance
- Supporting machine owners in the product use through apps and digital tools.

Further, the perceived level of maturity of each capability was assessed by the interviewee using a 0-to-3 scale:

- Level 0: "non-existing" capability.
- Level 1: "novice". The capability is being built.
- Level 2: "solid-but-static". The capability is acquired but with no intent to continuously improve it.
- Level 3: "thriving-and-optimizing". The capability is mastered, with the intention to continuously improve it.

This evaluation allows to quickly and intuitively distinguish between the capabilities that are yet to be acquired from the ones that are acquired and even mastered by the company.

The company of case study A will be henceforth referred to as company A. Overall, company A showed high maturity (3-score) in terms of truck customization and flexibility, largely due to highly skilled product designers and workforce, especially those responsible for the welding processes. In contrast though, company A showed low maturity (1-score) in targeting correct markets and improving internal efficiency and quality. Results of this first stage were disseminated to the interviewees and their extended network to check the accuracy of the information and to foster interest among more people in the company to join the study.

3.2. Interpretation

The second stage – *interpretation* – addresses RQ1 by representing the information gathered in the first stage in a way that reveals the current SM strategy and, most importantly, how it is being pursued.

In order to obtain this information, pieces of sentences from the interview data have been labeled with words deemed to concisely describe the meaning of the sentences, in relation to the goal of the study. In qualitative research, these words are called "descriptors" [26, 27]. Several aspects emerged from the interview data of the three case studies. The most predominant descriptors of the SM strategy were:

- The *complexity* of the concept of sustainability
- The *scope of the product life cycle*.

Complexity of sustainability was introduced by [28] in the context of engineering education. Previous research [28, 29] aimed to characterize how individuals comprehend sustainability by making them draw conceptual maps, where they could insert and connect concepts that define sustainability from a subjective and individual standpoint.

When following the method proposed by [29, 30], the complexity of sustainability is proportional to the number of links in a conceptual map connecting concepts that belong to different categories of sustainability, namely economic, environmental, social and institutional. The study presented in this paper defines sustainability complexity using a variation of this method [29, 30], identifying concepts within the capability statement and interview data instead of the conceptual map.

The scope of the product life cycle is assessed by the extent of the consideration of the product life cycle and of the stakeholders within it. The information that refers to this descriptor is, for instance, the focus (or any lack of) on raw material extraction, upstream manufacturing operations of components, downstream operations of recycling, upcycling and remanufacturing, along with concepts like "cradle to cradle" and "end of life". Furthermore, the relevance of these

categories for the goal of the study was confirmed by the experts.

For the case of company A, the data suggests a broad focus within the company in the realms of operation management, marketing, product and production systems design, and Information and Communications Technologies (ICT). Yet there was no consistent reference to environmental and social aspects within their value proposition and core capabilities, and no particular consideration of upstream and downstream product life cycle stages.

3.3. Alignment

The third stage – *alignment* – addresses RQ2. This means offering the information gathered from the previous stages in a way that helps the company formulate a desired SM strategy and understand how to pursue it. In particular, the characteristics of the current approach to develop an SM strategy are described in terms of complexity and scope of the product life cycle being considered. Following this, the findings from the first stage are used to question the fit with the current SM strategy and, when appropriate, encourage required alignment.

Reactions and feedback from the interviewees are collected through a questionnaire with open-ended questions. Key inquiries within the questionnaire are:

1. Do you think that the current strategy is the one that is needed in order to be ahead of the curve in the future?
2. If not, what SM strategy would best fit your company's goals for the future?
3. What resources do you need to have and what changes do you need to make in order to realize such a strategy?
4. Are these results and follow-up reflections going to spur any change or new course of action?

For company A, increased focus on social aspects was urged, such as behavioral changes in working methods within the key business processes, within and between departments and with the customer. One advocated change was to re-focus the targeted market (and therefore the entire product service provided) in light of high transports costs within Australia, the rise of driverless technologies, and the concentration of the global port market in the Middle-East area. Some excerpts from the interview with the sponsor of the study in company A illustrate alignment actions: "*We need to move further into the product life cycle. As a manufacturer and supplier, the position of selling premium products for good profit has long gone, with our competitors now matching our strength in this field, and thus dropping profits to low levels. To continue in business we need the focus to shift to 'whole-of-life'* (…) *Our CEO has a vision for this change and we have people willing to detail this out to run it. The limitation we currently have is that these people are currently too time poor for this endeavor, and we have a lack of systems and systems visionaries, which impedes the speed of this implementation*".

4. Results: Synthesis of CMSM

Synthetizing the three case studies resulted in the CMSM, a ten-step methodology that addresses the two RQs. The CMSM is divided into two phases (Fig. 1): the first part of Fig. 1 (steps 1-4) corresponds to the *identification* phase, in which the management identifies the specific SM strategy currently in place. The second part of Fig. 1 (steps 5-10) corresponds to the *alignment* phase, in which any gaps previously identified are addressed. The *identification* stage corresponds to the part of the CMSM concerning data collection and analysis, run by the analyst who adopts the CMSM. The *alignment* stage corresponds to the use of the results from the CMSM by the company.

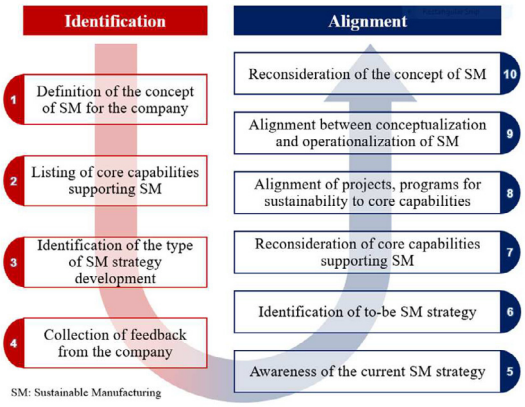

Fig. 1. Phases and steps of the CMSM.

Step 1 - *Definition of the concept of SM for the company* - is performed through unstructured or semi-structured interviews with the top management. Open questions or conceptual maps help the top management express the concept of SM.

Step 2 - *Listing of core capabilities for SM* - is either performed through in-depth interviews with single individuals or focus groups. Rating the maturity of these core capabilities is advised. A low maturity level is a symptom of strategic gaps.

Regardless of the method for data collection, the list of core capabilities must be shared among the interviewees.

In step 3 - *Identification of the type of SM strategy development* - the contents of the previous two steps are summarized in written form and analyzed using the relational matrix formulation illustrated in Fig. 2, and named *Complexity-Scope of Product Life Cycle* (C-S) matrix.

The C-S matrix is the tool designed to address RQ1 specifically, as it provides a guide to "decode" the collected information and boil it down to a comprehensive "archetype".

The C-S matrix visualizes four distinct archetypes of formulation and, consequently, development of an SM strategy.

Each archetype resulted from the intersection of the two dimensions of analysis: complexity, and scope of the product life cycle.

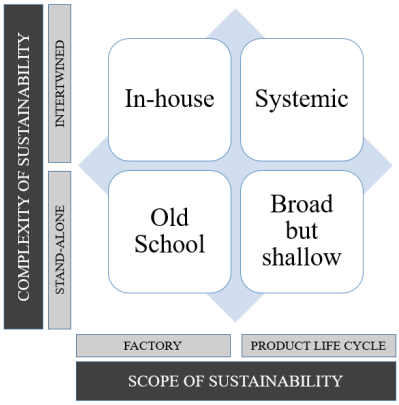

Fig. 2. The matrix Complexity-Scope of the Product Life Cycle (C-S).

Old School: this archetype results from two conditions. First, the management appears to be only concerned by factory operations (*factory* scope in Fig. 2). Second, management does not see connections and synergies between the manufacturing capabilities relating to different categories of sustainability (*stand-alone* complexity of sustainability in Fig. 1). This happens when, for instance, manufacturing capabilities are considered as either purely operational, environmental or social. As a result, the Old School is the least mature way to formulate an SM strategy amongst the four archetypes mapped by the C-S matrix.

Systemic: this archetype emerges when the two opposite conditions (to Old School) occur. First, the management intentionally considers the whole product life cycle when describing the strategy and capability of the company (*product-life cycle* in Fig. 2). Second, management does see meaningful connections and synergies between manufacturing capabilities relating to different categories of sustainability (*intertwined* complexity of sustainability). The systemic strategy is the most mature way to formulate an SM strategy in terms of sustainability understanding.

The remaining two archetypes in Fig. 2 represent hybrid archetypes between the Old School and the Systemic (see Fig. 2). A company that adopts a Broad but Shallow formulation of the SM strategy must increase its understanding of the complexity of sustainability issues through increased systems thinking. In contrast, a company that adopts an In-House formulation of the SM strategy must increase the scope of its focus, ideally by including the full life cycle of its main product in every sustainability strategy and practice in production.

In step 4 - *Collection of feedback from the company* - the results from step 1,2 and 3 are summarized and disseminated amongst the interviewees. It is advised that the results be organized within a template structured as follows:

a) summary of the workshop/interviews.
b) capability statement and the perceived level of maturity of each capability assessed by the interviewees.
c) the current archetype of SM strategy development, based on points (a) and (b).

The questions that are part of the alignment stage (see section 3) elicit key learning outcomes that can trigger any of the actions included from step 5 of to step 10 of the CMSM (see Fig. 1). In particular, the awareness of the as-is and to-be SM strategy (step 5 and step 6, respectively) triggers specific alignment actions. These actions are expressed in the CMSM from step 7 (*Reconsideration of core capabilities supporting SM strategy*) to step 10 (*Reconsideration of the concept of SM*).

The need for these actions to take place may or may not exist depending on the case being analyzed. Step 7 reviews what is deemed as manufacturing capability for the company, and establishes priorities in fostering capabilities with a low level of maturity. Step 8 and step 9 address alignment between strategy formulation of SM and its *operationalization*. More specifically, step 8 focuses on *projects and programs for sustainability*, whereas step 9 refers to the whole set of the KPIs with which goals are measured, and the design of manufacturing and business operations. Last, step 10 takes place when the management reviews the concept of sustainability and SM per se. The rest of this chapter provides instances of some of the steps of the CMSM within the case studies. Step 7 occurred in case study B, as the capability "refurbishing old equipment" was not considered to be core in the future despite being so in the past. This was because new and relatively cheap starch molding equipment is now available on the market. Interestingly, no particular alignment was needed in case study C, and therefore none of the steps from 7 to 10 took place. Company C produces modular, cost-competitive prescription glasses whose frame is made from recycled or recyclable plastics. Everything from product design, product packaging, selection of the workforce and the raw material, were aligned with their SM strategy, explained as "*Allowing people with visual impairment to see at the lowest possible price, no matter where they live and how much they can afford*". As a result, company C positioned itself in the systemic archetype, and of course intended to maintain that position.

5. Discussion

The CMSM is the synthesis of a methodology that was adopted and improved over the course of three case studies.

Although the case studies looked at different types of companies in terms of targeted market and size, more case studies are needed to validate the CMSM. Complexity and scope of product life cycle were the two dimensions used to represent archetypes of SM strategy development. The C-S matrix enables a better understanding of the construct of sustainability by business people, who might otherwise find it vague or unintelligible. However, other dimensions beyond complexity and scope of the product life cycle could be uncovered and mapped in new case studies. Motivation towards sustainability is an example of a dimension that would be of interest for future studies. In fact, a company might be internally motivated to achieve sustainability goals (e.g., because of the core values of the company) or externally motivated, for instance by environmental regulations [31].

Focus groups were a more suitable data collection method compared to individual in-depth interviews, whose data need to be "assembled together" and later approved. Focus groups allow different perspectives and opinions to emerge, allowing the management to converge towards the formulation of a

shared list of core capabilities. Moreover, having a sponsor within the company who champions the use of the CMSM is crucial, as the methodology relies on data that the management is willing to share. In the end, the mere application of the CMSM will not realize any desired change in the company unless top management involves and communicates with the lower levels of the organization throughout the operationalization of the strategy, as suggested by [32].

6. Conclusion

This paper proposes a methodology named CMSM for understanding and analyzing core capabilities of manufacturing companies. The CMSM ultimately allows top management to foster the desired SM strategy within the company, if specific conditions (pointed out in the Discussion chapter) exist. Although the proposed methodology raised interest from both industry and academia, further research through case studies is needed in order to 1) identify specific situations in which the CMSM can effectively provide support, or alternatively, whereby alternative methodologies are advised; and 2) tailor the CMSM according to different parameters, such as sector and size of the companies.

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