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Developing a library of sustainable manufacturing practices

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Abstract

As the body of sustainable manufacturing knowledge grows, there is a call for more examples of good practice to help manufacturers achieve their sustainability goals. Previous work has collated significant examples of what companies have achieved so far, in reducing the footprint of their factory operations, from literature and online sources. The contribution of this work is the creation of a conceptual model to inform the identification of the classification domain. A case based approach and an example is used to illustrate a potential classification scheme, for use in a library to support further understanding of how practices contribute to environmental performance improvement.

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Keywords: Sustainability; Manufacturing Practices; Library; Classification

1. Introduction

Increasingly, companies are reporting reductions in their environmental impacts, consumption of natural resources and improving business costs. Over 5000 companies are now reporting to the Global Reporting Initiative [1] and over 70,000 EU 27 companies have ISO 14001 certification [2]. Many of these companies typically give illustrative examples, within their sustainability reports, of the projects, which are contributing to their sustainability targets. However, there are examples of projects and initiatives, which are being missed at a factory level either because they are either being reported with a lack of detail or just not being reported at all within academic and industry literature.

Various empirical studies on the impact and success of environmental management systems have called for more case study data to be collected to help uncover some of the reasons that can explain how and why certain practices improve environmental performance [3–6].

Under a similar premise, there has been a call to build a library of ‘good examples’ of sustainable improvements to manufacturing systems [7] as a means of guiding companies to make effective changes.

The purpose of this work is to answer that call by developing a library with an appropriate classification scheme so that information can be coded and retrieved easily.

Exploratory research has been undertaken to investigate the current state of reported sustainable manufacturing practices, many of which are characterized by improvement activities [8]. For example: one company achieved process energy savings of 70%, when it noticed that a drying fan was being used constantly, instead of only when it was needed for production [9]. Another achieved a payback of 14 months when they removed one of three boilers from a part-loaded process [10]. A third company comprehensively reviewed their natural gas demand and educated their employees, using a government funded programme which generated improvement opportunities with less than a two month payback [11]. These are all examples of savings made which reduce environmental impacts and materialize in economic savings and are just some of the types of practices residing within the dataset. Many more practices cover aspects of performance improvement including; human behaviour, maintenance, production scheduling, and emissions reduction. The initial dataset included approximately 213 entries, however this has since been expanded to include over 1000 examples of practices.

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Given the volume of practices found, an appropriate classification scheme is needed so that practitioners wishing to find exemplars of how other companies have reduced their consumption of resources and environmental impacts can search easily. Other work has shown how practices can be classified with respect to specific issues; Beyene & Moman [12] developed a Process Oriented Energy Classification of technology whereas Behrendt et al., [13] demonstrated the classification of process improvement opportunities for machine tools according to energy efficiency axioms. However, there is little consensus on how to classify or define sustainable manufacturing practices.

This work reviews previous studies of practices in the literature, which have been linked to improving both operational and environmental performance. From this a definition of a sustainable manufacturing practice is proposed, in order to define the classification domain.

A conceptual model is used to demonstrate how the important elements of a manufacturing practice can be interpreted so that a similar model for sustainable manufacturing practices can be developed. Using a generic classification method, a characteristic based classification scheme for a library of sustainable manufacturing practices is presented.

Such a classification scheme would enable the practices to be organized in such a way so that more evidence can be found, that could support certain practices being associated with good quality environmental management and performance in line with environmental sustainability goals.

Subsequent gaps for investigation of new practices can then be found by examining the characteristics in more detail along with the relationships between multiple characteristics.

2. Literature Review

There has been much work on linking manufacturing practices and operational performance improvements over the years. However, there has been little consensus on how to classify practices that can improve environmental performance in manufacturing, so that the more detailed relationships can be investigated.

Manufacturing practices can be described as the approaches for attaining certain types of performance [14]. Typically these involve some kind of procedure or the application of tools either physical or managerial, which lead to some kind of performance improvement. A Recent evidence paper for the UK Manufacturing Foresight Report described practices as “the established processes, which a company has put in place to support the way in which business operates. Best practices are those that lead to world-class performances” [15].

However, it is often argued that there are limitations to how generalizable ‘best’ practices are, given the changing nature of business operations, and how practices are used differently in different contexts [16]. It is often assumed that the best performing companies must be using the best practices, however it is not always clear whether those companies became the best performers because of the practices they currently use, or whether best practices simply maintain high performance [14,17].

One main difficulty with understanding manufacturing practices is that different management and engineering communities view them differently. This means that academics and practitioners struggle to evaluate the merits of certain promising practices before the industry adapts to changing circumstances and older practices are ignored [18].

2.1. Environmental Practices

Building on an understanding of manufacturing practices, previous work has looked at how environmental technologies and green practices affect firm performance, with respect to regulation and voluntary initiatives. Environmental technologies have been defined as “production equipment, methods and procedures that conserve energy and natural resources, minimize environmental load of human activities and protect the natural environment”. [19]. This view includes: techniques (technologies, equipment, operating procedures) and a management orientation (approaches to product design, manufacturing, environmental management, technology choice and design of industrial systems).

In addition, Klassen & Whybark [20] build on the Natural Resource Based View that companies implement environmental technologies as practices. They present a typology of 3 types of environmental technologies namely; pollution control technologies (end-of-pipe); management systems and pollution prevention technologies (product and process adaptation).

Hajmohammad et al., [21] define environmental practices as “the level of resources invested in activities and know-how development that lead to pollution reduction at source”. This includes environmental management systems, waste reduction and recycling.

In essence, it is evident that environmental practices can be viewed as some combination of operational techniques and management processes, with a preference for prevention activities over end-of-pipe solutions. This view is echoed by Clelland et al., [22] who presented a typology of waste minimization practices in terms of; operating practices, inventory control, spill and leak prevention, raw material modification, product modifications, production process modifications, cleaning and degreasing and surface preparation and finishing.

One of the longstanding discussions in the environmental management literature has been on investigating the link between environmental and economic performance. Many investigations into the “Porter Hypothesis” [23], which has widely been interpreted as the “win-win” scenario of environmental improvement (guided by regulation) and economic performance [24], have yielded conflicting results. [3,6]. One of the suggested reasons for this is because, there seems to be an optimum point where companies with a low quality approach to environmental management can take advantage of quick wins, whereas established high performers have to make increasingly large investments to make absolute improvements to their environmental impact [25]. An approach that maximizes environmental value alongside the efficient use of economic capital is advocated for firms with established environmental management schemes [26].

In order to improve the quality of their environmental management systems, firms are increasingly adopting the ISO 14001 standard. However, empirical evidence has shown, that whilst there is a positive correlation between implementing the standard, there is no guarantee that all aspects of environmental performance will be improved above previous baselines [27–29]. Furthermore, it is evident that there is little understanding on how or why these environmental management systems are expected to improve specific indicators of environmental performance. [4].

This term 'environmental proactivity' has become increasingly used to describe company approaches to going beyond minimum regulatory requirements in environmental management [5,6,28,30]. Environmentally proactive companies are described as those who go beyond just a passive or reactive reaction to environmental regulation and incorporate environmental aspects into all areas of decision making [28].

The activities that firms undertake that go beyond standard environmental initiatives, have been investigated on a number of levels. "Environmental Management Practices (EMPs) are the techniques, policies and procedures a firm uses that are specifically aimed at monitoring and controlling the impact of its operations on the natural environment." [6]. Investigations into EMPs have shown positive correlations in terms of relations to firm performance [5,6], Lean manufacturing practices [3] and aspects of organizational learning and stakeholder satisfaction [30].

Whilst proactive EMPs are one way of understanding the link between operational activities and the strategic priorities of the firm, there are many more approaches to developing specific environmental improvements in manufacturing.

Aspects of reducing consumption of natural resources in production operations have been extensively researched. One of the main long-term studies has recorded over 680 unique improvement activities (Assessment Recommendation Codes), covering energy management, waste reduction pollution prevention and other productivity improvements, used in company audits [31]. There are now over 122,000 records of activities such as "reschedule plant operations or reduce load to avoid peaks (code 2.3131)" with data available on the associated environmental improvements.

Whilst these codes communicate the essential concept behind the improvement, what is not clear from the records are the existing policies that each firm has in place in order to manage their environmental impact. Furthermore, the fact that there are so many recommendations in the dataset that are recorded as not implemented, also suggests that there are many companies who could benefit from further research and advice into the managerial and organizational activities required to realize the improvements.

Other studies, have suggested certain measures to improve aspects of energy efficiency at a process level, a production system level and a technical building services level. [32] with various methods of assessing resource efficiency at process and systems levels are now being developed [33]. Furthermore, from an analysis of practices, it seems that there is evidence that a hierarchy of tactics in identifying improvement activities for sustainable manufacturing at a factory level [8,34]

2.2. Defining a Sustainable Manufacturing Practice

In spite of all the previous developments in resource efficiency improvements in production, manufacturers still face huge challenges in developing high quality environmental management systems, which compliment their competitive sustainable manufacturing strategies [35]. More research is needed into what high quality management looks like in applying sustainable manufacturing practices. Borrowing from the widely adopted U.S. definition [36], we propose a definition of sustainable manufacturing practices as:

*'**the techniques, policies and procedures a firm uses** to create manufactured products, that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities and consumers and are economically sound'.*

In light of previous research, it is clear that a classification scheme for sustainable manufacturing practices requires a comprehensive approach in elaborating what all of the attributes of the practices are. In order to respond to the call for more case study data, the core elements of practices have to be understood. There are various ways in the techniques, policies and procedures of a firm can be interpreted, especially when the premise for using them is linked to improving specific measures of performance.

3. Practices Conceptual Model

Whilst previous work has evaluated practices with reference to specific purposes such as lean manufacturing or energy efficiency, it is clear that there are other factors that affect the different ways in which practices can be interpreted. Antonacopoulou et al., [37] describe a heuristic for analysing practices in terms of '9Ps'. Practices have a **p**urpose, use some sort of **p**rocedure or technology, are implemented in a certain **p**lace, are based on **p**rinciples, have **p**ast which influences the **p**resent, develop at a certain **p**ace and involve **p**ractitioners and their **p**hronesis (practical judgement). It is in considering all of these contextual elements that a clearer picture of the term 'practice' can emerge.

In essence, there is something that motivates a practice; they evolve and are unique to certain time, applied in a specific location, by individuals who will have their own view of how successful the practice is. Is it proposed that these concepts can form the basis of a coding scheme so that more practices can be collected either from interviews, survey questionnaires, or through means of case studies, or content analysis of published company reports.

In light of the research analyzed, it seems that there is a strong emphasis in the literature to try to uncover the causal links as to why certain practices improve performance. Moreover, given that studies into why firm's environmental performance changes suggest that many different types of indicator are required, it seems sensible to alter the term **p**hronesis to **p**erformance for the classification.

4. Classification

For this work, a methodology for developing a classification for the practices was adapted from the generic methodology presented by [38]. This methodology was chosen due to the clarity of the procedure, and the inclusion of guidelines to improve the quality of the classification.

The methodology follows five steps; Inception, Elaborate Characteristics, Specify Classification Scheme, Test, Use and Maintenance. Work has been done on the first three steps as outlined below.

Inception*: The aim of this phase is to specify the domain of the system and the basic conditions of classification. Here, the purpose of the classification is articulated along with the relevant characteristics of the classification, the likely number of entries and the types of likely user queries.*

Elaborate Characteristics*: The aim of this phase is to collect a comprehensive set of potential characteristics, which are suitable to application area (domain).*

Specify the Classification Scheme*: The aim is to define all of the characteristics of the classification scheme and decide on the principle it is based on. There are four general principles of classification, namely; Basic, Hierarchical, Faceted (orthogonal e.g. Product-Process Matrix) and Characteristic based (multiple dimensions),* [38]. *During this phase, concise terminology is generated for each characteristic and the relationship between the classes are explained.*

Prior studies have investigated different ways of classifying improvement measures. Fleiter et al., [39] found, from a review of relevant literature, that three main groups of characteristics could be weighted against higher or lower adoption rates: relative advantage, technical context and information context. These groups were subdivided into more categories, which formed the basis of a characteristic based classification system. Whilst this type of analysis is useful for policy oriented decisions, the purpose of classifying practices is to try to capture as much information about the practices before then trying to ascribe a view on the utility of each one.

Another example classification focused on the energy intensity of different processes within industrial sectors [12], in order to target potential heat recovery and demand reduction improvements. It is anticipated that, with appropriate data, a similar analysis of the types of practices, which are most or least energy intensive in a particular industry or process, would be one of the likely queries from the users of the library.

Based on the literature review, the 9Ps conceptual model was adapted to incorporate important concepts from sustainable manufacturing domain. These concepts are explained and summarized as key characteristics of the classification scheme in Table 1.

One of the typical ways in which a practice is communicated is by the underlying **principle** or concept that serves as the basis for action. Some examples of environmental principles are in promoting; renewable resources, source reduction and remanufacturing, whereas social principles might concern reporting to stakeholders or social responsibility [40].

The operational objective typically defines the **purpose** of a sustainable manufacturing practice. Measures such as “minimizing energy requirements in standby mode” [32] or “use hot process fluids to preheat incoming process fluids” [31] serve as simple descriptions. The characteristic of relative advantage can also help to define the purpose, in terms of payback period or other benefits [39].

Another tool to help define the purpose, are sustainable manufacturing tactics, which generalize the inception of a sustainable manufacturing practice. This is done with respect to a hierarchy of improvement measures, so that “elimination of unnecessary activities to avoid usage at the source” is preferred over “replace technology” [34]

The CO_2PE! framework for Life Cycle Assessment, which uses a variation of a German standard classification for process technology. It is these types of characteristics that are useful to evaluate the ‘**procedures** and **technology’** element of the practices conceptual model [41].

In order to understand the context of where the practice is applied, there are various factors that can be associated with the **place** element. The SIC, allows for a quick reference to other processes within the same industry, however it will also be useful to understand whether the practice is applied to a core process and what part of the site it relates to.

The **past** and **present** conditions are also of useful to understand the context of practice and how it is adapted for use by the firm. Information on the change processes, the maturity of the techniques or technology and the readiness of the company to accept change are all important factors, along with the **pace** of change and whether **practitioners** such as energy champions helped the practice succeed.

Several aspects of measuring environmental sustainability **performance** could be developed. Whilst there are many indicators available, one of the most comprehensive sources is from the US National Institute of Standards and Technology [42], whilst other studies have investigated specific metrics for sustainable manufacturing [43].

Whilst all of these characteristics are important for the classification, some may be more textual than others. More work, such as content analysis on the case studies is required to refine the classification further.

4.1. Example:

In order to demonstrate how the classification works, an example of a freely available case study with an established energy saving programme is presented. As part of a comprehensive review of their natural gas consumption, Chrysler achieved costs savings of $620,000 annually with a payback of around 2 months [11]. One of the improvement opportunities reported is classified in the practices framework below:

Element	Typical Characteristics	Key Considerations
Principles	• Environmental Principles • Economic Principles • Social Principles • Continuous Improvement (Lean & Green) • Sustainable Manufacturing Tactics	The rules (heuristics) that inform the development of the practice The key concepts that serve as a basis for action
Purpose	• Relative advantage (payback etc.) • Triple Bottom Line Impacts, • Manufacturing Strategy/Objectives	The operational justification for the practice The predominant strategic objectives The type of decision support is required
Procedures & Technology	• CO_2PE! Process Taxonomy, • US DoE ARCs. • Modification type (Technology substitution/ replacement/ add-on. Organisational measure). • Related EMPs	The managerial procedures used The type of technologies used The key operational/engineering activities
Place	• Machine, cell, factory, site, supply chain • Standard Industrial Classification. • Distance to core process • Process Inputs / Outputs	The context/location of application Primary or auxiliary processes
Past & Present	• 'Fit' with current change processes. • Information transaction costs, diffusion progress (technological maturity of improvement)	The events leading up to the practice being thought of or implemented
Pace	• Speed of change. • Lifetime (of improvement)	Length of implementation
Practitioners	• Internal / External. Technology/process, engineering and maintenance personnel	Key change agents Key personnel/shop floor staff
Performance	• Performance figures & Individual Accounts. Initial rate of return, payback, expenditure, non-energy benefits. • Management / Operational Indicators • Environmental Impact Indicators	How success is/was understood by the participants Key performance indicators The practical judgement of those involved

Table 1. Typical Characteristics and Key Consideration for the classification of Sustainable Manufacturing Practices

Principle: Minimization / Reduction

Purpose: Optimize boiler Operation and Load Management Strategy. Short payback. Educate personnel.

Procedures & Technology: Use government programme and funding to train personnel to use freely available steam assessment tools. Analyse steam system to identify opportunities for natural gas savings. Turn off one boiler to improve loading across the others. Process Taxonomy; 8.1 Time Study, 8.2 Power Study.

Place: Automotive sector, natural gas (building services)

Past: Team already familiar with steam use patterns but unfamiliar with government analysis software

Present: 10 team members now trained to use the software to find opportunities at other sites

Pace: Long term improvement. Change process time not available.

Practitioners: Energy Champion, operations, maintenance and powerhouse staff.

Performance: 22,000 MMBTUs gas saved. Project allowed team to meet corporate efficiency goals quicker than anticipated.

5. Discussion

This work has set out to develop a classification scheme to record promising sustainable manufacturing practices. An initial classification scheme is demonstrated through the use of a freely-available example and a summary of the important information from the case. Furthermore, a novel definition of a sustainable manufacturing practice is proposed to help describe the domain of classification.

A conceptual model describing practices was needed to develop the detailed characteristics in the classification, however, when tailoring it to the concept of sustainable manufacturing practices, many issues were identified. It seems that much of the literature has been dedicated to linking performance improvements with practices. The need for data to help uncover some of the specific links between environmental sustainability and sustainable manufacturing practices is recognized but there is currently no clear framework for data collection. Also, the fact that there are so many ways in which to interpret the term 'environmental performance' and actions to improve it only serves to make the process of identifying good examples and promising practices more challenging.

The classification, although broad, has been influenced by the current dataset of good examples. More data collection is needed and analysis on the data to improve the detail of the classification. Due to the lack of data in some freely available sources, many more cases are needed with more robust evaluations of environmental performance Finally, guidance on how to interpret case study data needs to be developed, so that there can be consistency in describing the practices and adding them to the classification.

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