Use of Design Structure Matrix for Analysis of Critical Barriers in Implementing Eco-Design Initiatives in the Pulp and Paper Industry

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Abstract

Eco-design initiatives are gaining importance due to changing environmental conditions and the industry is developing different solutions. The purpose of this paper is the identification and evaluation of barriers related to the implementation of eco-design initiatives in pulp and paper industry. This study identifies the key barriers through literature research and provides information flow dependencies using design structure matrix through a case study of a company in Finland. This method differs from traditional management tools because it focuses on representing information flow rather than workflow. The findings provide policy recommendations to policy makers for managing eco-design implementation.

Keywords: Eco-Design; Design structure matrix; Pulp and paper industry; Management barriers

1. Introduction

During the past two decades, the sustainability concept has gained a great importance in the manufacturing industry.

This is due to continuously increasing the pressure from stakeholders, e.g., employees, investors, suppliers, customers, competitors, communities, government, regulatory bodies etc. for the improvement of the environment.

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There are current global tendencies for the improvement of environmental sustainability and minimizing the negative impacts on the environment, in other words, of sustainable development. As part of the tendency, authorities establish strict criteria and requirements for the environmental performance of companies and their products [1]. In the EU, for instance, the requirements are set in the form of directives from the European Commission [2, 3].

Sustainable product and process design aim to reduce waste, mitigate pollution and reduce health risks to humans and other species, while contributing to conserve energy and materials, eliminate toxic substances by establishing sustainable environmental, economic and social objectives [4]. Sustainable development seeks to optimize efficiency while minimizing negative environmental impacts and maintaining social equity. These represent the three pillars of sustainable development; financial, environmental and societal. It is also important to develop key performance indicators [5] for each of these three broad categories in order to evaluate the company’s sustainability performance. For example, environmental regulations in large manufacturing companies in China encourage adopting eco-design practices and use of recyclable materials and reusable parts, providing evidence that coordinating activities between eco-design and the external environment is mostly needed [6]. Therefore, adopting the eco-design initiatives for sustainable development in manufacturing is experiencing increasing importance from society, and companies seeking for sustainable manufacturing measures and environmental strategies are also becoming increasingly common.

The eco-design can extend (but is not limited to) to packaging, manufacturing and product and process design. Based on the literature review, eco-design has been adapted and included in the study, where product and design are analysed from a modern production perspective [7]. Eco-design consists of different stages [8], however, in the present study eco-design focuses on the design of new methods for product improvement, redesign tasks and derive eco-design improvement strategies. Consequently, an eco-design initiative in the pulp and paper industry is a complex system that involves many elements from various disciplines and functional areas. One of the key challenges of pulp and paper manufacturing today is to understand and optimize its environmental impact, and to identify the key barriers that hinder the implementation of eco-design. The motivation of this study is to propose and apply a novel approach that helps to identify and analyse the barriers in order to implement eco-design initiatives in pulp and paper manufacturing. The present study focuses on analysis of critical barriers for implementing eco-design initiatives using design structure matrix (DSM) based on three case studies of pulp and paper companies in Finland. The aim of this paper is to identify and evaluate the key barriers for implementation of eco-design for sustainable manufacturing in the pulp and paper industry. The research questions for this study are proposed as:

1) What are the key barriers in implementing of eco-design initiatives in the Finnish pulp and paper manufacturing industry?
2) What method can be used for analysis and evaluation of key barriers for implementation of eco-design initiatives in the Finnish pulp and paper manufacturing industry?

The rest of the paper is organized as follows: a review of relevant literature discussing barriers related to the implementation of sustainable process design and manufacturing is presented in Section 2. Section 3 introduces the methodology chosen in the present study; DSM, data collection and case studies. Data analysis and results are discussed in Section 4. The paper is wrapped up with a set of policy recommendations and conclusions in Section 5.

2. Literature Review

2.1. Eco / Sustainable Process Design

Sustainable manufacturing can be defined as the creation of goods or services that satisfy the customer needs while respecting the environment and communities’ wellbeing [9]. It aims to integrate sustainability into consideration for manufacturing activities, seeking a balance between financial, social and environmental factors thought the optimization of resource use, social value and environmentally responsible practices [9].

The eco-design initiatives can target increase the efficiency of use of energy or materials, reduction of waste and emitted pollutants, reduction of hazardous materials and substances in the manufacturing process, improvement of waste handling protocols or techniques, recycle and reuse, utilization of greener technologies and materials, etc. to mention some [10, 11]. Intense investment and strong commitment, both internal and external to the company, are
required to develop the human resource capable of deploying eco-design practices [12].

2.2. Barriers to eco-design initiatives in sustainable manufacturing

There are several barriers that even successful companies encounter in their eco-design initiatives’ deployment. The idea of eco-design initiatives is relatively new [13], and many of the barriers involve integrating sustainable manufacturing practices into day-to-day business operation. Training the employees on the need to change from status quo to sustainable business practices can present a difficult challenge. What has been assumed historically as a major barrier, the economic cost, has turned out to be less of a hurdle when companies realize the economic benefits associated with sustainable manufacturing practices.

Within the European context, the advanced technologies and highly trained working force are matched with tighter regulations. Hence, the context to which Finland is exposed is very specific, even within the region. From literature, a selected list of key barriers identified for the context of pulp and paper manufacturing in Finland are presented in Table 1. The barriers presented are the factors, which are considered the main obstacles to the implementation of eco-design initiatives in the Finnish pulp and paper industry, for companies that, either following tightening regulations or as part of ecological strategy, seek higher sustainability scores [14]. The importance of the key barriers for implementation of eco-design initiatives generally can be validated from expert’s inputs. In terms of adopting eco-design initiatives for implementation, different industrial organizations deal with different barriers in various ways. Nevertheless, barriers that have direct impact in implementing eco-design process must be identified. The 12 existing key barriers that affect implementation of eco-design initiatives in sustainable Finnish pulp and paper manufacturing industry were identified and collected through research and validated through expert’s inputs and interviews, and are presented in Table 1. The identified barriers were categorized in four major groups, which include institutional, management, technology and stakeholders and declared as system elements.

Table 1: Identified barriers affecting the implementation of eco-design initiatives in the supply chain of manufacturing company

<table>
<thead>
<tr>
<th>ID</th>
<th>Categories</th>
<th>Barrier</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>Institutional</td>
<td>Lack of coordination from academic experts for implementation of eco-design process initiatives</td>
</tr>
<tr>
<td>B2</td>
<td>Institutional</td>
<td>Lack of support from institutions for commercialization of cleaner production technology</td>
</tr>
<tr>
<td>B3</td>
<td>Institutional</td>
<td>Complex external institutional environment</td>
</tr>
<tr>
<td>B4</td>
<td>Institutional</td>
<td>Complexity in monitoring suppliers’ environmental practices</td>
</tr>
<tr>
<td>B5</td>
<td>Management</td>
<td>Lack of customer awareness on eco-design initiatives</td>
</tr>
<tr>
<td>B6</td>
<td>Management</td>
<td>Lack of internal coordination on eco-design investment</td>
</tr>
<tr>
<td>B7</td>
<td>Management</td>
<td>Lack of employee involvement in eco-design initiatives</td>
</tr>
<tr>
<td>B8</td>
<td>Management</td>
<td>Lack of top management encouragement for training initiatives on eco-design process</td>
</tr>
<tr>
<td>B9</td>
<td>Technology</td>
<td>Uncertainty in product demand</td>
</tr>
<tr>
<td>B10</td>
<td>Technology</td>
<td>Lack of capital investment opportunities for green process</td>
</tr>
<tr>
<td>B11</td>
<td>Stakeholder</td>
<td>Lack of coordination from customer on eco-design process</td>
</tr>
<tr>
<td>B12</td>
<td>Stakeholder</td>
<td>Lack of buyer/customer knowledge on eco-design initiatives</td>
</tr>
</tbody>
</table>

3. Methodology

3.1. Solution Methodology

A DSM is an efficient and commonly used method of showing the interdependency relationships among the design activities in a project [15]. DSM, introduced by [16], is a new paradigm that works from the structure of the information flow inherent in the problem. It is a qualitative, straightforward and flexible modelling technique for designing, developing and managing complex systems. DSM enables the representation of complex problems, using
a number of element dependencies, which are permitted to assume the relationship, interaction and interdependencies between them [17]. DSM, associated with a directed graph is a binary square matrix with \( m \) rows and columns, and \( n \) non-zero elements, where \( m \) is the number of nodes and \( n \) is the number of directed lines connecting these nodes in the directed graph. In DSM rows and column is corresponding to the design activities [16].

Given a set of \( n \) activities in a project, the corresponding DSM is an \( n \times n \) matrix where the project activities are the row and column headings listed in the same order. The precedence relationships among activities appear in the off-diagonal elements of the matrix. If activity \( j \) depends on activity \( i \) (that is, \( i \) feeds \( j \)), then the value of element \( ij \) (column \( i \), row \( j \)) is one (or flagged with a mark such as “X” or “●”) in a binary DSM. Otherwise, the value of the element is zero (or left empty) [18]. If the activities are executed in the same order as they appear in the DSM, then marks below the diagonal represent forward information from activity \( i \) to \( j \), while those above the diagonal represent feedback information from activity \( j \) to \( i \). The DSM can be define as follows:

**Definition 1.** Let it be the DSM with square matrix, \( n \) denotes the number of activities. DSM is binary Boolean matrix \( A = [a_{ij}]_{n \times n} \). Its element \( a_{ij} \) can only be “0” or “1”. Thus, it can be defined as

\[
0 \quad (i = j \text{ or } a_j \rightarrow a_i) \\
1 \quad (a_j \rightarrow a_i)
\]

(1)

In the matrix, the element \( a_{ij} = 0 \) is on the diagonal. In addition “\( a_j \rightarrow a_i \)” denotes that activity \( a_j \) input information to activity \( a_i \), then \( a_{ij} = 1 \), otherwise \( a_{ij} = 0 \) [19].

DSM method has been largely applied in the literature. It enables to improve the system structure by using matrix-based analysis techniques. DSM has been used for the analysis and improved understanding of complex systems, and applied in various fields including automotive [20], aerospace [21], construction and telecommunications [22], policy formulation [23], planning and operation management [24] and supply chain [25], among others. DSM model is used as a solution methodology in this work. It assists in decomposing, organizing, analysing and improving a complex problem. The method requires a cycle of analysis and a number of iteration steps. The DSM model shown in three case studies represents the barriers for eco-design practices launched since 2004 for the pulp and paper manufacturing industry in Finland as explained by the managers interviewed. The “ProjectDSM” software version 2.0.1 was employed to analyse the sequence of the information flow.

To illustrate how DSM can be applied, three case studies identifying and analysing the key barriers from the domain of pulp and paper manufacturing industry in Finland are presented. These case studies are exploratory because they are focused on implementing environmental strategies in a large-scale investigation. This helps to identify questions and select types of measurements prior to the main investigation. Although these issues are listed as a sequential step in the DSM modelling process, in a real world company the process of eco-design initiatives is quite complex.

### 3.2. Data Collection

In the first step, during the research phase, semi-structured interviews and documentation for the identified barriers through information system, annual reports and internal and external documents of the company were the information source used to identify and describe the current situation of the eco-design implementation process. First author was involved in data collection and interpretation. Next, the identified barriers through above-mentioned literature review were presented to industry experts to have their evaluation. The evaluation includes determining the strength dependencies and interdependencies related barriers. Nine interviews with managers and decision makers were conducted, all of them key decision makers involved with either development or implementation of eco-design initiatives. In addition, workshops held for implementing eco-design initiatives took place. Therefore, nine specialists from different areas (as are: director of strategic planning and decisions, vice president for sustainability, manager of environmental protection, manager of re-source platform, project manager in product safety/environment and responsibility team, planners and technical experts), have a rich knowledge and , each with
over ten years of work experience in the pulp and paper industry participated in the workshop. Through the interviews and workshops, the identified barriers were updated and evaluated based on the interactive cycle for their interdependent relationships. The multidisciplinary experts’ team then validated the barriers and the strength of the interaction dependencies.

3.3. Case Study of Finnish pulp and paper industry

The current case study was performed in the period of three months from January to March, 2017. The companies addressed in the case studies deal with the manufacturing pulp and paper products located in southern Finland. The target of the case studies analyses is to provide a set of appropriate policy recommendations in order to promote the implementation of sustainable practices. Wood processing, to produce a wide range of products from planks to pulp and paper, remains one of the largest industrial sectors in Finland. The pulp and paper industry in Finland, is today one of the world’s leading pulp and paper producers and wood processing. The companies have strategic targets of improving the performance of eco-design process through their business activities and identification and evaluation of the existing barriers is the first step to reach those targets. Policy makers and managers are looking to implement different types of eco-design initiatives and different approaches in order to achieve sustainability in a modern manufacturing company. In all cases, companies have received awards and public recognition for their commitment and intensive action related to sustainability. The cases are listed in Table 2, which presents some details of the interviewed experts of the industry in Finland. The experts from three companies, (labelled cases A, B and C), represent the three largest pulp and paper and wood processing consortiums of Finland, and all of them are decision makers in matters of environmental management, hence making the analysed sample very relevant to the Finnish pulp and paper industry.

Table 2. Demographic details of interviewed experts in Finland

<table>
<thead>
<tr>
<th>Company</th>
<th>Project</th>
<th>Examples of company activity type</th>
<th>Example of quality certifications</th>
<th>Example of expert title and responsibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company B</td>
<td>Packaging, biomaterials, wood and paper</td>
<td>ISO 9001, ISO 14001, OHSAS 18001 as well as PEFC™ and/or FSC® Chain of Custody</td>
<td>Vice President, Sustainability team</td>
<td></td>
</tr>
<tr>
<td>Company C</td>
<td>Producer of graphic papers and suppliers especially papers</td>
<td>ISO 14001, EMAS, ISO 9001, OHSAS 18001, ISO 50001 EES+, Chain of custody PEFC, FSC Certificate, EU Eco-label (Copying and graphic paper, Newsprint paper)</td>
<td>Manager, Product Safety, Environment and Responsibility team</td>
<td></td>
</tr>
</tbody>
</table>

4. Data analysis and Results

After collecting data, the DSMs are built. First, the barriers are represented and mapped in a 12 x 12 square DSMs, where these elements/barriers are listed on the left side of the DSM. Next, input information dependencies between each of the identified barriers were defined in the software based on the experts’ inputs. Based on the barriers interactions, the DSM graph structure is analysed. One of the key insights resulting from the DSM model is to see the planned and unplanned iterations.

In binary DSM notation (where the matrix is populated with black dots and empty cells) listed in the matrix, a single attribute was used to convey relationships between different systems elements; namely, the “existence” attribute which signifies the existence or absence of a dependency between the different elements. The pink shaded boxes along diagonal represent planned iterations and the black dots represent present iterations. This means that planned iterations are the parts of the process where work across several related activities (barriers in this case) is required in order to reach the optimal state from the first attempt. Next step, an analysis of the created DSM and...
optimized dependency sequence algorithm within iteration blocks was performed. The DSM optimization algorithm consists of sequencing and clustering. While sequencing is used to reduce iteration and sequence better the process flow of elements (e.g. processes, information flows), clustering is applied to create element groups that have strong internal and few external connections [18]. Analysing the process flow of the elements in the DSM, shown in Figure 1, presents the elements (in this case barriers) and their dependencies and interdependencies after clustering in the optimized matrixes for cases A, B and C respectively as indicated. The analysis identified the multidisciplinary interactions (shaded in pink), which occur between different categories. The different cases in Figure 1 show that implementing eco-design process involves different coupled blocks (or chunks) in design workflow. However, there are used different coupled blocks of information feedback to replace the initial complex design process.

![Figure 1. Barriers in DSM after clustering](image)

In Figure 1 is shown that even though barriers analysed for all case studies are the same, the distribution and sequence of the dependencies is quite different. This can be explained by the fact that the perception or effect of the barriers depends on many factors specific to the company, such as organizational structure, company size, or even geographical location, among others. Nevertheless, the interactions specific to each company are out of the scope of the presented research. Instead, the focus is given to the barriers that share correlations in between companies, and hence can be considered as barriers for the industry.

Shown in Figure 1 are the shaded blocks that represent critical dependencies. Critical dependencies require especial attention from the managers, and are often mutual (interdependent). It can be also noticed that the barriers which dependencies are common between companies, highlighted by the added circles, where green indicates a dependency common for all cases and blue circles represent a shared dependency in between two cases.

The dependency of barrier B7 to barrier B8 (both from management category, marked with the green circle for all cases), though is the only one present in all case studies, its appearance within the cases differs from case to case. For cases A and C, the dependency of the barriers appears below the diagonal, which means that the relationship of barrier B7 to B8 is perceived as independent to all other barriers. However, for case B barriers B7 and B8 are critical and interdependent of each other. Translated to natural language, it makes perfect sense, as the lack of employee involvement in eco-design practices can always be explained by a lack of encouragement for training from top management, but they can also be mutual.

The correlation of barriers B5 and B6 is perceived as critical and interdependent of each other for cases B and C (marked with blue circles). It is quite revealing that though both belong to the same category, it is clear that B5 is external and B6 is internal to the companies, nevertheless they are interdependent. Again, in natural language it makes sense, since many external factors act as drivers for eco-design implementation (e.g. customer demand, government regulations, certification requirements, etc.). When an uninformed external factor (in this case customer) does not provide a clear target for investments on eco-design to be made, a barrier is faced. But also, hesitating eco-design investments from the company side are not clearly perceived by a customer, hence they can be unnoticed by the later.

Similarly, the correlation of barriers B1 and B4 is common for cases A and C, but in different ways for each case. In case A, the correlation appears as independent and does not seem to interact with any other barrier. However, in case C this correlation appears inside a criticality (shaded) block, and above the diagonal. In other words, for case A it seems as if the lack of coordination of academic experts is only related to the complexity of monitoring of
provider’s practices, while for case C it seems to be the other way around, as if the complexity of monitoring provider’s practices hinders the coordination of academic experts. In reality, as field under continuous development, it makes sense that in different situations the monitoring of provider’s practices and academy may sometimes bottleneck each other over a developing technology, for example.

Finally, the correlation of barriers B2 and B8 appears in common for cases B and C. In this case, both cases perceive the correlation as independent and non-critical, unrelated to other barriers. Again, back to natural language, it makes perfect sense that the lack of support from institutions for the implementation of cleaner technologies to hinder the top management support for eco-design trainings, as new cleaner technologies are very often (if not always) the target of eco-design related trainings.

Overall, it is clear that achieving eco-design initiatives in a pulp and paper manufacturing company is not possible without strong governmental support and related policies. Therefore, the role of institutions is crucial for enforcing industries to promote the targeted activities, especially in the case of green technologies that support environmental improvement in a long-term life cycle perspective. Overall interactions in all abovementioned cases are called interdependent information flow. Managers should increase attention to the feedback of information flow in these blocks and should estimate the complexity level between related design activities. In addition, usability of DSM in capturing and evaluating the barriers in eco-design process in Finnish pulp and paper industry, undoubtedly, can clearly recognize the complex relationship between the coupled activities.

5. Conclusions

The aim of this paper was: 1) to explore the main barriers related to implementation eco-design process in Finnish pulp and paper industry and 2) to utilize DSM to tackle the identified issues. The objective was not to identify only a large number of barriers to implementing eco-design practices in the companies. Instead, the aim was to capture and analyse the critical barriers, and their interactions, that the companies have in common and therefore affect the pulp and paper industry in Finland related to environmental strategic objectives.

The method shows a great efficiency in eco-design analysis and as a new way to effectively manage the large-scale systems such as sustainable manufacturing. The analysis results indicate that the main barrier correlation for implementation of eco-design initiatives in Finnish pulp and paper industry are barriers B8 ‘Lack of top management encouragement for training initiatives on eco-design process’ with barrier B7 ‘Lack of employee involvement in eco-design initiatives’ from management category. Another barrier correlation very relevant for the industry is the interaction between barriers B5 and barrier B6, both critical for case studies B and C. Furthermore, common barrier correlations for the industry are barrier B2 with barrier B8, and barrier B1 with barrier B4. It requires more attention for further improvement. The results of this study also have shown that lack of collaboration between the company’s management and the government institutions remain the main obstacle in achieving implementation of eco-design initiatives. It can be concluded that an intensive collaboration between academic research institutions and industrial organizations could enhance the potential for systematic investigation of new product design and their market development strategy to overcome barriers and facilitate decision-making in the pulp and paper sector.

The main contribution of this paper is to present the identification of potential barriers for implementing eco-design initiatives in the Finnish pulp and paper industry and structure those into four main categories. Next, clustering and systematic analysis of barriers through DSM has brought changes and mix interactions for each barrier. The proposed method provides insights into the process structure, identifies problem areas in processes and enables process re-designing. Systematic analysis of three case studies in this paper has significant managerial implications. DSM methodology used in this study provides managers in Finnish pulp and paper industry with deeper insights of the different barriers, which should be considered, while adopting eco-design practices.

In line with the current literature about strategy development, business environmental goals and improvements of performance indicators and their effectiveness for sustainable manufacturing, the presented DSM analysis highlighted barrier interdependencies between the institution, management, technology and stakeholders. Finally, the improvement of eco-design initiatives happens through the design activities and development of legal framework for the establishment of clean and green technologies, which play a crucial role in the commercialization of products
in order to reach maximum benefits from sustainability practices. Furthermore, from the evaluations of barriers for adopting eco-design initiatives in Finnish pulp and paper industry to determine their dependency strength using DSM, it was possible to develop and propose the following set of policy recommendations and related environmental strategies to address the barriers.

- Development of the strategic policies for long-term investment in green technology for sustainable process and product development.
- Companies need to focus on the product stewardship, which includes a wide range of sustainability practices from product design to supply chain.
- Management and decision-making body in manufacturing companies need to integrate programs for monitoring activities in eco-design process throughout the supply chain.
- Development of environmental training programs and activities for workers in the production departments.
- Involvement of all staff levels in the environmental training events for integrated programs in adopting eco-design initiatives.
- Extension of internship programs for students and researchers to strengthen academic collaboration.
- Development of interdepartmental communication channels for coordination of eco-design implementation.

Since this study was the first attempt to use DSM for identifying key barriers in eco-design initiatives for the Finnish pulp and paper industry, there are some limitations that require further research. First, the identification of the barriers was based on interviews and experts’ knowledge, which was not completely structured. This limitation can be overcome by considering the extended list of policy recommendations with detailed guidelines in each barrier to be carried out in the next stage of the research. Second, the scope of this study is limited only to the current Finnish geographical, political and economic situation.

The future research extension will focus on integrating DSM with ranking methodology in order to show which barrier has priority within a cluster and to quantitatively evaluate the implementation of eco-design initiatives (i.e. benefits on time, cost benefits, effect relevance and technical complexity) in order to remove some of the inherent vagueness and uncertainty.

Acknowledgements

One of the authors would like to acknowledge The Research Foundation of Lappeenranta University of Technology [LUT Tukisäätiö grant number 122/16] and The Foundation for Economic Education, [Grant number 160039] for the support. The main author would also like to extend gratitude to Javier Farfan for his professional English proofreading and reviewing of the article. Especial gratitude goes to all the Finnish collaborators from the industry for their vital input to this research.

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