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Expanding DRM framework to Formulate Supreme Causal Models from Research articles in the Area of Product Disassembly

S. Harivardhini[a] and Amaresh Chakrabarti

IDeaS Lab, CPDM, Indian Institute of Science, Bangalore – 560012, India

Abstract: This study focuses on the implementation of a Causal Model for extracting causal relationships from research articles in the area of product disassembly. A Causal Model is a Model with a network of influencing factors to describe situations, as proposed by the DRM framework. In this work, DRM framework is further aided by formulating Supreme Causal Models. Individual Causal Models were generated using causal relationships extracted from research articles; Supreme Causal Models were formulated by collating these individual Models. The methodology adopted includes the following steps: data was collected from forty research articles in the area of product disassembly, which were analyzed using the concept of Causal Model from the DRM framework. Results include individual Causal Models, extracted from research articles, and Supreme Causal Models. The individual Causal Models elaborate some of the existing situations within the area of product disassembly; the Supreme Causal Models give a more complete picture of these existing situation fragments. Also, they represent some of the potential desired situations, such as maximizing profit or minimizing environmental impacts, and provide insights on how to achieve these desired situations.

Keywords*: DRM's Causal Model, Causal relationship, Reference Model, Impact Model*

1 Introduction

The Causal Models within the DRM framework [1] is intended to help achieve (i) a comprehensive understanding of a research area through identifying causal relationships from research articles; (ii) identifying major research gaps in the area by revealing the weaker or non-existent links among the factors in the causal network; and (iii) determining the important parameters of the area, i.e. those which, if strengthened with the help of a support, would enhance the performance of other important parameters. All of these should, as proposed in DRM, lead to the betterment of some aspects in that particular research. In this work, DRM framework is not only implemented but also further strengthened by formulating Supreme Causal Models as a collation of individual Causal Models. Formulation of Supreme Causal Models has helped us in developing significant insights into the way in which various important parameters of product disassembly processes and outcomes influenced one another, as to how strong these influences have been, and whether the influences are positive or negative. Also, the

[a] S.Harivardhini
Tel: +91-7259961576
email: vardhini@cpdm.iisc.ernet.in

Supreme Causal Models helped us identify the potential parameters within the area of product disassembly that require intervention in the form of support for improvement.

In the current study, DRM's Causal Models have been implemented to extract causal relationships from research articles in the area of Product disassembly. Section 2 discusses the details of Causal Models within the DRM framework, and the important concepts within the framework that were used in this study. Section 3 details on generation of individual Reference Models from causal relationships and elaborates on some of the individual Reference Models developed in our research. Section 4 discusses the formulation of Supreme Causal Models from these individual Reference Models. Discussions and conclusions are provided in Section 5.

2 Causal models within DRM

DRM Framework [1] distinguishes between two types of networks of influencing factors, Reference Model and Impact Model, to describe respectively two types of situations, existing situation and desired situation. These Causal Models are made up of **nodes**. Each node represents an **Influencing Factor**. These nodes are connected by **links**. Each link represents the causal relationship between two nodes i.e., the causal relationship between two Influencing factors, one factor being the cause and the other being the consequence or effect. Main concepts of these causal models are provided below [1]:

Influencing Factor or Factor: It is an aspect of a situation (existing situation in case of Reference Models, and desired in the case of Impact Models). It is formulated as an **attribute** of an **element** that can be observed, measured or assessed, i.e., for which a so-called **Operational definition** can be formulated.

Operational definition: It defines "what to do" and "what to measure" in a concept.

Links: These are edges connecting the nodes, which show how the factors influence or are desired to influence each other.

Key Factors: These are influencing factors that seem to be the most useful ones to address in order to improve an existing situation.

Success Factors: These are the factors at the 'top' of the network, i.e., at the end of the cause-effect chains that provide the justification of the research.

Success Criteria: These are the desired values of the Success Factors.

Measurable Success Criteria: These are criteria that are linked to the chosen Success Criteria and can be applied to judge the outcomes of the research, given the resources available within the project or programme.

Measurable Success Factors: These are the factors whose desired values are taken as Measurable Success Criteria.

Proxies: When it is not possible to use Success Criteria as Measurable Success Criteria, Measurable Success Criteria should be chosen such that they can serve as reliable indicators (or proxies) for the Success Criteria.

Support: DRM framework proposes that in a research project that involves developing a support, the envisaged support, i.e. the **Intended Support** is defined first, and is realized to such an extent that its core concepts can be demonstrated and core effects evaluated.

Reference Model: This model represents an existing situation in design, and is the reference against which the intended improvements are to be benchmarked.

Impact Model: This model represents a desired situation in design, and represents the assumed impacts of the support to be developed.

3 Extraction of Causal relationships from Research articles

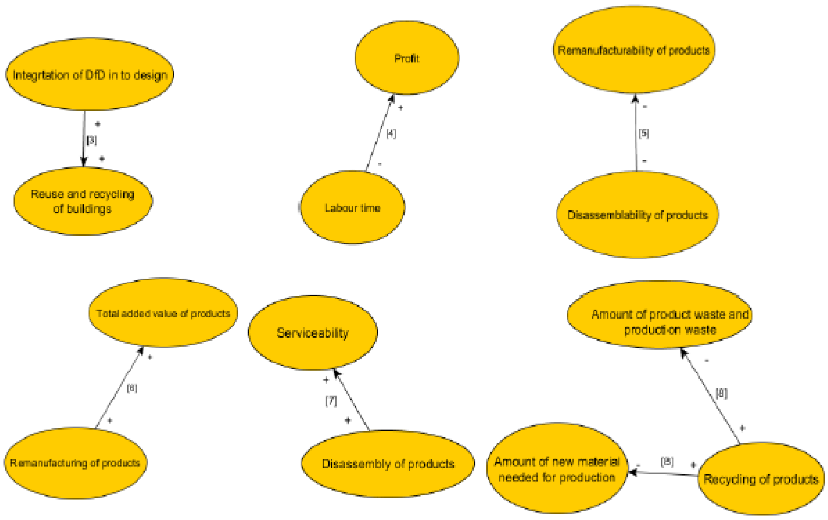

Figure 1 Some of the causal relationships in the form of Reference Models extracted from research articles in the product disassembly field (As per DRM's framework, research articles [3],[4],[5],[6],[7] & [8] are quoted on the links)

In this research, causal relationships were extracted from forty research articles in the area of product disassembly. However, for demonstrating its research approach in this paper, causal relationships extracted from only ten of these articles have been used to generate illustrative Supreme Causal Models used in this paper. These articles were published between 1996 and 2008, covering the following aspects of the research area: integration and optimization of product design for ease of disassembly; Design for Disassembly (DfD) to increase service life of buildings; disassembly process planning; integrated development of assembly and disassembly; enhancing disassembly and recycling planning; evaluation of disassemblability; and development of Design for Remanufacturability guidelines.

The causal relationships are represented in Reference Models, which represent fragments of the existing situation within the research area as reflected in these articles only, since the articles used represent only a section of the state of the art of research in this area (see Appendix 1 for the list of research articles used). “It is important to base the Reference Model on the original statements found in the literature, even if this implies a non-continuous line of argumentation. The Reference Model represents the current understanding as-is” [1]. As per this statement, Reference Models were generated based on the original statements found in the research articles, as shown in Fig.1.

4 Formulation of Supreme Causal Models

4.1 Supreme Reference Model

The individual Reference Models as shown in Fig.1 were collated to form a Supreme Reference Model. The potential individual Reference Models that were to be collated were selected based on a Success Criterion (see Section 3). Each Supreme Reference Model was formulated based on this Criterion. The concept of formulation of Supreme Reference Model from the individual islands of Reference Models based on the Success Criterion is new, and introduced for the first time in this study. This concept is based on the following reasoning: Rather than selecting Reference Models at random, there should be a rationale which should drive the selection of individual Reference Models that are to be collated to form a Supreme Reference Model. Thus, a Success Criterion is chosen such that it is closely equivalent to an objective of a research project. This helps construct the complete Supreme Reference Model based on lines of argumentation that are aligned with the goals of the project. Since desired situations (or goals) could vary based on different perspectives with which the area is approached, Success Criteria should also vary. This should be used proactively to build the Supreme Reference Models. It should also be noted that, in some cases, the Supreme Reference Model contains links on assumptions (see Fig. 3). These links represent causal relationships that are hypotheses, since they are neither validated empirically nor established as original statements in the research articles. In the current study, two Supreme Reference Models (Fig. 2 and 3) were formulated based on two Success criteria: (i) maximizing profit obtained from the End of life phase of a product life cycle; and (ii) minimizing the environmental impact in the Production and End of life phases of the product life cycle.

In Supreme Reference Model 1, most of the Influencing factors were extracted from research article [1], which is quoted on the link as well as shown in Fig. 2. From the figure, it can be seen that Factor “Integration of DfD in to design” has a positive influence on factors such as “Accessibility of parts”, “Efficiency of disassembly operations” and “Probability to meet environmental standards”. Also, the Factor “Integration of DfD in to design” has a negative effect on Factors namely “Complexity of product structure”, “Number of disassembly steps” and “Potential risk of contamination”.

Figure 2 Supreme Reference Model 1

Factor "Efficiency of disassembly operations" in turn has a negative effect on "Disassembly cost" and "Disassembly time". Research articles [4], [2] and [10] helped in identifying causal relationships among Factors such as "Disassembly time", "Degree of automation of disassembly", "Retention of material purity", and the Success Factor "Profit obtained from the End of life phase of a product life cycle.

In Supreme Reference Model 2, causal relationships between Factors such as "Disassemblability of products" and "Remanufacturability of products" were identified from research article [5]. This article also helped in identifying that the Factor "Remanufacturability of products" has a negative influence on the "Use of landfill", "Production of green house gases" and "Level of virgin material and energy used in production", and have positive effects on Factors "Profit" and "Total added value of products" [6]. The existence of a causal relationship between "Remanufacturability of products" and "Production of green house gases" is strongly confirmed by another research article [2], see Fig. 3. It was also found from this article that, "Preservation of functional value of products" tend to reduce the "Impact on environment". Research articles [7] and [8] show respectively the existence of causal relationships between Factors such as "Disassemblability of products" and "Serviceability" and between "Disassemblability of products" and "Recyclability of products". Factor "Recyclability of products" in turn negatively influences "Amount of new material needed in production" and "Amount of product and production waste" [8].

Some of the causal relationships assumed are also shown in Fig. 3. These assumptions were made following the DRM framework, see Section 2.4.1 of [1]. It was identified from research article [3] that, "Integration of DfD in to design" positively influences "Reuse and recycling of buildings". Based on this relationship, an assumption was made and a new causal relationship was established between "Integration of DfD in to design" and "Recyclability of products". Also it was assumed that, improving disassemblability improves the ease of isolation of hazardous components. Based on this assumption, a causal relationship was established between "Disassemblability of products" and "Ease of isolation of hazardous components". Similarly, one more assumption was made and a causal relationship was established between factors "Total added value of products" and "Preservation of functional value of products". In this way, two Supreme Reference Models were built by collating individual Reference Models, each based on a different Success Criterion.

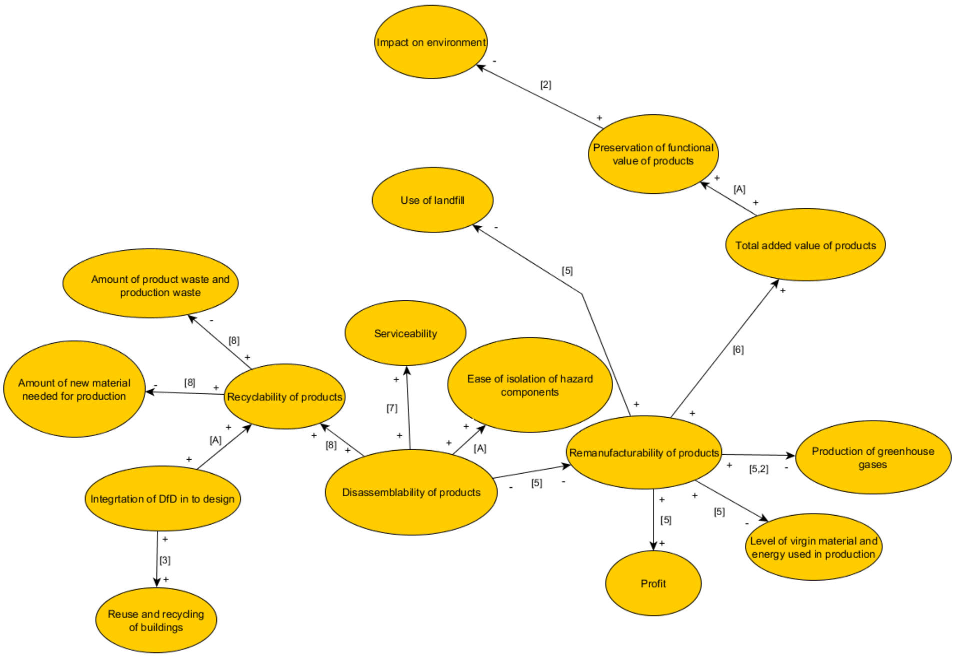

Figure 3 Supreme Reference Model 2

4.2 Supreme Impact Model

Two Supreme Impact Models were then derived, as shown in Fig. 4 and 5, from the two Supreme Reference Models in Fig. 2 and 3. These are Impact Models, describing some of the potential desired situations for product disassembly. Each Supreme Impact Model can be taken as a research project with its corresponding Success Criterion as the research goal. With the help of DRM's Causal Model framework, some of the key Factors and

Proxies identified for two Supreme Impact Models are shown in Table 1. Table 1 also shows the Success Factors and Success Criteria identified while generating the Supreme Reference Models.

The Key Factors helped identify some of the most important parameters influencing product disassembly. Two different pieces of support were intended to be introduced; one for improving the performance of key factor associated with each Supreme Impact Model. Supporting both their key factors should, we assumed, help in achieving both the success criteria: maximizing profit and minimizing environmental impact.

Table 1 Some of the Important Factors of Supreme Impact Models 1 and 2

Supreme Impact Model	Key factor	Proxy	Success Factor	Success criterion
1	Integration of DfD in to design	Disassembly time Disassembly cost	Profit obtained from End of life phase of the product life cycle	maximizing the profit obtained from End of life phase of the product life cycle
2	Disassemblability of products	Use of landfill Production of green house gases	Environmental impact in the Production and End of life phase of the product life cycle	Minimizing the environmental impact in the Production and End of life phase of the product life cycle

Figure 4 Supreme Impact Model 1

In Supreme Impact Model 1, “Integration of DfD in to design” is chosen as the key Factor. It was found from research article [1] (see Appendix 1) that this Factor can influence many other Factors in both positive and negative manners. This reveals the importance of this parameter and thus has been chosen as a Key Factor. Proxies should be chosen as close (i.e. as directly connected) as possible to the Success Factors. The link between Proxy and Success Criteria is assumed to exist either based on existing evidence or based on reasoning (see Section 2.5 in [1]). Based on this guideline from the DRM framework, Proxies such as “Disassembly cost” and “Disassembly time” were chosen in order to closely satisfy the research goal.

“Statements that are found in the literature cannot simply be reversed….”, if reversed it would be an assumption (see Section 2.4.1 in [1]). Based on this guideline, the causal relationship between Factors “Number of components” and “Disassembly cost” is marked as an assumption. Factor “Modularisation” is added to Supreme Impact Model 1, since it is assumed that “Integration of DfD in to design” will improve “Modularisation” and this in turn will minimize the “Complexity of product structure”. The relationship ‘Reduction of “Disassembly cost” will increase “Profit”’ link is marked as [O], which implies that this relationship is established based on one’s own investigation (as per DRM guideline given in Section 2.4.1 in [1]).

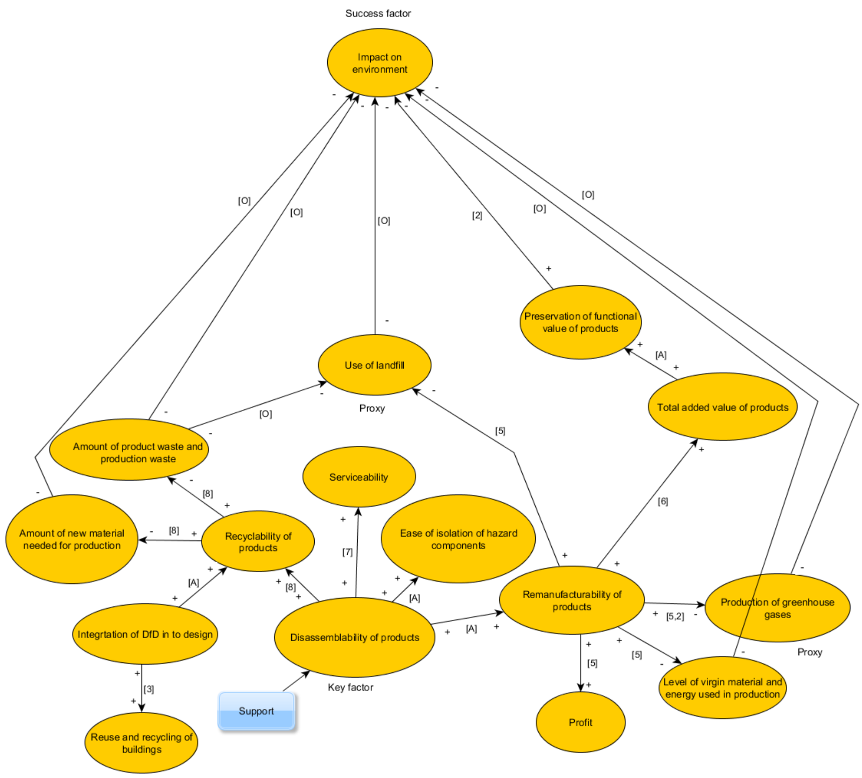

Figure 5 Supreme Impact Model 2

In Supreme Impact Model 2, all the Factors were retained from Supreme Reference Model 2. “Disassemblability of products” was chosen as the Key Factor, for the following reason: (i) this is one of the most important parameters of the product disassembly field, and (ii) enhancing the performance of this factor will improve the performance of many other important aspects of the situations of the research field.

Six new links were added to the Model based on our own investigation (Fig. 5). Among these links, five are causal relationships established between Success Factor “Impact on Environment” and the remaining five factors which include two Proxies: “Use of landfill” and “Production of greenhouse gases”.

Of the six Factors that are directly linked to the Success Factor, “Use of landfill” and “Production of greenhouse gases” were chosen as Proxies, since Proxies should be chosen such that they should be measurable quantities, i.e. able to be assessed within the time scale of the project. The sixth link is established between “Amount of product waste and production waste” and “Use of landfill”, based on our own investigation.

5 Discussions and Conclusions

We argue that the work reported in this paper enriches the canon of DRM framework by introducing two new supporting elements. One is the concept of “Supreme Causal Model”, which integrates multiple, individual Causal Models. Supreme Causal Models give insights into the various important parameters influencing product disassembly, and how they influence one another. The second element is the use of Success Criterion to select individual Reference Models and construct Supreme Causal Models. Using DRM’s Causal Models, various aspects of the existing situation and potential desired situations for product disassembly have been identified. These need not be the only desired situations in this area. In our study, two Supreme Causal Models have been formulated based on two separate Success Criteria. More such Models could be formed if Success Criteria were altered around other Success Factors.

Using this approach, the major results obtained in the area of product disassembly are: (i) the individual Reference Models and (ii) the two Supreme Reference Models and two Supreme Impact Models reflecting some aspects of the existing and desired situations in this area. Also, several important parameters within the area were identified: Disassemblability of products and Efficiency of disassembly operations. They influence various other important parameters such as Remanufacturability, Recyclability, Serviceability, Disassembly time, Disassembly cost, and Integration of DfD into design. The last factor influences Accessibility, Complexity of product structure, Disassembly steps, Probability to meet standards, and Material contamination.

Use of the DRM’s Causal Model brings two major benefits. The first is that this Model works on the concept of causality. The relationships among important parameters of the field have been understood less ambiguously with the help of causality. Thus, with a higher confidence level, the existence of such Causal relationships could be confirmed. This helped in carrying out research on identifying and resolving current issues associated with the area in a focused manner. The second benefit is that, as per DRM’s framework, these Causal relationships in the research articles are represented in a graphical form (See Fig. 1), which made them more readable and easier to understand.

Several difficulties were also faced in using the Causal Models. One was to identify whether a Causal relationship belonged to an existing or a desired situation. Unless the context was thoroughly understood, it was difficult to place them in the right (Reference or Impact) Causal Model. Another difficulty was in selecting individual Reference Models to be included in a Supreme Model. Since, the long and in some cases, the indirect chain of links in the Supreme Model should be known in order to include the appropriate individual Reference Models. Care should be taken not to leave any important Factor while selecting individual Reference Models in formulating Supreme Causal Models. It is better to include all the factors that are linked to the important factors in a Supreme Causal Model while formulating that Model.

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APPENDIX 1 (References as marked on Links (see Fig. 1, 2, 3, 4 & 5)

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