Assessment of hierarchy and inter-relationships of barriers to environmentally conscious manufacturing adoption

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Abstract

Purpose – The purpose of this paper is to develop hierarchy and inter-relationship among barriers to environmentally conscious manufacturing (ECM) adoption using an interpretive structural modeling (ISM) technique. The paper will demonstrate how ISM supports policy makers in the government and industry in identifying and understanding interdependencies among barriers to ECM. Interdependencies among barriers will be derived and structured into a hierarchy in order to derive subsystems of interdependent elements with corresponding driving power and dependency.

Design/methodology/approach – ISM was used to identify hierarchy and inter-relationships among barriers to ECM adoption and to classify the barriers according to their driving and dependence power using MICMAC analysis. The barriers to ECM adoption are identified through the review of literature followed by developing a model of barriers using ISM based on the inputs from experts from industry and academia.

Findings – The main findings of the paper include the development of hierarchy and inter-relationship and ISM model of barriers to ECM adoption. The developed model divided the identified barriers into five levels of hierarchies showing their inter-relationship depicting the driving-dependence relationship. These five levels have been classified into three categories – internal barriers, economy barriers, and policy barriers category.

Originality/value – The developed ISM model is expected to provide a direction to the policy makers in the government and industry and the top management of the organizations to leverage their resources in timely manner to adopt ECM successfully.

Keywords Interpretive structural modelling, ECM barriers, Environmentally conscious manufacturing

Paper type Research paper

1. Introduction

Manufacturing firms consume natural resources in highly unsustainable manner and release large amounts of green house gases leading to many economic, environmental, and social problems from global warming to local waste disposal (Sangwan, 2011). But the growth of manufacturing industry is essential, particularly in the developing and emerging economies as this provides direct and indirect employment to the rising population. This leads to the improvement in quality of life and prosperity in poor and developing countries. The rising world population and the improving living standards in developing countries have put pressure on the industry to grow which has impacted the environment not only in these countries but globally. The emerging countries like India and China have accelerated the industrial environmental impact through their high economic growth. This is expected to continue until people in developing countries have a decent living standard. Therefore, there is a strong need, particularly, in emerging and developing economies to improve manufacturing performance so that there is less industrial pollution, less material and energy consumption, less wastage, etc. One such potential system is environmentally conscious manufacturing

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(ECM). It consists of methods and tools to achieve sustainable production through process optimizations across the supply chain with environmental costs in mind (IEA, 2007). This paradigm shift to newer manufacturing system is urgently required in emerging countries like India and China to balance their economic growth *vis-à-vis* ecological balance. The industry is well aware of its responsibility toward environment and society but there are some factors that hinder the adoption of ECM (Singh, 2010).

This study aims at finding ECM barriers and developing a structural model to obtain hierarchy and inter-relationship among these barriers. These relationships are expected to help in mitigating these barriers strategically within limited resources. In this paper, 12 barriers to ECM, found from literature, are modeled using interpretive structural modeling (ISM) technique to establish the hierarchy and inter-relationship among these barriers for successful adoption of ECM. The paper is structured as follows: next section focusses on literature review. Section 3 presents development of ISM model of ECM barriers. The results and discussion of the model are presented in Section 4. The conclusions are given in Section 5.

2. Literature review

In the last decade, several studies have investigated the barriers hindering the adoption of ECM under various synonymous names like green manufacturing, sustainable manufacturing, cleaner production (CP), etc. Wang *et al.* (2008) identified 13 barriers to energy saving in China through the review of literature and opinion of experts from energy industry and academia. Veshagh and Li (2006) examined the status of eco-design and manufacturing in automotive SMEs of UK through a questionnaire designed to identify the barriers faced by SMEs in their move toward greater sustainability in automotive product design and manufacture. Later, Yu *et al.* (2008) identified six barriers to eco-design in Chinese electrical and electronics companies. However, these studies are conducted with limited scope of energy savings and eco-design adoption in industry instead of holistic approach of ECM, which covers the whole life cycle of the products and processes.

Studer *et al.* (2006) analyzed barriers to engage Hong Kong businesses with voluntary environmental initiatives. Zhang *et al.* (2009) pointed out ten barriers to engage enterprises in environmental management initiatives in China through a questionnaire survey. Nevertheless, the strategies are limited either to a partial environmental initiatives or compliance of management initiatives only.

Shi *et al.* (2008) applied an analytic hierarchy process to examine and prioritize underlying barriers to adoption of CP by SMEs in China from the perspectives of government, industry, and expert groups. Cooray (1999) summarizes the SME-specific barriers to implement CP schemes in Sri Lankan SMEs through an industrial survey of food and beverages, hospitality, and steel industries. Zhang (2000) identified barriers to CP promotion in China through a CP demonstration program. Montalvo (2008) presents a selective survey of papers from 1997 to 2007 representing the general wisdom concerning the factors affecting adoption, diffusion, and exploitation of cleaner technologies. Yuksel (2008) identified barriers to implementation of CP practices in Turkey through the well-designed questionnaire survey of 105 large firms. Mitchell (2006) explored why CP has not been widely adopted by industry in Vietnam, despite the promotion of CP by government, academia, and research institutions. Siaminwe *et al.* (2005) identified 11 barriers hindering the process of CP implementation in Zambian industry. It was realized that large number of studies were conducted in emerging nations of Asia focussing on CP only. Although the studies conducted on CP strategies adoption, but all the studies lacked the development of model of relationship and hierarchy among various barriers, which is a vital issue in the mitigation of barriers to ECM.

Luken and Van Rompaey (2008) illustrated the findings of a survey in nine developing countries across four manufacturing sub-sectors on factors affecting environmentally sound technology adoption. Seidel *et al.* (2009) described the barriers faced by SMEs in moving toward environmentally benign manufacturing. Recently, Singh *et al.* (2012) identified 12 barriers affecting green manufacturing practices from the survey of Indian industry. Although the studies were conducted on the holistic approach of ECM, but again lacked the establishment of inter-relationship and hierarchy among various barriers. This provided the research gap to fill by the development of ISM model of barriers to ECM adoption.

There are three types of research gaps in the study of barriers to ECM. One, the studies have limited scope in term few aspects of ECM like energy conservation or eco-design adoption and do not consider important aspects of ECM like pre-manufacturing, transportation, use, and end-of-life phases of the products. Second, there is need to converge the study on barriers as each study in literature investigated different barriers, industry sectors, and different geographical areas of the world. Third, there is no study providing the hierarchy and inter-relationship among the barriers so that government and industry can focus on few critical root barriers. This study aims at removing this third gap in the literature. The 12 barriers to ECM are identified through a review of literature on ECM barriers as shown in Table I.

Sl. no.	Barriers	Description
1	High short-term costs	High costs of buying newer efficient technology and its implementation
2	Uncertain benefits	Uncertainty of achievable benefits after making huge investments in newer technologies
3	Technology risk	State of the art technologies, materials, operations, and industrial processes are often not easily and cheaply available to the company
4	Low top management commitment	Low top management commitment deterring ability to influence, support and champion the actual formulation and deployment of environmental initiatives across the organization
5	Lack of organizational resources	Limited technical and human resources affect the ability of firms to adopt new practices like environmentally conscious manufacturing
6	Lack of awareness/ information	Insufficient information about the available technology choices and limited access to green literature or the information diffusion
7	Weak legislation	Complete absence of environmental laws or complex and ineffective environmental legislations
8	Low enforcement	Ineffective enforcement of environmental laws because of lack of organizational infrastructure, lack of trained human resources, cost of monitoring, and dishonest officials, etc.
9	Uncertain future legislation	Possibility of upcoming legislations with unforeseen impacts on the huge investments on newer technologies
10	Trade-offs	Outsourcing of dirty manufacturing work to developing or emerging markets where environmental laws are less stringent which reduces company's share of emissions
11	Low public pressure	The absence of pressure by key social actors like local communities, media, NGOs, banks, insurance companies, or politicians
12	Low customer demand	Low customer demand for environment friendly products and processes because of price-sensitive and uninformed customers

Table I.
Description of barriers to ECM adoption

3. Development of ISM model of ECM barriers

ISM is an interactive learning process whereby a set of different directly and indirectly related elements are structured into a comprehensive systemic model. The model so formed portrays the structure of a complex issue in a carefully designed pattern employing graphics as well as words (Sage, 1977; Jharkharia and Shankar, 2005).

ISM methodology helps to impose order and direction on the complexity of relationships among elements of a system for complex problems like the one under consideration (Sage, 1977). However, the direct and indirect relationships between the barriers describe the situation far more accurately than the individual factor taken into isolation. Therefore, ISM develops insights into collective understandings of these relationships.

The ISM is interpretive as the judgment of the group decides whether and how the variables are related (Sage, 1977; Mandal and Deshmukh, 1994). It is structural as on the basis of relationship an overall structure is extracted from the complex set of variables. Developing inter-relationships among variables through the expert opinion has been used and recommended by many researchers (Singh *et al.*, 2003, 2007; Luthra *et al.*, 2011). It is a modeling technique as the specific relationships and overall structure are portrayed in a graphical model. It is primarily intended as a group learning process but can also be used individually. The various steps involved in the ISM methodology are (Ravi and Shankar, 2005):

- *Step I*: identify the elements, which are relevant to the problem or issue, this could be done by a literature survey or any group problem-solving technique.
- *Step II*: establish contextual relationship among elements.
- *Step III*: develop a structural self-interaction matrix (SSIM) of elements indicating pair-wise relationship among elements of the system.
- *Step IV*: develop a reachability matrix from the SSIM, and checking the matrix for transitivity.
- *Step V*: level partition the reachability matrix into different levels and draw ISM model.

Lastly, review of the ISM model to check for conceptual inconsistency and make the necessary modifications. The following shows the development of an ISM of 12 barriers to ECM adoption in industry.

Step I: identification of ECM barriers

In total, 12 barriers to ECM adoption (Table I) have been identified through the review of literature (Koho *et al.*, 2011; Sangwan, 2006, 2011; Massoud *et al.*, 2010; Herren and Hadley, 2010; Wang *et al.*, 2008; Yu *et al.*, 2008; Shi *et al.*, 2008; Cooray, 1999; Zhang *et al.*, 2009; Luken and Van Rompaey, 2008; Montalvo, 2008; Studer *et al.*, 2006; Siaminwe *et al.*, 2005; Moors *et al.*, 2005; Mittal *et al.*, 2012, 2013; Dwyer, 2007; Ioannou and Veshagh, 2011; Zhu and Geng, 2013; Del Río *et al.*, 2010; Schönsleben *et al.*, 2010; Del Río González, 2005; Mittal and Sangwan, 2011; Seidel *et al.*, 2009; Veshagh and Li, 2006; Singh *et al.*, 2012; Mitchell, 2006; Kaebernick and Kara, 2006; Zhang, 2000).

Step II: SSIM

Experts from the Indian industry and academia were consulted in identifying the nature of contextual relationships (see Table II) among the barriers though ISM methodology suggests the use of expert opinions alone based on management

Sl. no.	Barriers	Barriers 2	3	4	5	6	7	8	9	10	11	12
1	Weak legislation	V	V	X	V	V	X	V	X	V	V	A
2	Low enforcement		O	A	O	V	A	V	A	V	V	A
3	Uncertain future legislation			A	O	V	A	V	A	V	V	A
4	Low public pressure				V	V	X	V	X	V	V	A
5	High short-term costs					V	A	V	A	V	V	A
6	Uncertain benefits						A	X	A	X	V	A
7	Low customer demand							V	X	V	V	A
8	Trade-offs								A	X	V	A
9	Low top management commitment									V	V	A
10	Lack of organizational resources										V	A
11	Technological risk											A
12	Lack of awareness/information											

Table II.
Structural self-interaction matrix (SSIM)

techniques such as brain storming, nominal group technique, etc. For analyzing the barriers in developing SSIM, the following four symbols have been used to denote the direction of relationship between barrier i and j: V = Barrier i will help achieve barrier j; A = Barrier j will be achieved by barrier i; X = Barrier i and j will help achieve each other; O = Barrier i and j are unrelated.

Step III: initial reachability matrix

The SSIM has been converted into a binary matrix called the initial reachability matrix by substituting V, A, X, and O by 1 and 0 as per the following rules (see Table III):

- If the (i, j) entry in the SSIM is V, the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry becomes 0.
- If the (i, j) entry in the SSIM is A, the (i, j) entry in the reachability matrix becomes 0 and the (j, i) entry becomes 1.
- If the (i, j) entry in the SSIM is X, the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry also becomes 1.
- If the (i, j) entry in the SSIM is 0, the (i, j) entry in the reachability matrix becomes 0 and the (j, i) entry also becomes 0.

Sl. no.	Barriers	Barriers 1	2	3	4	5	6	7	8	9	10	11	12
1	Weak legislation	1	1	1	1	1	1	1	1	1	1	1	0
2	Low enforcement	0	1	0	0	0	1	0	1	0	1	1	0
3	Uncertain future legislation	0	0	1	0	0	1	0	1	0	1	1	0
4	Low public pressure	1	1	1	1	1	1	1	1	1	1	1	0
5	High short-term costs	0	0	0	0	1	1	0	1	0	1	1	0
6	Uncertain benefits	0	0	0	0	0	1	0	1	0	1	1	0
7	Low customer demand	1	1	1	1	1	1	1	1	1	1	1	0
8	Trade-offs	0	0	0	0	0	1	0	1	0	1	1	0
9	Low top management commitment	1	1	1	1	1	1	1	1	1	1	1	0
10	Lack of organizational resources	0	0	0	0	0	1	0	1	0	1	1	0
11	Technological risk	0	0	0	0	0	0	0	0	0	0	1	0
12	Lack of awareness/information	1	1	1	1	1	1	1	1	1	1	1	1

Table III.
Initial reachability matrix

Step IV: final reachability matrix

The final reachability matrix (Table IV) is developed from the initial reachability matrix after incorporating the transitivities as discussed previously in this section. Transitivity of the contextual relation is a basic assumption in ISM which states that if element A is related to B and B is related to C, then A is necessarily related to C. The driving power and dependence of each barrier are also shown in Table IV. Driving power for each barrier is the total number of barriers (including itself), which it may help achieve. On the other hand dependence is the total number of barriers (including itself), which may help achieving it. The driving power and dependency will be used later in the classification of barriers.

Step V: level partitions

From the final reachability matrix, the reachability and antecedent sets for each barrier are found. The reachability set consists of the element itself and other elements, which it may help achieve, whereas the antecedent set consists of the element itself and the other elements, which may help achieving it. Next, the intersection of these sets is derived for all elements. The element for which the reachability and intersection sets are same is the top-level element in the ISM hierarchy. The top-level element of the hierarchy would not help achieve any other element. Once the top-level element is identified, it is separated out from the other elements. This process continues till all elements are assigned levels. The identified levels help in building the final model. In the present case the barriers along with their reachability set, antecedent set, intersection set, and the levels are shown in Table V.

Step VI: ISM-based model building

The structural model is generated by means of vertices/nodes and lines of edges. A relationship between the barriers *j* and *i* is shown by an arrow which points from *i* to *j* or *j* to *i* depending upon the driver-driven relationship between *i* and *j* as discussed above. ISM model developed after removing the transitivities as described in ISM methodology is shown in Figure 1.

All the 12 barriers to ECM adoption have been divided into five levels. These barriers can be classified into three categories namely internal barriers, economy

Table IV.
Final reachability matrix

		Barriers												
Sl. no.	Barriers	1	2	3	4	5	6	7	8	9	10	11	12	Driving power
1	Weak legislation	1	1	1	1	1	1	1	1	1	1	1	0	11
2	Low enforcement	0	1	0	0	0	1	0	1	0	1	1	0	5
3	Uncertain future legislation	0	0	1	0	0	1	0	1	0	1	1	0	5
4	Low public pressure	1	1	1	1	1	1	1	1	1	1	1	0	11
5	High short-term costs	0	0	0	0	1	1	0	1	0	1	1	0	5
6	Uncertain benefits	0	0	0	0	0	1	0	1	0	1	1	0	4
7	Low customer demand	1	1	1	1	1	1	1	1	1	1	1	0	11
8	Trade-offs	0	0	0	0	0	1	0	1	0	1	1	0	4
9	Low top management commitment	1	1	1	1	1	1	1	1	1	1	1	0	11
10	Lack of organizational resources	0	0	0	0	0	1	0	1	0	1	1	0	4
11	Technological risk	0	0	0	0	0	0	0	0	0	0	1	0	1
12	Lack of awareness/information	1	1	1	1	1	1	1	1	1	1	1	1	12
Dependence		5	6	6	5	6	11	5	11	5	11	12	1	84

Iteration	Barrier	Reachability set	Antecedent set	Interaction set	Level
1	11	11	1,2,3,4,5,6,7,8,9,10,11,12	11	V
2	6	6,8,10	1,2,3,4,5,6,7,8,9,10,12	6,8,10	IV
2	8	6,8,10	1,2,3,4,5,6,7,8,9,10,12	6,8,10	IV
2	10	6,8,10	1,2,3,4,5,6,7,8,9,10,12	6,8,10	IV
3	2	2	1,2,4,7,9,12	2	III
3	3	3	1,3,4,7,9,12	3	III
3	5	5	1,4,5,7,9,12	5	III
4	1	1,4,7,9	1,4,7,9,12	1,4,7,9	II
4	4	1,4,7,9	1,4,7,9,12	1,4,7,9	II
4	7	1,4,7,9	1,4,7,9,12	1,4,7,9	II
4	9	1,4,7,9	1,4,7,9,12	1,4,7,9	II
5	12	1,4,7,9,12	12	12	I

Table V.
Level partitions

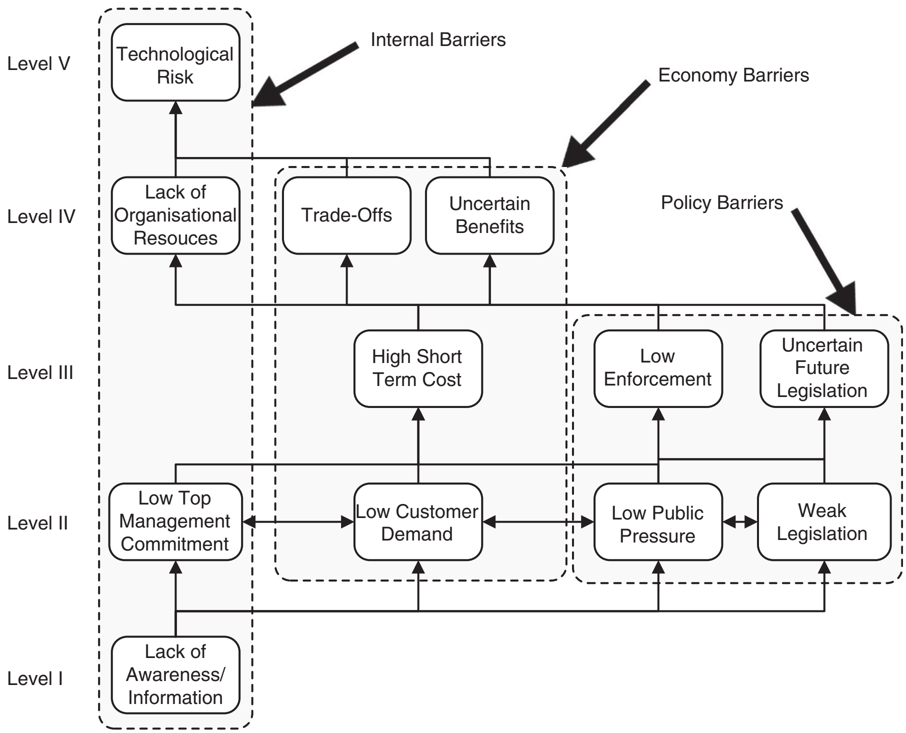

Figure 1.
ISM model of barriers to ECM adoption

barriers, and policy barriers, where internal barriers refer to the barriers which are internal to the organization in terms of awareness/information, commitment, and resources in ECM adoption; economy barriers refer to the barriers which are related to the economy of the organization and affect the organization in economic terms whether it is about the direct financial resources required to implement the ECM or indirect economic losses from technology failure; and policy barriers refers to the barriers which deal with the government and organizational policies affecting ECM adoption.

Next, barriers are classified into four clusters – autonomous barriers, dependent barriers, linkage barriers, and driver barriers as shown in Figure 2. Autonomous barriers (first cluster) have weak driving power and weak dependence, so these drivers are generally disconnected from the system. The second cluster is named dependent barriers. These barriers have weak driving power and strong dependence power. Four barriers namely uncertain benefits, trade-offs, lack of organizational resources, and technological risk belong to this cluster.

The third cluster is named as linkage barriers having strong driving power and strong dependence power. In this study, no barrier lies in this cluster. The fourth cluster is named as driving barriers which has strong driving power and weak dependence power. Five barriers namely weak legislation, low public pressure, low customer demand, low top management commitment, and lack of awareness/information belong to this cluster.

4. Results and discussion

The developed ISM model consists of five levels of hierarchy as shown in Figure 1. The first level, consisting of lack of information and awareness among the public, government, and industry is the root barrier to ECM adoption and implementation which in turn influences the public pressure, customer demand, top management commitment, and legislative structure. This barrier has strong driving power and weak dependence. Scarcity of general awareness alleviates the lack of pressure from public to incorporate environmental thinking in manufacturing. It also alleviates the lack of demand from the customer which forces the industry to manufacture environmentally conscious products and lack of management commitment to use environmentally conscious technologies for production. The lack of information and awareness among governments leads to insufficient legal structure which is essential to force the industry to manufacture in most ecological way. The third level consists of high short-term cost, low enforcement, and uncertain future legislation. The high short-term cost of switching over to newer energy efficient and pollution free technologies, the low enforcement of existing regulations at

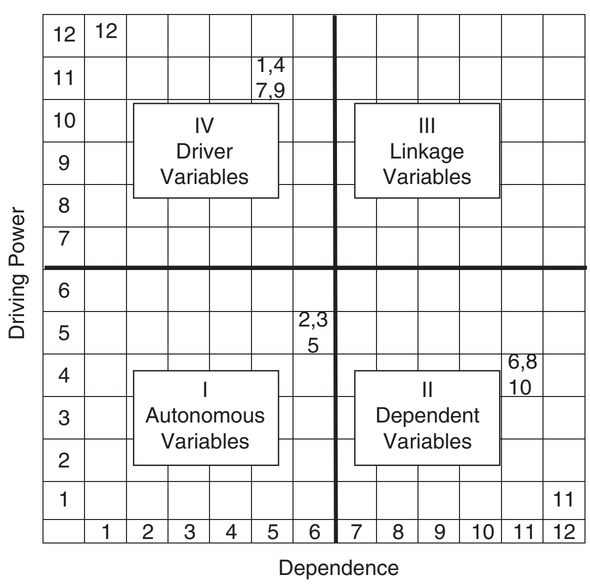

Figure 2.
MICMAC analysis

ground level, and uncertainty among industries for any legislation which may appear in future are level II barriers. Lack of organizational resources in terms of finance, technology and human resources, trade off's, and uncertain benefits of ECM technologies are level IV barriers to ECM adoption. Generally, any new technology has its own risk depending upon the maturity level. Hence, technology risk is level V barrier.

Although, three barriers, namely low enforcement, uncertain future legislation, and high short-term cost lies in autonomous cluster, but these barriers lie exactly on the line dividing the clusters 1 and 2, so these barriers have properties of the barriers of cluster 2 also. Higher value of "dependence" for a barriers means that other barriers in the network are to be addressed first. High value of "driving force" of a barriers means that these barriers are to be addressed before taking up the other barriers.

5. Conclusions

In this paper, a model of 12 barriers; identified from the review of literature; for the successful adoption of ECM has been developed using ISM technique. The developed model divided the identified barriers into five levels of hierarchies showing their inter-relationship and depicting the driving-dependence relationship. These five levels have been further classified into three categories – internal, economy, and policy barriers. The developed ISM model is expected to provide a direction to the policy makers in the government and industry and the top management of the organizations to mitigate the barriers by focussing on few root barriers which directly or indirectly mitigate other barriers.

However, the ISM model is developed through the input of experts from an emerging economy. The model needs to be tested by the input of experts from different countries under different situations. Further, the model can be tested for different segments of industry.

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