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*Multi-objective decision modeling using Interpretive Structural Modeling(ISM) for Green Supply Chains*

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**Abstract**

*Determining key variables, which an organization can opt to initiate green supply chain activities with a motive to improve overall performance is a challenge. Therefore this paper provides a multi-objective decision model using interpretive structural modeling (ISM) based approach to enrich and initiate the green supply chain activities in an organization. Variables such as supplier commitment, cost, regulations etc. have been identified and categorized under enablers and capacity utilization, customer satisfaction, energy consumption etc. under results. These enablers help to boost the GSC (Green Supply Chain) variables, while results variables represent outcomes. Finally, paper interprets GSC variables in terms of their driving and dependence powers that have been carried out.*

**Keywords:** *Green supply chain (GSC), Interpretive Structural Modeling (ISM), reverse logistics, sustainable development*

## **1. Green supply chain (GSC)**

Some of the earliest work that can be tied to the today's greening of the supply chain towards sustainable development, occurring even before the formation of the U.S. Environmental Protection Agency, can be traced to (Ayres, 1978). This work presented some of the earliest issues related to reconciling industrial metabolism and material balancing as well as the roles of production and consumption in the supply chain. Although their work focused on a linear relationship from an extraction to disposal, some loops were incorporated into the evaluation and there were concerns about the possibility of integrating 'residuals' back into the system. Interestingly, not only were solid and water pollution waste included in the discussion, but warnings of global climate change due to carbon and other greenhouse gas emissions was also prevalent in the argumentation on evaluating the roles of inter-organizational relationships.

Further refinement of the industrial metabolism and material flow balance ideas occurred throughout the 1970s (Ayres, 1978). Discussion on how to utilize the mass balance for organizational and governmental decision making was also introduced in the early 1970s through “a process-chain evaluation model estimates the cumulative costs (direct and hidden) of various processes or steps that form ‘chains’ leading from a set of raw material inputs to a marketable output, such as semi- finished or consumer products”. (Stern et al.,1973). This work incorporated inventories of pollutants and their impacts in the decision modeling software, not unlike most of the today’s life cycle analytical tools.

Many researchers have defined a green supply chain in various manners using different terms. Some studies defined it as a closed loop supply chain (van Hoek, 1999; Beamon, 2005; Steven, 2004; Inderfurth, 2004; Spengler et al., 2004; Zhu and Sarkis, 2006). It has been described as a sustainable supply chain by Linton et al. (2007) and Beamon (2005). Some have called it as an environmental supply chain (Hall, 2000; Beamon, 2005), ethical supplychain (Roberts, 2003; Beamon, 2005), and integrated supply chain (Vachon and Klassen, 2008, Wadhwa et al., 2009b). The growth in this green supply chain literature extends back to the early 1990s with the advent of corporate environmental management, environmentally conscious manufacturing strategy, and i.e. “environment”. Green supply chain management is thus defined as the totality of green purchasing, green manufacturing and material management, green distribution and marketing, and finally reverse logistics (Hervani et al., 2005; Linton et al., 2007; Zhu and Sarkis, 2006). This is in line with the explanation given by Vachon and Klassen (2008) that suppliers, manufacturers and customers should work together towards the reduction of environmental impact from production processes and products. The schematic of the material flow and the echelons involved in a green supply chain is presented in Fig. 1. Reverse logistics is highlighted

as making the forward supply chain becomes a closed loop Which takes into consideration the reuse, remanufacturing, and recycling of materials into new materials or other products (Tsouflias and Pappis, 2008). Sabri and Beamon (2000) stated that following the nature of the chain, any factor which affects any particular element in the chain will be extended to the rest of the chain. Bond (1999) posited that performance measurement has the benefits of stabilizing the green supply chain and identifying areas for further improvement within the system that leads to sustainable development.

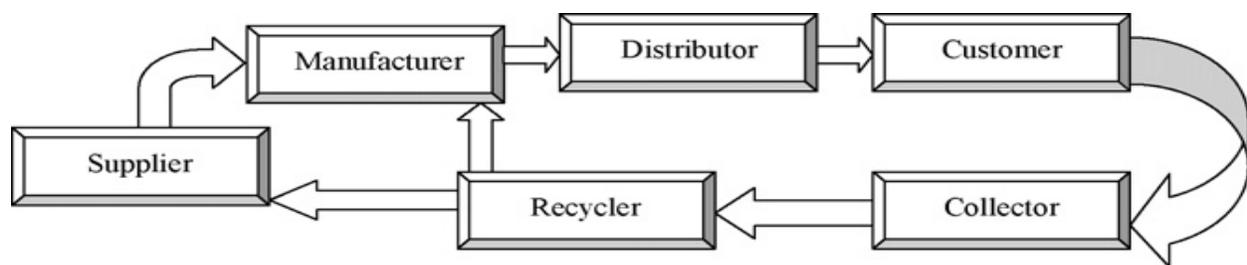


Fig.1 Green Supply Chain

Olugu and Wong(2009) expatiated that measuring the performance of a green supply chain will also reveal whether there is a need for an organization to continue with its current strategy or to adopt a re-engineering of its strategy. Moreover green supply chains are more complicated since return flows may include products, subassemblies and/or materials and may enter the forward supply chain in several return points. the collection, inspection/separation, reprocessing (direct reuse, recycling, repair, remanufacturing), disposal and re-distribution of used products as the main operations of a reverse channel. Here is focus on a single product closed-loop supply chain which includes the following distinct operations: supply, production, distribution, use, collection (and inspection), recycling and disposal. The forward supply chain includes two echelons (producer and supply chain management literature Zhu and Sarkis, 2006, Wadhwa et. al. 2009 a). It was also termed as a socially responsible supply chain (Salam, 2009) and the list can continue.

Irrespective of the nomenclature adopted, the bottom line remains the same, awareness and recycling regulations have been putting pressure on many manufacturers and consumers, forcing them to produce and dispose of products in an environmentally responsible manner.

## **2. Problem definition**

While many case studies exist exploring barriers in Mexico (Miraftab, 1997), India (Kudva, 1996), and Indonesia (Walker, 1996) among others, ISM-based case studies from the aid organization perspective are limited. Here the organization under study is engaged in the manufacturing of various kinds of Paper in northern India. The company produces Kraft Paper and Writing & Printing Paper Kraft Paper finds its application in the packaging Industry especially for making Corrugated Boxes / Cartons and for other packaging requirements. The firm is well-known in India as a Kraft Paper manufacturer. The special feature of its Kraft Paper is loaded bearing Capacity and tensile Strength which makes its most suitable for corrugated packing application. Writing and Printing Paper is used for multiple purposes. The identification of the variables that are at the root of some more variables (called driving barriers) and those which are most influenced by the others (called driven barriers) would be helpful for the top management implementing the green supply chain programs (Diabata & Kannan, 2011). This can be a guide for taking appropriate action to tackle barriers in green supply chain. Interpretive Structural Modeling (ISM) can be used for identifying and summarizing relationships among specific variables which define a problem or an issue (Ravi V & Shankar R 2005). Therefore, in this paper, various variables categorized under enablers and result outcomes of the green supply chain in pulp & paper industries have been analyzed using the ISM methodology, which shows the interrelationships of the barriers and their levels. These variables are also categorized depending on their driving power and dependence. After review of literature on green supply

chain and the opinion of experts, both from paper mill industries and the academia, 14 important variables of green supply chain have been identified. The literature review, together with the experts' opinion, was used in developing the relationship matrix, which is later used in the development of an ISM model. The major variables involved in this study are listed in Table 1 & Table 2 as below:-

Table 1, List of performance focused enablers/barriers in GSC

S.NO.	ENABLERS/BARRIERS	SOURCES
1	Supplier commitment	Zhu and Sarkis (2006), Zhu et al. (2008c), Lippmann (1999), Vachon and Klassen(2008), Lippman (2001) and Hu and Hsu (2006)
2	Cost	Carter, C.R. and Ellram, L.M. (1998)
3	Regulations	Green et al. (1998), Beamon (2005), Hall (2000), and Walker et al. (2008)
4	Environmental issue	Srivastara, S. K. (2007)
5	Industry Specific Barriers	Wei, ZH., 2004 and Srivastara, S. K. (2007)
6	Market edge	Georgiadis, P., Vlachos, D. (2009)
7	Customer Redundancy	Wells P, Seitz M. (2005)

Table 2, List of results/outcome in GSC

S.NO.	RESULTS	SOURCES
8	Green Products	Zhu et al. (2008c), Hu and Hsu (2006), Routroy (2009) and Zhu and Sarkis (2006)
9	Capacity Utilization	Vlachos, D., Georgiadis, P., Iakovou., E. (2006).
10	Customer Satisfaction	Zhu et al. (2008c), Paulraj (2009), and Vachon and Klassen (2008)
11	Environmental Benefits	Green et al. (1998)
12	Energy consumption reduction	Rao and Holt (2005), Holt and Ghobadian (2009), Paulraj (2009)
13	Processing time	Fleischmann M, Beullens (2001)
14	Green Productivity & efficiency	Vlachos, D., Georgiadis, P., Iakovou., E. (2006)

### 3. Interpretative Structural Modeling(ISM) as Multi Criteria Decision Modeling Tool:

Interpretive structural modeling (ISM) is an interactive learning process in which a set of different and directly related elements is structured into a comprehensive systemic model Warfield (1974) & Sage (1977). ISM can be used extensively in identifying and analyzing interactions among the barriers (or elements) of a system. Malone (1975) first demonstrated the use of ISM in analyzing the barriers for investment for an urban city. Mandal and Deshmukh (1994) used ISM models to identify vendor selection criteria. Singh and Kant (2008) used ISM model to study the barriers in knowledge management in certain manufacturing industries. Ravi and Shankar (2005) applied ISM to analyze the barriers in the reverse logistics supply chain in India. Wang et al. (2008) used ISM in analyzing barriers to energy saving in China. Kannan and Haq, (2007) presented an integrated supplier selection and multi-echelon distribution inventory model in a built-to-order supply chain environment using fuzzy AHP and genetic algorithm. Kannan and Haq, (2007) proposed a structured model for evaluating vendor selection using AHP and fuzzy AHP, proposed a structured model for evaluating vendor selection using AHP and fuzzy AHP. The model so formed portrays the structure of a complex issue or problem, a system or a field of study, in a carefully designed pattern implying graphics as well as words. Interpretive structural modeling (ISM) helps in identifying the inter-relationships among variables. It is a suitable modeling technique for analyzing the influence of one variable on other variables. It provides systemic approach for improving supply chain agility. ISM is primarily intended as a group learning process. The method is interpretive as the judgment of the group decides whether and how the variables are related. It is structural as on the In this work, interpretive structural modeling (ISM) has been applied to develop a framework for a case supply chain to achieve the following broad objectives:

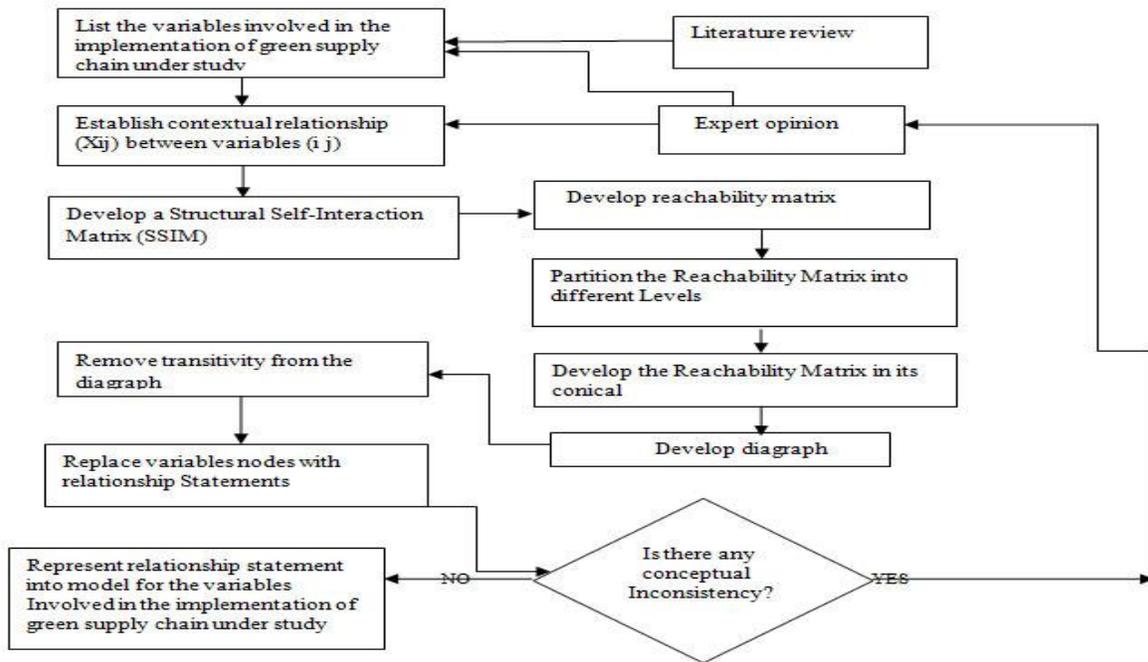
1. to derive interrelationships among the variables affecting green supply chain

2. to classify the these variables according to their driving and dependence power

On basis of relationship, an overall structure is extracted from the complex set of variables. It is a modeling technique as the specific relationships and overall structure is portrayed in a digraph model. ISM starts with an identification of variables, which are relevant to the problem or issue and then extends with a group problem-solving technique ISM methodology helps to impose order and direction on the complexity of relationships among elements of a system

### **3.1 ISM methodology and model development**

The various steps involved in the ISM methodology are given below (Kannan and Haq, 2007 and Kannan et al., 2009). The flow chart for the ISM methodology is shown in Fig. 2. Step 1: The variables affecting the green supply chain for the firm under study are listed. Step 2: For each pair of variables identified in Step 1, a contextual relationship is established. Step 3: A Structural Self-Interaction Matrix (SSIM) is developed, which indicates pair wise relationships among variables of the system under consideration. Step 4: A reachability matrix is developed from the SSIM and the matrix is checked for transitivity. The transitivity rule states that if a variable 'A' is related to 'B' and 'B' is related to 'C', then 'A' is necessarily related to 'C'. Step 5: The reachability matrix obtained in Step 4 is partitioned into different levels. Step 7: The resulting digraph is converted into an ISM by replacing the variable nodes with statements. Step 8: The ISM model developed in Step 7 is reviewed to check for conceptual inconsistencies, and necessary modifications are made. We now apply the ISM methodology to the firm under study. Each of the following subsections corresponds to one step of the ISM methodology.



**Fig.2** Flow for ISM Methodology

### 3.2 Development of Structural Self-Interaction Matrix (SSIM)

Based on contextual relationship among identified variables, a Structural Self-Interaction Matrix (SSIM) was developed (Table 3). This matrix indicates the pair wise relationships among the variables affecting the green supply chain initiatives for the firm under consideration. The symbols used to denote the direction of the relationship between the variables is given below. Let us assume that the variables (barriers and results) under study are  $i$  and  $j$ , then the symbol ‘V’ denotes that variables  $i$  will help to achieve variables  $j$ , the symbol ‘A’ means that variables  $j$  will help to achieve variables  $i$ . The symbol ‘X’ means that variable  $i$  and  $j$  will help each other to be achieved and the symbol ‘O’ means the variables are unrelated.

V – Variables  $i$  will help to achieve Variables  $j$ ; A – Variables  $j$  will help to achieve Variables  $i$ ;

X – Variables  $i$  and  $j$  will help to achieve each other; and O – Variables  $i$  and  $j$  are unrelated.

The following statements illustrates the use of symbols V, A, X and O in the SSIM matrix.

- Environmental benefits variable will be achieved by energy consumption reduction variable (A);
- Environmental issue variable will help to achieve environmental benefits variable (V).

Table 3: Structural Self-Interaction Matrix (SSIM)

S.N.	Variables	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	Supplier commitment	V	O	V	V	V	O	V	O	O	O	A	A	A	
2	Cost	V	V	V	O	O	V	V	V	V	V	A	O		
3	Regulations	V	V	V	A	O	V	V	O	O	O	A			
4	Environmental issue	V	V	V	V	V	V	V	V	V	V				
5	Customer Satisfaction	V	O	V	O	A	O	O	O	O					
6	Industry Specific Barriers	V	V	O	O	O	O	O	O						
7	Capacity Utilization	V	O	V	A	A	O	A							
8	Green Products	V	O	V	A	V	V								
9	Processing time	V	O	V	O	V									
10	Environmental Benefit	V	O	V	A										
11	Energy Consumption Reduction	V	O	O											
12	Market edge	V	O												
13	Customer Redundancy	V													
14	Productivity & Efficiency														

Table 4, initial reachability matrix for the variables

S.N	Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Supplier commitment	1	0	0	0	0	0	0	1	0	1	1	1	0	1
2	Cost	1	1	0	0	1	1	1	1	1	0	0	1	1	1
3	Regulations	1	0	1	0	0	0	0	1	1	0	0	1	1	1
4	Environmental issue	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	Customer Satisfaction	0	0	0	0	1	0	0	0	0	0	0	1	0	1
6	Industry Specific Barriers	0	0	0	0	0	1	0	0	0	0	0	0	1	1
7	Capacity Utilization	0	0	0	0	0	0	1	0	0	0	0	1	0	1
8	Green Products	0	0	0	0	0	0	1	1	1	1	0	1	0	1
9	Processing time	0	0	0	0	0	0	0	0	1	1	0	1	0	1

10	Environmental Benefits	0	0	0	0	1	0	1	0	0	1	0	1	0	1
11	Energy Consumption Reduction	0	0	1	0	0	0	1	1	0	1	1	0	0	1
12	Market edge	0	0	0	0	0	0	0	0	0	0	0	1	0	1
13	Customer Redundancy	0	0	0	0	0	0	0	0	0	0	0	0	1	1
14	Productivity & Efficiency	0	0	0	0	0	0	0	0	0	0	0	0	0	1

We derived the reachability matrix from the structural self-interaction matrix (SSIM) developed in the previous step. The initial reachability matrix is constructed from the structural self-interaction matrix (SSIM) using the following rules:

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

The final reachability matrix shown below in Table 5 is constructed from the initial reachability matrix taking into account the transitivity rule, which states that if a variable ‘A’ is related to ‘B’ and ‘B’ is related to ‘C’, then ‘A’ is necessarily related to ‘C’.

### 3.3 Level Partitions of reachability matrix

The reachability matrix obtained as above was partitioned into different levels. The reachability and antecedent set for each variables (Warfield, 1974) were found from the final reachability

matrix as shown in, Table 6. The reachability set for an individual variables consists of itself and the other variables which it may help to achieve.

The antecedent set consists of the variables themselves and the other variables which may help in achieving it. The intersection of both these sets was also derived for all variables. The variables for which the reachability and the intersection sets are same is assigned as the top level variables

Table 5, final reachability matrix for the variables

S.N	Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Driving power
1	Supplier commitment	1	0	0	0	0	0	0	1	0	1	1	1	0	1	6
2	Cost	1	1	0	0	1	1	1	1	1	0	0	1	1	1	10
3	Regulations	1	0	1	0	0	0	0	1	1	0	0	1	1	1	7
4	Environmental issue	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
5	Customer Satisfaction	0	0	0	0	1	0	0	0	0	0	0	1	0	1	3
6	Industry Specific Barriers	0	0	0	0	0	1	0	0	0	0	0	0	1	1	3
7	Capacity Utilization	0	0	0	0	0	0	1	0	0	0	0	1	0	1	3
8	Green Products	0	0	0	0	0	0	1	1	1	1	0	1	0	1	6
9	Processing time	0	0	0	0	0	0	0	0	1	1	0	1	0	1	4
10	Environmental Benefits	0	0	0	0	1	0	1	0	0	1	0	1	0	1	5
11	Energy Cons. & Red.	0	0	1	0	0	0	1	1	0	1	1	0	0	1	6
12	Market edge	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2
13	Customer Redundancy	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2
14	Productivity & Efficiency	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Net	Dependence power	4	2	3	1	4	3	6	6	5	6	3	10	5	14	

Table 6 Level partition of variables – Iteration 1

Variables	Reachability Set	Antecedent Set	Intersection set	Level
1	1,8,10,11,12,14	1,2,3,4	1	
2	1,2,5,6,7,8,9,12,13,14	2,4	2	
3	1,3,8,9,12,13,14	3,4,11	3	
4	1,2,3,4,5,6,7,8,9,10,11,12,13,14	4	4	
5	5,12,14	2,4,5,10	5	
6	6,13,14	2,4,6	6	
7	7,12,14	2,4,7,8,10,11	7	
8	7,8,9,10,12,14	1,2,3,4,8,11	8	

9	9,10,12,14	2,3,4,8,9	9	
10	5,7,10,12,14	1,4,8,9,10,11	10	
11	3,7,8,10,11,14	1,4,11	11	
12	12,14	1,2,3,4,5,7,8,9,10,12	12	
13	13,14	2,3,4,6,13	13	
14	14	1,2,3,4,5,6,7,8,9,10, 11,12,13,14	14	Level 1

The ISM hierarchy as it would not help achieve any other variable above their own level. After the identification of the top level element, it is discarded from the list of remaining variables. From table 6, it is seen that the Green Productivity (variable 14) is found at level 1<sup>st</sup>. thus, it would be positioned at top of ISM hierarchy. This iteration is repeated till the levels of each variable are found out. The identified levels aids in building the digraph and final model of ISM. Table 6 shows 1<sup>st</sup> iteration in partition of variables. For 1<sup>st</sup> iteration, Productivity & efficiency variable is found to have same reachability and the intersection sets, and so qualifies to hold level 1. It is then discarded from the list of remaining variables and again intersection set was computed for remaining variables.

### 3.4 Formation of ISM model

With the help of the level partition shown in Tables 4 and 5, a model of the various variables important to implementing green supply chain management for the firm under study was developed, and is shown in Fig. 3.

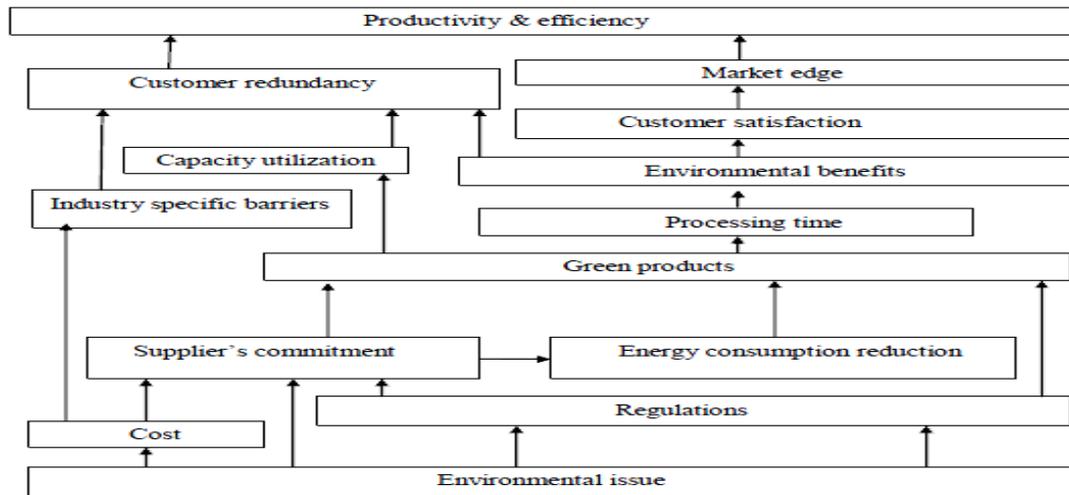


Fig.3 ISM model for the variables associated with Green Supply Chain

### 3.5 MICMAC analysis

In MICMAC analysis, the dependence power and variables power of the variables are analyzed. On the basis of the above study, the variables were classified into four sectors. The four sectors are autonomous, dependent, linkage, and variables/independent. In the final reachability matrix, shown in table 5, the driving power and dependence of each of the variables are calculated. The variables involved in initiating the green supply chain pose considerable challenges for the environment. Due to the complexity of GSC practices, customer and cost pressures and regulation uncertainty, implementing GSC is considered as a thankless task that increases overall product cost. Decision makers must be aware of the relative importance of the various variables and the techniques for implementing them. Highlighting the 14 types of variables, an ISM model was developed and the interactions between these variables were analyzed for the firm under study using the ISM model and MICMAC analysis. The managerial implication and concluding remarks emerging from this study are as follows: The variables that have weak variables power and weak dependence will fall in SECTOR 1 and are called autonomous elements. Variables that

have weak variables power, but strong dependence power will fall in SECTOR 2 and are called dependent elements. Variables that have both strong variables power and dependence power will fall in SECTOR 3 and are called linkage elements. These elements are unstable due to the fact that any action on these elements will affect the others, and may also have a feedback effect on them. Variables that have strong variables power but weak dependence power will fall in SECTOR 4 and are called independent elements given by Kannan and Haq (2007).

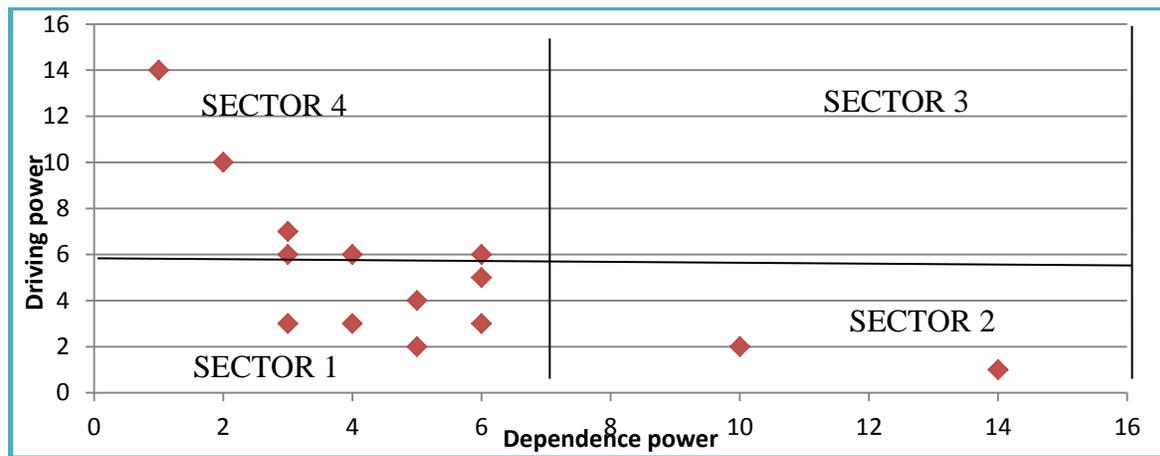


Fig.4 driving power and dependence power diagram

The drivers involved in the implementation of green supply chain for the firm under study pose considerable challenges for the management of the firm. One of the primary goals of a supply chain of the companies is to increase its productivity and performance such that it is able to satisfy its customers. Liberal return policies and more demanding customers have led to an increase of returned products in pulp & paper mill industry. These obsolete products should be reused or recycled should be done to recapture value from them. If these products are not reused in any form further, they should at least be properly disposed off such that there is no harmful effect on the environment. Reverse logistics and sustainable development is thus becoming a necessity in these supply chains.

#### 4. Discussions and Conclusion

In this research, an ISM based model has been developed to analyze the interaction among the green supply chain variables. It identifies the hierarchy of actions to be taken for the conduct product recovery system operations in pulp & paper mill supply chains in order to achieve superior productivity and performance. It can also act as a guide to the top management to decide the course of action in the successful implementation of product recovery programs to increase the productivity and performance. The driver power-dependence matrix (Fig. 4) gives some valuable insights about the relative importance and interdependencies among the green supply chain variables. The managerial implications emerging from this study are as follows:

- Environmental benefits, processing time, capacity utilization, customer redundancy, industry specific barriers and customer satisfaction are autonomous variables for enhancement of productivity and efficiency of green supply chain. These variables appear as weak driver as well as weak dependent and do not have much influence on the other variables of the system.
- Productivity and efficiency and market edge are weak drivers but strongly dependent on other variables. They are seen at the top of the ISM hierarchy; these variables represent the desired objectives of the green supply chain product recovery system.
- No variable is seen as a linkage variable that has a strong driving power as well as strong dependence. Thus, it can be inferred that among all the variables chosen in this study, no variable is unstable.
- The independent variables of green supply chain product recovery system such as environmental issue, supplier's commitment, cost, energy consumption reduction, green products and regulations are at the bottom of the model having greater driving power.

Thus there is a strong need to address these variables help to achieve desired result variables, which appear at the top of the ISM hierarchy. Therefore, it can be inferred that there must be strategies to enhance the deployment of independent variables so that the desired level of productivity and efficiency can be achieved.

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