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Productivity improvement of a computer hardware supply chain

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Abstract

Purpose – To determine the key reverse logistics variables, which the top management should focus so as to improve the productivity and performance of computer hardware supply chains.

Design/methodology/approach – In this paper, an interpretive structural modeling (ISM) based approach has been employed to model the reverse logistics variables typically found in computer hardware supply chains. These variables have been categorized under "enablers" and "results". The enablers are the variables that help boost the reverse logistics variables, while results variables are the outcome of good reverse logistics practices.

Findings – A key finding of this modeling is that environmental concern is the primary cause of the initiation of reverse logistics practices in computer hardware supply chains. For better results, top management should focus on improving the high driving power enabler variables such as regulations, environmental concerns, top management commitment, recapturing value from used products, resource reduction, etc.

Originality/value – In this research, an interpretation of reverse logistics variables in terms of their driving and dependence powers has been carried out. Those variables possessing higher driving power in the ISM need to be taken care on a priority basis because there are a few other dependent variables being affected by them. Variables emerging with high dependence contribute to productivity and performance of green supply chain.

Keywords Supply chain management, Computer hardware, Recycling

Paper type Research paper

Introduction

Reverse logistics is the process of moving goods from their typical final destination for the purpose of capturing value or proper disposal (Rogers and Tibben-Lembke, 1999). It is a process whereby supply chains can become more environmental friendly through recycling, reusing, and reducing the amount of materials used (Carter and Ellram, 1998). It is observed that all the sales transactions carried in many product-based supply chains are not final with the payment recovery at the point of sales as they need to cope up with returns of the product due to recalls, warranty claims, service returns, recovery at the end-of-use, disposal at the end-of-life etc. Thus, the reverse distribution, which is from consumer to producer, has gained tremendous importance in the recent years. Reverse logistics stands for all the operations related to reuse of products coming back from customers, excess inventory of products and

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materials including collection, disassembly and processing of used products, product parts, and/or materials. The computer hardware industry is characterized by a rapidly changing environment with new models appearing in a very short span of time. With the obsolescence rates on the rise, what could be done to these end-of-life computers is an important issue, which has both environmental and economic implications. In this sense, reverse logistics operations assume great importance in the productivity of a computer hardware supply chain.

The concept of reverse logistics has received growing attention in the last decades due to a number of factors (Fernández, 2003). Economic, environmental and legislative reasons are the main concerns now. In the present scenario when there is a growing concern for environment, and there are customers who are ready to pay more for environmental-friendly products, there are not many options left for companies but to go for reverse logistics practices. This requires proper disposal of end-of-life products which otherwise have a negative impact on the environment. Public concern for environment has created opportunities for companies to market their green products.

An implementation of reverse logistics program involves many financial and operational issues, which determine the productivity and performance of the supply chains in a long run. A critical analysis of the variables affecting reverse logistics and their mutual interactions can be a valuable source of information for the decision makers. In this paper, an approach based on interpretive structural modeling (ISM) has been employed to model the productivity issue of reverse logistics of a computer hardware industry. The productivity variables are grouped into enabler and result category. The enablers are the variables that help boost the reverse logistics activities. Results are those variables, which show the outcome of good reverse logistics practices. It is seen that the reverse logistics variables not only affect the performance, but also influence one another. Thus, it is important to understand their mutual relationships variables so that those variables (called driving variables) which are at the root of some more variables and those (called driven variables) which are most influenced by the others are identified. The proposed ISM model described in this paper captures the interactions among different variables of reverse logistics. It can act as a guide to the top management to devise ways to improve the performance and productivity of reverse logistics activities.

A reverse logistics framework for the computer hardware supply chains is schematically represented in Figure 1. The returns management operations in the recovery chain involve collection of returns of the product from the customer, inspection of its status, and then separation for reuse, re-manufacturing and recycling. This is followed by re-distribution of the recovered products or parts in the original or secondary markets (Kokkinaki *et al.*, 2000).

When a product reaches its end-of-life, many of its parts can still be used in their original functionality. For example, state-of-art computers procured by companies may become outdated or obsolete with the arrival of newer designs in the market. Though they remain in function yet they are not able to support their operations in the manner as intended. This may be due to evolving industry standards due to which the original computers can no longer support their intended use. Subsequently, the product is traded in the market at a down price. This is denoted by the flow from the original user to next user as shown in Figure 1. The main idea for reverse logistics is to promote and support alternative course of action for end-of-life products. For example, the computer's keyboard could be directly re-used, its motherboard may be remanufactured to fit into an electronic toy and other parts like casing could be

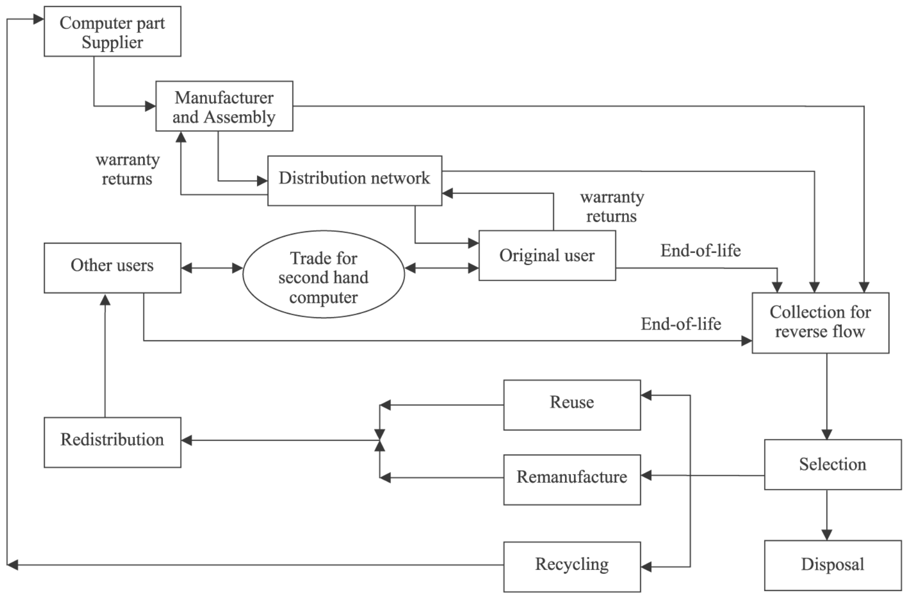

Figure 1.
Reverse logistics framework for computer hardware supply chains

recycled. With this new or old functionality, the product or its parts again enters the market where it may go through several trading cycles. This concept is denoted by the closed loop between "other user" and "trade" as shown in Figure 1. At some future point in time, this product will reach to the end-of-life in the reverse logistics network. The primary objective of reverse logistics is to either recapture value from these end-of-life products or properly dispose these products. In case the products have attained their end-of-life and are classified into the category of scrap, they need to be disposed off in an environment-friendly manner. In case of computers, there are several non-degradable and difficult to reprocess type of materials, which may cause serious damage to the environment.

The main objectives of this paper are:

(1) to identify and rank the variables of reverse logistics activities in computer hardware industry;

(2) to find out the interaction among identified variables; and

(3) to understand the managerial implications of this research.

This paper is further organized as follows. The next section discusses the identification of some of the major variables for implementation of reverse logistics in computer hardware industries, which is followed by the discussion of ISM methodology. MICMAC analysis of developed ISM model is carried out subsequently to understand the driving power of these variables. Finally, the results of this research are presented, which is followed by discussion and conclusion.

Identification of variables of reverse logistics in computer industry

In this model, there are 15 important variables under the "enabler" and "results" categories. These have been selected from the literature and through discussion with six experts – three from a computer hardware industry and remaining three from academia (Table I).

Enablers for reverse logistics

Green purchasing leads to sustainable development with benefits to environment (Green *et al.*, 1995). Green *et al.* (1998) have suggested that the nature of firm's response to environmental pressures is leading to a much more significant and central role for purchasing and supply management than the function has ever experienced before. Drumwright (1994) has conducted a field study of ten organizations to determine the reasons for adopting green purchasing by them. The environmental sustainability and ecological performance of a company may depend on these aspects, as demonstrated by the suppliers (Godfrey, 1998). Regulations refers to any jurisdiction that may make it mandatory for the companies to recover used products produced by them or accept them back after end of the useful life of the product. Regulations are generally credited as having the greatest influence on a firm's reverse logistics activities (Carter and Ellram, 1998). The German packaging ordinance of 1991 resulted in the companies working closely with their competitors to put tough environmental policies into practice (Cairncross, 1992; Cooke, 1992). Environmental concerns are a significant force shaping the economy, as well as one of the most important issues faced by businesses (Murphy *et al.*, 1995). Companies have focused on reverse logistics operations because of environmental reasons (Rogers and Tibben-Lembke, 1999). Wu and Dunn (1995) have examined the logistics issues to achieve proactive environmental management focus. Kopicki *et al.* (1993) gave attention to environmental concerns by pointing out opportunities on reuse and recycling in reverse logistics programs. State-of-art technologies are necessary to support reverse logistics operations during different stages of product life cycle. Information and communication technologies assume tremendous importance in reverse logistics, which are needed to process and transmit information (de Brito *et al.*, 2002). Information support is necessary for developing linkages to achieve efficient reverse logistics operations (Daugherty *et al.*, 2002). A sincere commitment from

SN	Reverse logistics variables
Enablers of reverse logistics	
1	Green purchasing by companies
2	Regulations
3	Environmental concerns
4	State-of-art technologies
5	Top management commitment
6	Vertical co-ordination among supply chain partners
7	Recapturing value from used products
8	Resource reduction
9	Competitiveness
Variables resulting from reverse logistics	
10	Proper disposal of end-of-life products
11	Customer benefits
12	Environmental benefits
13	Cost benefits
14	Green products
15	Productivity and performance

Table I.
Variables used in the ISM model

the top management is the dominant driver of corporate endeavors (Mintzberg, 1973). Efficient leadership is needed to provide a clear vision to reverse logistics programs. Carter and Ellram (1998) have opined that top management commitment is essential for successful implementation of reverse logistics initiatives. Vertical co-ordination among supply chain partners is necessary for reverse logistics (Carter and Ellram, 1998). In an increasing competitive marketplace the vertical co-ordination among supply chain partners will permit marketers to effectively allocate finite resources, and respond to rising service expectations of customers. Turner *et al.* (1994) have examined the potential benefits of symbiotic relationships in reverse logistics. The symbiotic relationships between the supply chain partners are necessary as the volume of products is probably too small to economically justify individual efforts at product reclamation in reverse logistics programs. Recapturing value from used products is essential for reverse logistics (Johnson, 1998; Ravi *et al.*, 2005). By means of the returned products, companies can explore the possibility of recovering constituent material that no longer needs to be purchased in same quantities. Resource reduction should be the ultimate goal of reverse logistics processes (Stock, 1992; Kopicki *et al.*, 1993; Ravi and Shankar, 2005). Resource reduction refers to the minimization of materials used in production, and minimization of waste and energy achieved through the design of green products (Carter and Ellram, 1998). Companies initiate reverse logistics programs in organization for competitive reasons (Carter and Ellram, 1998). Reverse logistics system combined with source-reduction processes can be used to gain competitive advantage in the market (Marien, 1998).

Variables resulting from reverse logistics

Reverse logistics processes include recycling programs, hazardous material removal, obsolete equipment disposition and asset recovery operations from end-of-life products. Reverse logistics operations lead to proper disposal of products without harming the environment (Rogers and Tibben-Lembke, 1999; Dowlatshahi, 2000). Proper disposal is required for those products that cannot be reused for technical or economical reasons (Fleischmann *et al.*, 2000). Reverse logistics offers benefits to customers. The reverse distribution activities involve the removal of defective and environmentally hazardous products from the hands of customers (Jayaraman *et al.*, 2003). Practice of reverse logistics leads benefits to environment. Reverse logistics is a process whereby companies can become more environmentally efficient through recycling, reusing, and reducing the amount of materials used (Carter and Ellram, 1998). By reusing the end-of-life products the environment is benefited. Many times the practice of reverse logistics would lead to cost reduction. Companies continually strive for achieving cost savings in their production processes. Companies that make use of remanufacturing in the product recovery are estimated to save 40-60 percent of the costs compared to manufacturing a completely new product (Cohen, 1988; Heeb, 1989; Toensmeier, 1992) while requiring only 20 percent of the effort (Sturgess, 1992). Andel (1997) observed that companies are following reverse logistics practices for a second chance to gain profits. If a firm does reverse logistics well, it will make money (Stock, 1998). Guide and Wassenhove (2003) give an example of the US firm named ReCellular, which by refurbishing the cell phones, had gained economic advantage. Reverse logistics lead to production of green products. There are examples that the present day consumers are ready to pay more for green products (Vandermerwe and Oliff, 1990).

Reverse logistics also lead to increase of productivity and performance of firms. By recapturing value from used products and emphasizing on resource reduction, reverse logistics programs result into cost savings for companies (Carter and Ellram, 1998). Farrow, the founder of Walden Paddlers, Inc., whose concern for the velocity at which consumer products travel through the market to the landfill pushed him to an innovative project of a 100-percent-recyclable kayak leading to the increase of productivity (Farrow *et al.*, 2000).

ISM methodology and model development

In this section, we explain the rationale for choosing ISM methodology for the research done in this paper. We then subsequently enumerate the details of ISM methodology. Ill-defined problems tend to be dynamic problems that involve human factors. Soft systems methodology (SSM) is generally used for dealing ill-defined problems as to what shall be done, because at the onset there is no obvious or clearly defined objective. But the main limitation of SSM is that it can be used to solve only some ill-parts of the system and not for building the system as a whole (Anonymous, 2004). In addition, SSM is a very time-intensive process. The Delphi method is a structured technique used for forecasting information in technology, business, education, science, and other fields. It follows a series of steps to develop a consensus among a group of experts. The main disadvantage associated with the Delphi method is that it is very difficult to collect questionnaires from busy individuals. The structural equation modeling (SEM) is a confirmatory approach to data analysis requiring a priori assignment of inter-variable relationships. It tests a hypothesized model statistically to determine the extent the proposed model is with the sample data (Wisner, 2003). One of the limitations of SEM is that it requires the statistical data to obtain results.

The ISM methodology on the other hand compared to the other methods described earlier has a lot of advantages. In this research, we are interested in increasing the productivity improvement of computer hardware supply chain. The productivity improvement of the computer hardware supply chain depends on a number of variables. A model depicting those key variables that should be focused on such that desired results could be achieved would be of great value to the top management. ISM can rightly be employed under such circumstances because on the basis of relationship between the variables, an overall structure can be extracted for the system under consideration. ISM is primarily intended as a group learning process, but can also used individually. The ISM process transforms unclear, poorly articulated mental models of systems into visible, well-defined models useful for many purposes (Sage, 1977).

The ISM methodology is an interactive learning process. In this a systematic application of some elementary notions of graph theory is used in such a way that theoretical, conceptual, and computational leverage are exploited to explain the complex pattern of contextual relationship among a set of variables (Malone, 1975). ISM is intended for use when desired to utilize systematic and logical thinking to approach a complex issue under consideration. It can act as a tool for imposing order and direction on the complexity of relationships among the variables (Sage, 1977; Singh *et al.*, 2003; Jharkharia and Shankar, 2004).

Saxena *et al.* (1992) applied the ISM methodology for the modeling of variables of energy conservation in Indian cement industry and identified the key variables using direct as well as indirect interrelationships among the variables. Sharma *et al.* (1995)

used the ISM methodology to develop a hierarchy of action required to achieve the future objective of waste management in India. Mandal and Deshmukh (1994) have employed the ISM to analyze some of the important vendor selection criteria and have shown the interrelationships of criteria and their levels. They have also categorized these criteria depending on their driving power and dependence. A number of variables determine the reverse logistics operations in computer industries. An examination of the direct and indirect relationships among these variables can give a clearer picture of the situation than considering individual variables alone in isolation. There are few limitations of the ISM methodology. The contextual relation among the variables always depends on the user's knowledge and familiarity with the firm, its operations, and its industry. Therefore the biasing of the person who is judging the variables might influence the final result. ISM can only act as a tool for imposing order and direction on the complexity of relationships among the variables. It does not give any weightage associated with the variables.

Steps involved in ISM methodology

The various steps involved in ISM modeling are as follows.

(1) Identifying of the variables that are relevant to the problem or issue. This can be done by survey or group problem solving technique.

(2) Establishing the contextual relationship among variables. This represents the relationship indicating whether or not one variable leads to another.

(3) Developing a structural self-interaction matrix (SSIM) of variables, which indicates pair-wise relationship between variables of the system.

(4) Developing a reachability matrix from the SSIM, and check the matrix for transitivity. The SSIM format is transformed in the format of reachability matrix by transforming the information in each entry of the SSIM into 1s and 0s in the reachability matrix. Transitivity of the contextual relation is a basic assumption in the ISM which states that if element A is related to B and B is related to C, then A is necessarily related to C.

(5) Partitioning the reachability matrix into different levels.

(6) Based on the relationships in the reachability matrix, removal of the transitive links.

(7) Constructing the ISM model by replacing element nodes with statements.

(8) Review of the ISM model to check for conceptual inconsistency, and make the necessary modifications.

These steps, described above which lead to the development of the ISM model are discussed below.

Structural self-interaction matrix (SSIM)

ISM methodology suggests the use of the expert opinions based on various management techniques such as brain storming, nominal group technique etc in developing the contextual relationship among the variables. In this research, six experts, three from the computer hardware industry and another three from academia were consulted in identifying the nature of contextual relationship among the variables of reverse logistics. Two industry experts were the senior managers of different companies in operations area while the third one was a supply chain manager of another company. These experts from the industry and academia were well conversant with reverse logistics practices in the computer hardware industry having an experience of over ten years in this area. In order to analyze the relationship among the reverse logistics variables, a contextual relationship of "leads to" type is chosen. For example, the environmental concerns lead to the proper disposal of the end-of-life products by the companies. In a similar manner, the contextual relationships between the variables are developed.

Keeping in mind the contextual relationship for each variable, the existence of a relation between any two variables (*i* and *j*) and the associated direction of the relation are questioned. Four symbols are used to denote the direction of relationship between the variables (*i* and *j*):

V = Variable *i* will help achieve variable *i*;

A = Variable *j* will be achieved by variable *i*;

X = Variable *i* and *j* will help achieve each other; and

O = Variables *i* and *j* are unrelated.

Based on the contextual relationships the SSIM is developed for the 15 variables identified for the reverse logistics in computer industry (Table II).

Reachability matrix

The SSIM is transformed into a binary matrix, called the initial reachability matrix by substituting V, A, X, O by 1 and 0 as per the case. The rules for the substitution of 1s and 0s are as follows:

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

Variables	15	14	13	12	11	10	9	8	7	6	5	4	3	2
1. Green purchasing by companies	V	V	O	O	O	O	O	V	O	V	O	V	A	A
2. Regulations	V	V	O	O	V	V	V	V	O	V	V	V	A	
3. Environmental concerns	V	V	V	V	V	V	V	V	V	V	V	V		
4. State-of-art technologies	V	V	A	V	O	O	A	V	O	V	A			
5. Top management commitment	V	V	V	V	V	V	O	V	V	V				
6. Proper disposal of end-of-life products	V	O	A	O	A	A	A	V	O					
7. Customer benefits	V	O	O	A	A	O	O	O						
8. Environmental benefits	V	A	O	O	A	A	A							
9. Vertical co-ordination among supply chain partners	V	V	O	O	O	O								
10. Recapturing value from used products	V	V	V	O	V									
11. Resource reduction	V	V	V	V										
12. Competitiveness	V	O	A											
13. Cost benefits	V	V												
14. Green products	V													
15. Productivity and performance														

Table II.
Structural self-interaction matrix (SSIM)

- If the (*i, j*) entry in the SSIM is X, then 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 O, then the (*i, j*) entry in the reachability matrix becomes 0 and the (*j, i*) entry also becomes 0.

Following these rules, initial reachability matrix for the reverse logistics variables identified is shown in Table III.

The final reachability matrix is obtained by incorporating the transitivities as enumerated in Step 4 of the ISM methodology. This is shown in Table IV. In this table, the driving power and dependence of each variable are also shown. The driving power of a particular variable is the total number of variables (including itself), which it may help achieve while the dependence is the total number of variables, which may help achieving it. These driving power and dependencies of variables will be used in the MICMAC analysis, where the variables will be classified into four groups of autonomous, dependent, linkage and independent (driver) variables.

Level partitions

The reachability and antecedent set (Warfield, 1974) for each variable are obtained from final reachability matrix. The reachability set for a particular variable consists of the variable itself and the other variables, which it may help achieve. The antecedent set consists of the variable itself and the other variables, which may help in achieving them. Subsequently, the intersection of these sets is derived for all variables. The variable for which the reachability and the intersection sets are the same is assigned as the top-level variable in 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 V, it is seen that the productivity and performance (variable 15) is found at level I. Thus, it would be positioned at the top of the ISM hierarchy. This iteration is repeated till the levels of each variable are found out. The identified levels aids in building the digraph and the final model of ISM.

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Green purchasing by companies	1	0	0	1	0	1	0	1	0	0	0	0	0	1	1
2. Regulations	1	1	0	1	1	1	0	1	1	1	1	0	0	1	1
3. Environmental concerns	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4. State-of-art technologies	0	0	0	1	0	1	0	1	0	0	0	1	0	1	1
5. Top management commitment	0	0	0	1	1	1	1	1	0	1	1	1	1	1	1
6. Proper disposal of end-of-life products	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1
7. Customer benefits	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
8. Environmental benefits	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
9. Vertical co-ordination among supply chain partners	0	0	0	1	0	1	0	1	1	0	0	0	0	1	1
10. Recapturing value from used products	0	0	0	0	0	1	0	1	0	1	0	0	1	1	1
11. Resource reduction	0	0	0	0	0	1	1	1	0	0	1	1	1	1	1
12. Competitiveness	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1
13. Cost benefits	0	0	0	1	0	1	0	0	0	0	0	1	1	1	1
14. Green products	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1
15. Productivity and performance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Table III.
Initial reachability matrix

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Driver Power
1. Green purchasing by companies	1	0	0	1	0	1	0	1	0	0	0	1	0	1	1	7
2. Regulations	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	14
3. Environmental concerns	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
4. State-of-art technologies	0	0	0	1	0	1	1	1	0	0	0	1	0	1	1	7
5. Top management commitment	0	0	0	1	1	1	1	1	0	1	1	1	1	1	1	11
6. Proper disposal of end-of-life products	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	3
7. Customer benefits	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	2
8. Environmental benefits	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	2
9. Vertical co-ordination among supply chain partners	0	0	0	1	0	1	0	1	1	0	0	1	0	1	1	7
10. Recapturing value from used products	0	0	0	1	0	1	0	1	0	1	0	1	1	1	1	8
11. Resource reduction	0	0	0	1	0	1	1	1	0	0	1	1	1	1	1	9
12. Competitiveness	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	3
13. Cost benefits	0	0	0	1	0	1	1	1	0	0	0	1	1	1	1	8
14. Green products	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	3
15. Productivity and performance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Dependence	3	2	1	9	3	10	8	12	3	4	4	10	6	10	15	

Table IV.
Final reachability matrix

Variable	Reachability set	Antecedent set	Intersection set	Level
1	1, 4, 6, 8, 12, 14, 15	1, 2, 3	1	
2	1, 2, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	2, 3	2	
3	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	3	3	
4	4, 6, 7, 8, 12, 14, 15	1, 2, 3, 4, 5, 9, 10, 11, 13	4	
5	4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15	2, 3, 5	5	
6	6, 8, 15	1, 2, 3, 4, 5, 6, 9, 10, 11, 13	6	
7	7, 15	2, 3, 4, 5, 7, 11, 12, 13	7	
8	8, 15	1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 13, 14	8	
9	4, 6, 8, 9, 12, 14, 15	2, 3, 9	9	
10	4, 6, 8, 10, 12, 13, 14, 15	2, 3, 5, 10	10	
11	4, 6, 7, 8, 11, 12, 13, 14, 15	2, 3, 5, 11	11	
12	7, 12, 15	1, 2, 3, 4, 5, 9, 10, 11, 12, 13	12	
13	4, 6, 7, 8, 12, 13, 14, 15	2, 3, 5, 10, 11, 13	13	
14	8, 14, 15	1, 2, 3, 4, 5, 9, 10, 11, 13, 14	14	
15	15	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	15	Level 1

Table V.
Iteration 1

Formation of ISM-based model

The structural model is generated from the final reachability matrix and the digraph is drawn. Removing the transitivities as described in the ISM methodology, the digraph is finally converted into the ISM as shown in Figure 2. It is observed from this figure that environmental concern (variable 3) is a very significant factor for the reverse

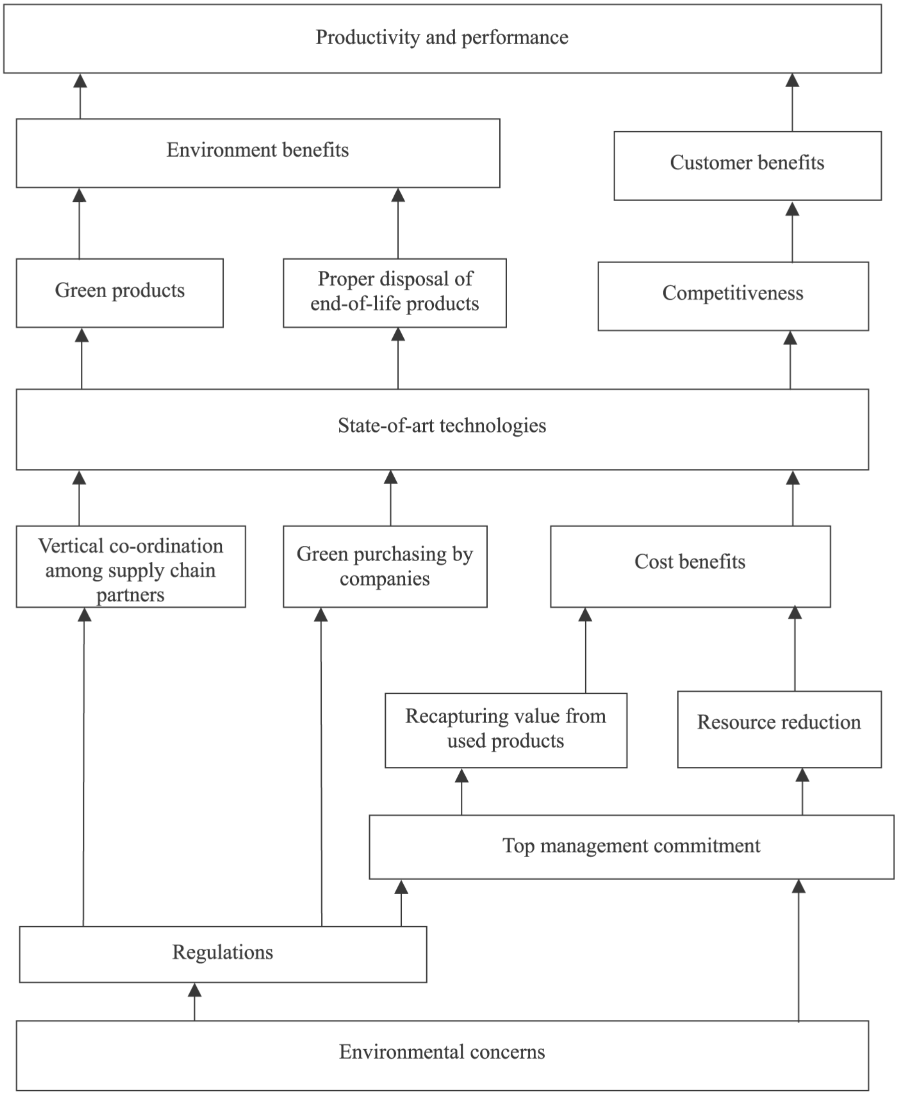

Figure 2.
ISM-based model for the reverse logistics variable in computer industry

logistics of computer hardware industries as it forms the base of the ISM hierarchy. Productivity and performance (variable 15) is the reverse logistics variable, which depicts the successful implementation of reverse logistics operations. This variable has appeared at the top of the hierarchy.

The environmental concerns (variable 3) lead to the enforcement of regulations (variable 2). The regulations lead to vertical co-ordination among the members of the supply chain partners (variable 9) and green purchasing by the supply chain partners (variable 1). All the trading partners work for a common goal and interact with each other to realize the benefits of an integrated supply chain (Christopher and Towill, 2001). This results into state-of-art technologies (variable 4) much needed for the success of reverse logistics operations. The concern for environment (variable 3) also leads to top management commitment to reverse logistics initiatives. They initiate reverse logistics operations, which lead to recapturing value from the used products (variable 10) as well as resource reduction (variable 11) and emphasize on the minimization of waste and effective utilization of resources. Thus, recapturing value from used products and emphasis on resource reduction lead to cost benefits (variable 13) leading to the reduction in the overall cost of the product. The cost benefits can in turn be utilized to procure state-of-art technologies (variable 4), which can help in persuing green products (variable 14), proper disposal of end-of-life products (variable 6) and increase in the competitiveness (variable 12). The production of green products and proper disposal of end-of-life products in turn lead to environmental benefits (variable 8). The competition in the market leads to benefits to customer (variable 7). The environmental benefits and the customer benefits together increase the productivity and performance of reverse logistics operations.

MICMAC analysis

The objective of the MICMAC analysis is to analyze the driving power and the dependence of the variables (Mandal and Deshmukh, 1994). In this analysis, the reverse logistics variables described earlier are classified into four clusters (Figure 3). The first cluster consists of the "autonomous variables" that have weak driving power and weak dependence. These variables are relatively disconnected from the system, with which

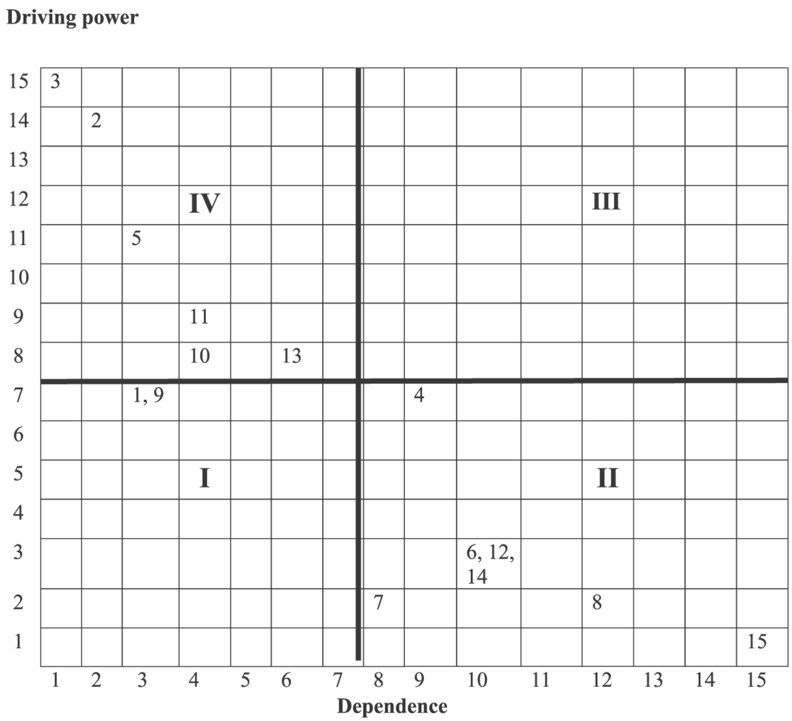

Figure 3.
Driving power and dependence diagram

they have only few links, which may not be strong. The "dependent variables" constitute the second cluster which have weak driving power but strong dependence. Third cluster has the "linkage variables" that have strong driving power and strong dependence. These variables are unstable due to the fact that any change occurring to them will have an effect on others and also a feedback on themselves. Fourth cluster includes the "independent variables" having strong driving power but weak dependence. The driving power and dependence of each of these variables are shown in Table IV. In this table, an entry of "1" added along the columns and rows indicates the dependence and driving power, respectively. Subsequently, the driver power-dependence diagram is constructed and is shown in Figure 3. For example, it is observed from the Table IV that the variable five is having a driver power of 11 and dependence of three. Therefore, in this figure, it is positioned at a place corresponding to driver power of 11 and dependency of three.

Discussion and conclusion

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. Shorter product life cycles, liberal return policies and more demanding customers have led to an increase of returned products in computer hardware supply chains. These obsolete products should be reused or cannibalization 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. End-of-life computer hardware components contain hazardous materials such as plastics, lead, cadmium, mercury, etc, which if not disposed off properly can cause serious damage to the environment. Reverse logistics is thus becoming a necessity in these supply chains. In this research, an ISM based model has been developed to analyze the interaction among the reverse logistics variables. It identifies the hierarchy of actions to be taken for the conduct of reverse logistics operations in computer hardware 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 reverse logistics programs to increase the productivity and performance.

This study has some other implications for the practicing managers. The driver power-dependence matrix (Figure 3) gives some valuable insights about the relative importance and interdependencies among the reverse logistics variables. The managerial implications emerging from this study are as follows:

- The driver power-dependence matrix (Figure 3) indicates that green purchasing by companies and vertical coordination among supply chain partners are the autonomous variables for the enhancement of productivity and performance of reverse logistics in computer hardware supply chains. These enabler 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 performance, environmental benefits, customer benefits, green products, proper disposal of end-of-life products, competitiveness, and state-of-art technologies are weak drivers but strongly dependent on other variables. They are seen at the top of the ISM hierarchy (Figure 2). These variables represent the desired objectives of the reverse logistics operations.

- 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 15 variables chosen in this study, no variable is unstable.
- The driver power dependence diagram indicates that independent variables of reverse logistics such as environmental concerns, regulations, top management commitment, recapturing value from used products and resource reduction are at the bottom of the model having greater driving power. Thus the management needs to address these enabler variables more carefully in the supply chains. It can be seen that these variables help to achieve the desired result variables, which appear at the top of the ISM hierarchy. Therefore, it can be inferred that management should devise strategies to enhance the deployment of independent variables so that the productivity and performance are improved.

The main contributions of this research include the following:

- In this paper, an attempt has been made to identify the important reverse logistics variables found in computer hardware supply chains on a single platform. A large amount of literature is available on reverse logistics, but majority of these focus on rather narrow issues such as recycling, remanufacturing, etc. This research assumes importance in this context.
- A key finding of this research is that environmental concerns are the primary cause of the initiation of reverse logistics practices in computer hardware supply chains. The end-of-life computers contain many hazardous materials, which if untreated would cause severe damage to the environment. Thus, the concerns for environment have increased the relevance of reverse logistics activities.
- There are a lot of variables affecting the productivity and performance of reverse logistics activities. In this research, an interpretation of the variables of reverse logistics in terms of their driving and dependence powers has been carried out. Those variables possessing higher driving power in the ISM need to be taken care on priority basis because there are a few other dependent variables being affected by them.
- The variables with higher driving powers are more of the strategic orientation. On the other hand, the dependent variables are more towards productivity and performance orientation. Thus, superior productivity and performance can be achieved by continuously improving the driving variables.

Despite the fact that the ISM based model developed in this research is for the enhancement of productivity and performance of reverse logistics of computer hardware supply chains, some generalizations of results of the model are still possible. The reverse logistics operation is becoming a necessity due to concerns for the environment. This assumes similar importance in many other supply chains. The variables identified in this ISM based model are quite generic and with marginal adjustments can be used for increasing the productivity and performance for other supply chain.

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Further reading

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