MODELLING THE ENABLERS AND ALTERNATIVES FOR SUSTAINABLE SUPPLY CHAIN MANAGEMENT

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ABSTRACT

Modelling the enablers and alternatives for sustainable supply chain management

Mohammed Hussain

There has been a rapid growth in industrialization over the last few decades. This has in-turn lead to an increase in production and consumption of various goods. Industrialization at such a rapid pace has done a considerable amount of damage to the society and environment including depletion of natural resources, wastes generation during production, rising transport emissions and congestion, non-disposability of goods at the end of their product life-cycle, and stressful work environment for employees. These emerging issues have put forth the need for greater emphasis on sustainability issues and consequently development of sustainable supply chains to sustain this rapid economic growth while respecting environmental and social issues.

In this thesis, we present a modeling framework to study the different enablers for sustainable supply chains, analyze their inter-relationships and propose alternatives for sustainable supply chain development. In the first step, a comprehensive literature review is performed to identify the enablers and provide insights on the triple bottom line concept (environment, social, economic) of sustainability. In the second step, Interpretative Structural Modelling is used to develop the relationship among various enablers for each dimension of sustainability. In the third and the last step, results of

ISM are used as an input to Analytic Network Process along with potential list of alternatives to determine the best alternative(s) for developing sustainable supply chains.

The proposed approach is novel and deals with an important problem of modeling enablers and alternatives for sustainable supply chain management. The results have strong practical applicability and can be adapted by organizations with least changes in their existing work structure.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ANP - Analytic Network Process

GBEP - Global Bio-energy Partnership

GGL - The Green Gold Label

ISCC - International Sustainability & Carbon Certification

ISEAL - International Social and Environmental Accreditation and Labelling Alliance

ISM - Interpretative Structural Modelling

ISO - International Organization for Standardization

LowCVP - Low Carbon Vehicle Partnership

MICMAC - Matrice d'Impacts Croisés Multiplication Appliqué á un Classement

RED - EU Renewable Energy Directive

SEM – Structural Equation Modelling

sSCM - Sustainable Supply Chain Management

TBL - Triple Bottom Line

TOPSIS - Technique for Order Preference by Similarity to Ideal Solution

VIKOR - VlseKriterijumska Optimizacija I Kompromisno Resenje in Serbian, meaning Multicriteria Optimization and Compromise Solution

Chapter 1:

Introduction

1.1 Background

In recent years, there has been an increasing concern over the environmental effects caused due to industralization and advent of techonology. Several studies have been carried out over the past decades that depict the past, current and future status of our planet (Markley and Davis, 2007). There are concerns over depletion of ozone layer, natural resources, and other haphazardous environmental effects. As the population is increasing, the demand is increasing, as the demand is increasing, the production is increasing which eventually impacts the natural systems, resources and ecology. These issues elevate the need, more than ever before to focus on environmental hazards caused by organizations. The term sustainability, which is increasingly referred to an integration of social, environmental, and economic responsibilities, has begun to appear in the literature of business disciplines such as operations and management (Carter et al., 2007). Though the major stream of research on sustainable supply chain management dates back to mid – 1990's its only of late that there has been an increasing demand and organizations are waking up to incorporate sustainability in their operations.

Every process that is involved in the production, manufacturing, distribution of products adds to environmental concerns. Supply chains are critical links that connect an organisation's inputs to its outputs. Traditional challenges have included lowering costs, ensuring just-in-time delivery, and shrinking transportation times to allow better reaction to business challenges. However, the increasing environmental costs of these networks and growing consumer pressure for eco-friendly products has led many organisations to look at supply chain sustainability as a new measure of profitable logistics management. This shift is reflected by an understanding that sustainable supply chains frequently mean profitable supply chains.

In recent years the topic of sustainability in supply chain management (sSCM) has received growing attention and has become increasingly popular research area (Tueteberg and Wittstruck, 2010). Tsoulfas et al (2008) present a model for supply chains environmental performance analysis and decision making. Srivastava (2007) presents a literature review on green supply chain management. Hervani and Helms (2005) present performance management techniques for green supply chain management. Kainuma and Tawara (2006) present a multiple attribute utility theory approach to lean and green supply chain management. Kannan et al (2009) present a hybrid approach using ISM and fuzzy TOPSIS for the selection of reverse logistics provider. Teuteberg and Wittstruck (2010) present a systematic review of sustainable supply chain management research. Theyel (2001) emphasizes the importance of customer and supplier relations for environmental performance. Ninlawan et al (2010) present implementation of green supply chain management practices in electronics industry. Companies now have to face multiple challenges such as addressing problem of rapid climate changes, financial crisis, and also deal with growing public interest in ecology and ensure environmental sustainability.

1.2 Problem Statement

There is a growing need for sustainability in supply chains to reduce the environmental impacts and meet the economic and social needs of a supply chain. Previously work has been done on supply chains and also on sustainability but not enough research or literature is available on the merger of these two concepts. A framework is missing for effective implementation of sustainable practices in supply chains.

There are two main problems that have been explored and solved in this thesis.

- Modelling the enablers for sustainable supply chains.

Enabler as defined in layman’s term is “an entity that makes it possible or easy”. Therefore enablers for sustainable supply chains are processes that can drive a supply chain to being sustainable. The existing state of research does not directly or extensively focus on enablers for sustainability. These enablers will be modelled based on three dimensions of sustainability (environmental, social and economic) and ranked hierarchically in order of their importance and driving powers in this thesis.

- Selection of alternatives

Since the topic of sustainable supply chains is important it is necessary to provide alternatives to achieve this state in supply chains. The current state of research mainly focuses on supplier selection and other supply chain activities totally neglecting the importance of making them sustainable. Thereby this thesis proposes a set of alternatives and also prioritizes each of these alternatives.

1.3 Thesis Contribution

This thesis analyzes the important concept of sustainable supply chains, providing solutions to the following questions:

- What are enablers of a sustainable supply chain?

Enablers for sustainable supply chains are found based on the literature review and disseminated based on each sphere of Triple bottom line.

- What is the relationship among the enablers and their hierarchy?

Interpretative structural modelling (ISM) is applied to determine the relationship between the various enablers and also their hierarchy giving us a structural framework to achieve sustainable supply chains. The MICMAC analysis provides the independent enablers, dependent enablers, autonomous enablers and linkage enablers. This provides us with further ground to implement sustainable supply chains effectively.

- What are the best alternatives for effective implementation of sustainable supply chains?

Once the relationships are obtained from ISM they are used as an input to analytic network process (ANP) along with potential alternatives to determine the best alternative(s) for each sphere of triple bottom line and also for sustainable supply chains on the whole.

The findings of this research can be further used to develop a framework/model that can be applied by organizations to make their supply chains – sustainable.

1.4 Thesis Outline

This thesis consists of five chapters:

Chapter 1 includes the background, problem statement and thesis contributions.

Chapter 2 provides a comprehensive literature review on sustainability and sustainable supply chains. It also includes an analysis of the research available so far on barriers, enablers, best practices and alternatives for sustainable supply chain management.

Chapter 3 introduces the solution approaches that have been implemented in this thesis. These include Interpretative structural modelling (ISM) and Analytic network process (ANP).

Chapter 4 contains a detailed numerical analysis implementing the proposed ISM and ANP approaches for sustainable supply chain management.

Finally, Chapter 5 summarizes the research, and gives conclusions and future works.

Chapter 2:

Literature review

In this section, we provide a review of the literature that is available on the topic of sustainable supply chains. We have taken into consideration all the famous journals and publications related to the topic for the purpose of this review and laid focus on years 2008 to 2010. This does not mean that the papers before 2008 were not used in the study, they are just excluded from the literature analysis since, Seuring and Muller (2008) have provided a very detailed literature review from the years 1994 – 2007, outlining 191 papers from various journals. Their paper can be used as a base reference for comprehensive review on sustainable supply chain research conducted during the years 1994 – 2007.

The search for major journal publications was carried out on sciencedirect, emeraldinsight, and Interscience Wiley. Keywords used in our search were sustainability, sustainable supply chain, reverse logistics, sustainable manufacturing, green supply chain management, social sustainability, economic sustainability, and green supplier development. From the search, only most relevant papers in terms of technical content were considered. It was found that a total of 37 papers relevant to sustainability and supply chains have been published from 2008 till now. Table 2-1 provides the list of journals and the number of papers published during the study eriod 2008 - 2010.

Publication	**Number of Papers Published from 2008 - 2010**
Journal of Cleaner Production	6
International Journal of Physical Distribution & Logistics	6
Business Strategy and the Environment	4
International Journal of Production Economics	4
Computers & Chemical Engineering	3
Corporate Social Responsibility and Environmental Management	2

Table 2-1: Most popular publications for sustainability (2008 – 2010)

Figure 2-1 classifies the papers published during 2008-2010 on yearly basis. It is quite evident that the numbers are increasing by the year. In 2008 there were 10 papers on sustainable supply chains, in 2009 the number increased to 13 and in the year 2010 (until May) 14 papers have already been published. This shows the growing interest of people in the topic and the demand for more research in this area.

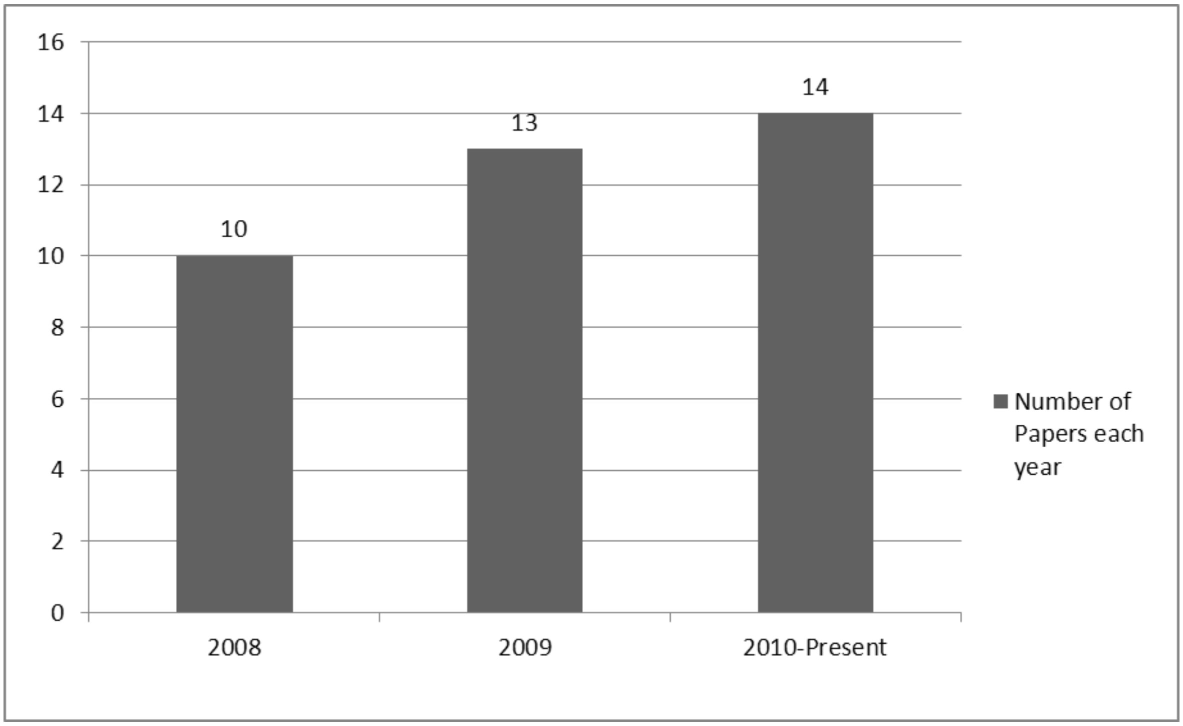


Figure 2-1: Papers per year on sustainable supply chain

Table 2-2 provides classification of papers according to the type they belong to. Here we have broadly classified the papers into 4 main categories: Literature review, Conceptual, Case study, Research.

Case study	14
Conceptual Papers	11
Research Papers	10
Literature Review	2
Total	**37**

Table 2-2: Classification of papers based on type

Most of the papers found were case studies developed on the basis of applications in particular industry. Apart from case studies, a lot of conceptual papers are also available. However, the number of theoretical research papers is not as many as conceptual or case studies. The least number of papers available are on literature reviews.

Table 2-3 presents the methodologies used in modelling sustainable supply chains. Life Cycle Analysis (LCA) is one of the common methodologies to assess the life cycle of a product from cradle to grave. Surveys and questionnaires are another common practice which give insight on the problematic areas in supply chains and those that need focus. Hypothetical analysis is another technique where theories are based on assumptions and conclusions drawn from them, not a very effective method though. A few mathematical models are also available and Multi-Objective Programming (MOP) is one of them often used for designing sustainable networks.

Methodology
Life-Cycle Analysis
Survey/Questionnaire
Overall Business Impact Assessment
Multi-Objective Programming
Hypothetical Analysis

Table 2-3: Methodologies used to implement Sustainable Supply Chains.

2.1 What are sustainable supply chains?

Numerous definitions have been proposed for the term "sustainable supply chain". Here are a few simplistic and more common definitions for the purpose of better understanding the term sustainability in context of supply chains:

- "A sustainable supply chain is a system of aligned business activities throughout the lifecycle of products that creates value to stakeholders, ensures ongoing commercial success, and improves the well-being of people and the environment" (Business for social responsibility, 2007).

- "Sustainable supply chain refers to an integration of social, environmental, and economic issues in traditional supply chain" (Carter and Rogers, 2007).

- "The potential for reducing long term risks in a supply chain associated with resource depletion, fluctuations in energy costs, product liabilities, and pollution and waste management" (Srivastava, 1995).

- "Management of raw materials and services from suppliers to manufacturer/service provider to customer and back with improvement of social, economic and environmental impacts explicitly considered" (NZBCSD, 2003).

We prefer the first and last definition as they explicitly explain the importance of each element of sustainability (TBL). They are simplistic and practical definitions.

NZBCSD (2003) states "in general the supply chain considers the interactions between a business and its customers and suppliers. The greatest benefits are derived by extending the focus as far as possible upstream towards the raw materials, downstream towards the consumer and then back again as the products and wastes are recycled".

2.2 How is sustainable supply chain different from a traditional supply chain?

The interaction between sustainability and supply chains is the critical step from recent examinations of operations and the environment (Corbertt and Kleindorfer, 2003; Corbett et al., 2005) and operations sustainability (Linton et al., 2007). The concept of supply chain has existed for years. Supply chain can be defined as "a system of organizations, people, technology, activities, information and resources involved in moving a product or service from supplier to customer" whereas sustainable supply chain is in fact "a sophisticated supply chain wherein the used products may re-enter the supply chain at any point where residual value is recyclable". Sustainability is the current need and current trend and becoming more important day by day for every business organization.

Sustainability provides a cutting edge by not only protecting the environment but also increasing the profits of an organization. As cited earlier, a sustainable supply chain means a profitable supply chain from all three dimensions of sustainability.

Generally, in supply chains the focus is only on flow of products or services from the supplier to end customer through all the intermediate entities, but in sustainable supply chains there is also focus on reverse logistics which is a framework for retrieval of materials at the end of their lifecycle. Sustainability can be achieved in supply chains by integrating three main components: the natural environment, society and economic performance. It is these three components that distinguish a supply chain from a sustainable supply chain. These components or rule is generally known as triple bottom line and has been discussed by many researchers (Teuteberg and Wittstruck, 2010; Clift, 2003; Daly and Cobb, 1989). There needs to be a fine balance among all three components in order to achieve sustainability and thereby improve company's performance and profits. These components have been discussed in detail in the next section.

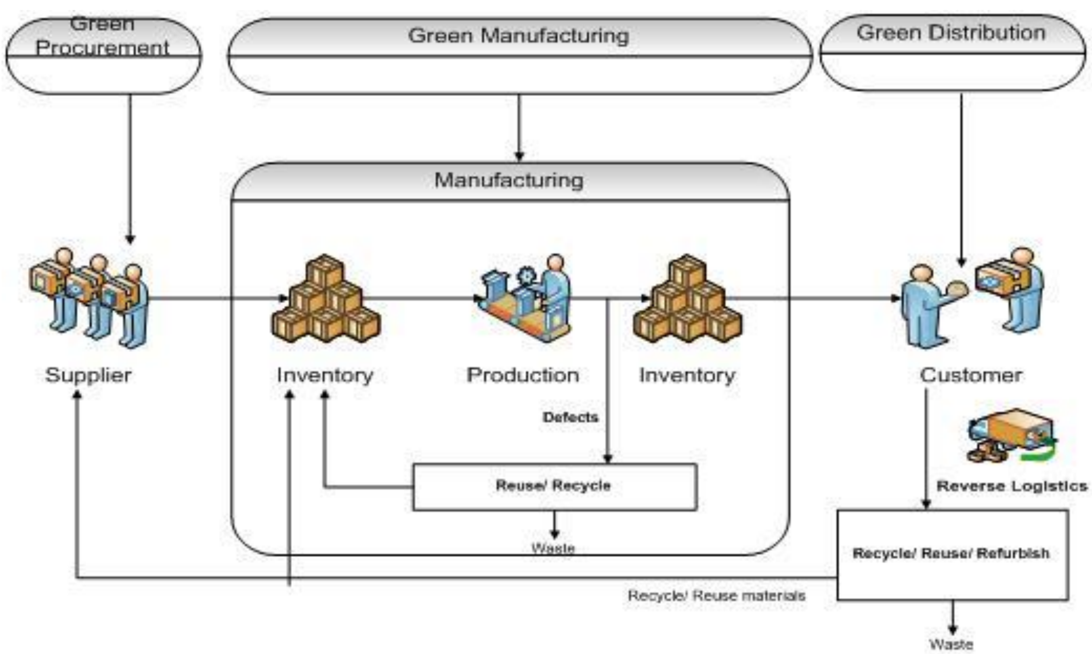


Figure 2-2: Framework of Sustainable Supply Chain

A general purpose framework for sustainable supply chain management is shown in Figure 2-2. This framework is based on previous work by Hervani (2005). Figure 2-2 depicts a sustainable supply chain that is very similar to a regular supply chain but except that Reverse logistics, Reuse / Recycle / Refurbish activities are incorporated into the supply chain.

From the above discussion it becomes clear that supply chain and sustainability are two different concepts yet they are closely integrated. This integration is achieved by implementing the triple bottom line concept.

Traditional Supply Chain	**Sustainable Supply Chain**
Focus is only on supply of goods from supplier to end customer	Environmental, social, and economical aspects are also considered along the chain.
Flow of materials and information is linear	Flow of materials is complex due to integration of triple bottom line dimensions
There is limited collaboration and visibility	There is higher collaboration and visibility.
Reverse logistics is not an integral part of the process	Reverse logistics is an important part of the supply chain process.

Table 2-4: Key Differences between Sustainable Supply Chain and Traditional Supply Chain

2.2.1 The Triple Bottom line

"In order to achieve the balance between the environmental, social and economic dimensions, the idea of "triple bottom line" was developed by Elkington (1997)" (Teuteberg and Wittstruck, 2010). Each of these components are defined as follows:

Economy: This is the dimension with focus on the financial needs. Economic dimension is seen as the most important one. It can be argued that, without economic success, no supply chain will exist in long run.

Social: This is the dimension that focuses on the social needs of employees such as equity, healtcare, employee benefits to name a few. Every organization has to pay attention to these needs of employees in order to achieve success. When employees needs are not satisfied or not taken care of, the productivity of thier work decreases. This has been explained by Maslow's heirarchy of needs (1954) which is employed by most organizations (Maslow, 1954). As per Maslow's theory the higher levels remain latent until the lower level needs are satisfied (Clift, 2003). Figure 2-3 illustrates this concept.

Environment: This dimension focuses on one of the most important aspect in today's world, Environmental Hazards. It deals with protecting environment from the hazards caused by industrialization and other technological advancements. Humans are so busy focusing on their own needs and demands that they forget they are depleting resources and causing damage to the nature. This eventually will lead to catastrophic effects; a few of them are already evident like global warming, depletion of Green lands, degradation of ozone layer and so on.

These topics have been in focus for over a decade now giving rise to the need for focusing on green supply chains. The governments across the world are also helping achieve this objective by imposing laws and specifications for environment friendly production and recycling of products in order to achieve green supply chains.

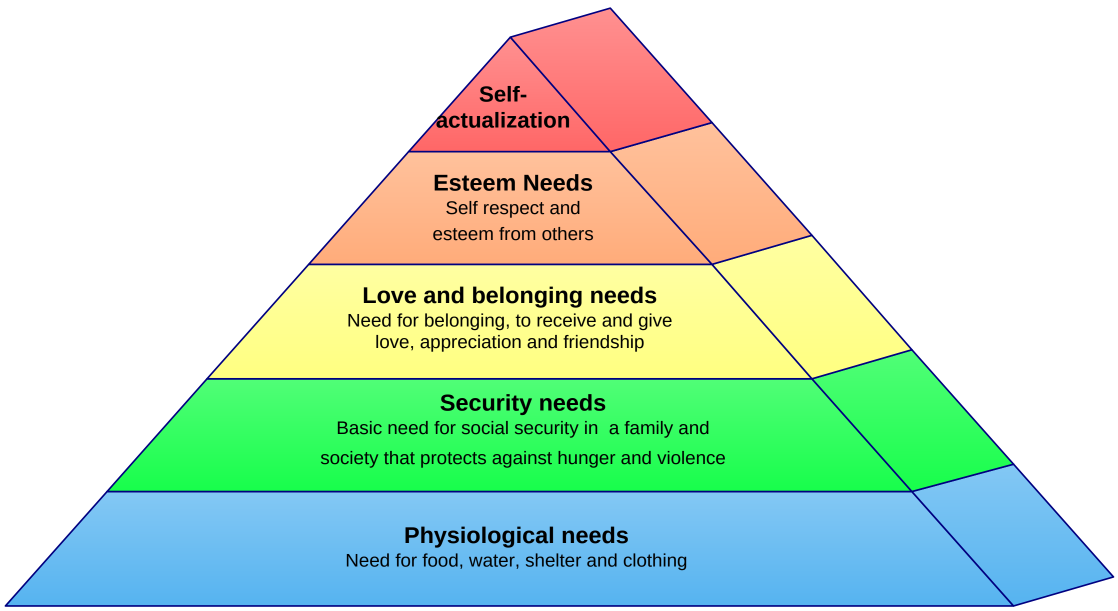


Figure 2-3: Maslow's Hierarchy of Needs (Maslow, 1954)

After discussing the three dimensions of sustainability and developing an understanding of what each stands for; it is important to understand their integration. From this perspective, the economy is a subsystem of human society, which is itself a subsystem of the biosphere and a gain in one sector is a loss from another (Daly and Cobb, 1989). This is illustrated through three concentric circles as shown in Figure 2-4:

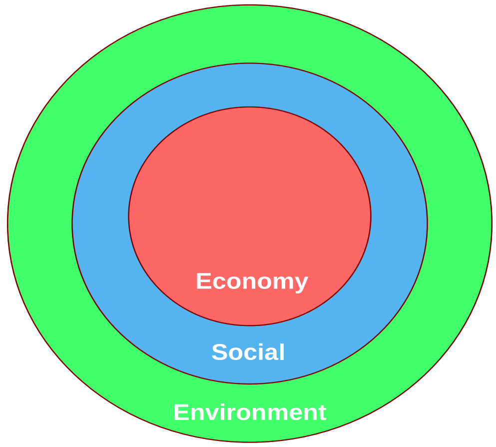


Figure 2-4: Hierarchy of sustainability dimensions (Daly and Cobb, 1989)

In order to achieve sustainability there has to be a strategic, transparent integration of organization's social, environmental, and economic goals in the systematic coordination of key inter-organizational business processes for improving long-term economic performance of the individual company and its supply chains (Carter and Rogers, 2007). This has been illustrated in the Figure 2-5.

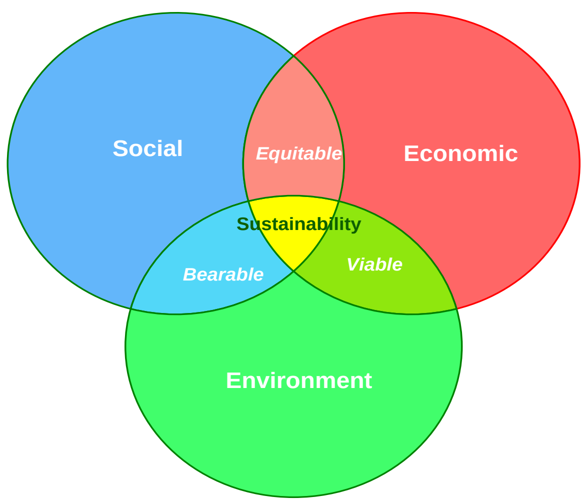


Figure 2-5: Scheme of sustainable development: at the confluence of three constituent parts (Carter and Rogers, 2007)

Figure 2-5 demonstrates that fulfilling either one or two of the components of triple bottom line will not help achieve sustainability. For instance with integration of environment and economic factors the process is viable, similarly when there is integration of environment and social factors the process is bearable, and when there is integration of social and economic factors the process is equitable; but a process is sustainable only when there is an integration of all three elements i.e. social, economic, and environmental.

2.3 Metrics for measuring Supply Chain Sustainability

A lot of research has been done on the topic of sustainability over the past decade, but most of them speak of benefits of sustainability and its effects. So far very few models address measurement of sustainability or propose a specific metric system for sustainability. Few authors have laid focus on measuring sustainability using the constraints of triple bottom line. Commonly most of the authors have addressed the environmental pillar of sustainability, and over the last decade, organizations have started to realize the importance of the other two dimensions but still there is a lot of work that needs to be done on integration of these three dimensions. Though there has been a growing need and interest in sustainability until recently, the social dimension was not well-defined. There was a little literature review available but once again the focus was not as broad as it should have been as compared to environmental aspect on which a lot of literature is available (Linton et al., 2007; Hutchins, 2008; Seuring, 2004; Kliendorfer et al., 2005)

An approach proposed by Clift (2003) called Global Reporting Initiative (GRI) proposes that it is useful to proceed from following broad categories of metrics through definite aspects to specific indicators, interpreted as:

Categories: broad areas or grouping of economic, environmental or social issues.

Aspects: general types of information related to specific category (e.g. greenhouse gas emissions, or donations to host communities)

Indicators: specific measurements of an individual aspect that can be used to track and demonstrate performance.

Table 2-5 lists various metrics used for measuring sustainability. The different metrics are categorized according to the economic, environment and social dimensions of sustainability.

Social Performance	Economic Performance	Environmental Performance
Internal social criteria	***Cost***	**Environmental practices**
Employment practices	Low initial price	***Pollution controls***
Disciplinary and security	Compliance with cost	Remediation
Employee contracts	Cost reduction	End-of-pipe controls
Equity labour sources	Compliance with sectorial price	***Pollution prevention***
Diversity	***Quality***	Product adaptation
Discrimination	Conformance quality Suppliers	Process adaptation
Flexible working arrangements	Consistent delivery	***Environmental management***
Job opportunities	Quality philosophy	Establishment of environmental
Employment compensation	Prompt response	Identification of environmental
Research and development	***Time***	Planning of environmental
Career development	Delivery speed	Assignment of environmental
Health and safety	Product development time	Checking and evaluation of
Health and safety incidents	Partnership formation time	**Environmental performance**
Health and safety practices	***Flexibility***	***Resource consumption***
External social criteria	Product volume changes	Consumption of energy
Local communities influence	Short set-up Time	Consumption of raw material
Health	Conflict resolution	Consumption of water
Education	Service capability	***Pollution production***
Housing	***Innovativeness***	Production of polluting agents
Service infrastructure	New launch of products	Production of toxic products
Mobility infrastructure	New use of technologies	Production of waste
Regulatory and public services		***Post Use***
Supporting educational		Recyclability
Sensory stimuli		Re-manufacturing
Security		Re-design
Cultural properties		
Economic welfare and growth		
Social cohesion		
Social pathologies		
Grants and donations		
Supporting community projects		
Contractual stakeholders		
Procurement standard		
Partnership screens and standards		
Consumers education		
Other stakeholders influence		
Decision influence potential		
Stakeholder empowerment		
Collective audience		
Selected audience		
Stakeholder engagement		

Table 2-5: Metrics for measuring sustainability

2.4 Stakeholders in Sustainable Supply Chains

There are two types of stakeholders involved in a sustainable supply chains. These can be classified as primary stakeholders and secondary stakeholders:

Primary Stakeholders: They have a direct interest or stake in the organization. For example,

- Customers
- Share holders
- Employees
- Suppliers
- Distributors
- Manufacturers
- Retailers
- Regulators

Secondary Stakeholders: They are not engaged in transactions but can affect or are affected by the supply chain activities. For example,

- Academic Institutions
- NGO’s
- Social Activists
- Environmental Groups
- Safety Advocates

2.5 Barriers in Sustainable Supply Chains

Walker et al. (2008) states that there are two primary factors acting as barriers: Internal barriers and external barriers. Internal barriers being those internal to the organization and external barriers are those arising outside the organization. A better understanding of this concept can be gained by reading the following concepts.

2.5.1 Internal barriers:

- **Costs:** According to Orsato (2006) costs can cause hindrance to application of green supply chain management. A study carried out at US firms revealed that cost is one of the main concern and the most serious obstacle when it comes to implementing green methodologies (Min and Galle, 2001; Walker et al., 2008).

- **Lack of Legitimacy:** The most famous con of green supply chain management is that the companies do not change practice but merely advertise that they do, creating a greenwash (Greer and Bruno; 1996). This leads to a very poor display on the companies' part. In order to avoid this from happening there is a grave need for audits and certifications such as ISO 14000 and stricter government policies. This also requires management commitment to avoid such mishaps from happening.

2.5.2 External barriers:

- **Regulation:** There are numerous environmental regulations and legislations on one hand they play a role of a driver, on the other they are also barriers as they cause unnecessary inhibitions to innovations (Porter and Linde, 1995; Walker et al., 2008).

- **Lack of cooperation among supply chain partners:** In a study carried out at chemical firms in US, it was found that cooperation among supply chain partners led to waste reduction and environmental innovation (Theyel, 2001). Generally there is lack of trust and commitment in the supply chain due to confidentiality which acts as a barrier.

- **Industry Specific Barriers:** It is reasonable to say that different industries have different drivers and barriers depending on the industry (Zhu, 2006). The drivers and barriers may vary depending on the type, size, product and customers of the specific supply chain (Walker et al., 2008).

2.6 Existing standards for sustainable supply chain planning

International Organization for Standardization (ISO)

- **ISO 14001**: ISO 14001 is part of a family of ISO 14000 standards. It provides a framework and requirements for Environment Management Systems. Most of the organizations thrive to be ISO 14001 certified along with other ISO certifications.

- **ISO 14004**: It provides general Environment Management System guidelines.

Carbon tax: "It is an Environmental tax levied on carbon emissions" (Hoeller, P. and M. Wallin, 1991). Carbon taxes are levied in order to reduce the emissions caused due to burning of fossil fuels, and also conserve the natural resources.

GBEP (Global Bio-energy Partnership): "This project was launched in partnership with G8 and 5 other countries in developing nations. It provides a forum to suggest rules and tools to promote sustainable biomass and bio-energy development" (GBEP, 2010).

The Green Gold Label: "This is a certificate system for sustainable biomass. It covers production, processing, transport and final energy transformation". (GGL, 2010)

IDB Bio-fuels Sustainability Scorecard: "The primary objective of this Scorecard is to encourage higher levels of sustainability in bio-fuel projects. It provides a tool to think through the range of complex issues associated with biofuels" (IDB, 2010).

IEA Task Force 40 (Fair-bio-trade): "It is one of the task forces of the International Energy Agency Bioenergy Implementing Agreement". Task 40 stands for Sustainable International Bio-energy Trade in Securing, Supply and Demand. It is working towards developing standards to evaluate their impact on markets and trade. (IEA, 2010)

EU Renewable Energy Directive (RED): European Union adopted a directive setting of a common EU framework for the promotion of energy from renewable sources. "The aim of this legislative act is to achieve by 2020 a 20% share of energy from renewable sources in the EU's final consumption of energy and a 10% share of energy from renewable sources in each member state's transport energy consumption by 2020" (BEFSCI, 2010).

International Sustainability & Carbon Certification: "It is a multi-stakeholder process to develop an implementable certification scheme for sustainable biomass and bio-energy production and to test these in a process-oriented pilot phase" (ISCC, 2010).

Low Carbon Vehicle Partnership: "Partnership of nearly 250 organisations from the automotive and fuel industries, the environmental sector, government, academia, road user groups and other organisations with a stake in the low carbon vehicles and fuels agenda". LowCVP has done important work in developing a life-cycle analysis tool for green-house gas emissions.

International Social and Environmental Accreditation and Labelling Alliance (ISEAL): "This Alliance defines and codifies best practice, at the international level, for the design and implementation of social and environmental standards systems" (ISEAL, 2010).

2.7 Sustainability in Service vs. Manufacturing based supply chains

Lin et al. (2010) states "Supply chain management techniques have mostly been applied to manufacturing industries, seldom on service industries. Recently, service industry has become an increasingly important force in the world economy. Along with the explosive development of the service economy, labour force evolved in a majority transformation from manufacturing to service sector". It has been found that lately more and more organizations are generating greater revenues from the service units rather than the manufacturing units, IBM and GM are good example of this (Quinn, 1992). According to Machuca et al., (2007) good services add an extra value to the traditional manufacturing supply chains.

According to Lin et al., (2010) "The service supply chain is a network of suppliers, service providers, customers and other service partners that transfer resources into services or products delivered to and received by the customers". The service supply chain can be moreover defined as the supply chain that focuses on after-sales relationship with the customer, till end of life of the product. On the other hand, a manufacturing or product based supply chain is the traditional supply chain which includes the flow of products from supplier to end-customer.

Sengupta et al. (2006) states that in service supply chains, physical labour plays the most important role as it involves direct involvement of humans to cater to the needs of the customers. Also many of the decisions are to be taken locally as per the variations in the need leading to uncertainties in output due to human involvement, unlike manufacturing supply chains where this seldom happens and standardized procedures are followed.

Though these two supply chains are different at operational levels there still exist some similarities between the two including demand management, customer relationship management and supplier relationship management (Sengupta et al., 2006; Ellram, 2004).

2.8 Areas of application

Sustainable techniques and methods have been employed in various sectors including service, manufacturing, logistics etc. Deloitte Canada, one of the member firms of the Deloitte Touche Tohmatsu network have been increasingly relying on video and teleconferencing as a critical element of the firms' green initiatives. With tele-presence, participants forget after five minutes that they are in a video conference; they can read body language and turn their heads when someone speaks. Telepresence not only enhances the productivity of its professionals but it also reduces travel time, saves costs and is more environmentally considerate as well (Deloitte Canada, 2008).

Likewise a consumer product giant Unilever is hoping to change its user attitudes toward an increasingly scarce and precious resource: water. As per a report in 1995, Unilever initiated a worldwide effort to reduce its consumption of fresh water. The whole process started by assessing their water usage. Unilever first took steps to reduce their Canadian water footprint. Their efforts were largely appreciated and also recognized when they won Green Toronto Awards for two consecutive years which led to implementation of green attitude throughout the organization. There efforts were achieved largely by implementing water recycling and conservation of resources. They also improved processing techniques and product innovations contributed largely towards this effort. Unilever demonstrates a good example of strong corporate social responsibility, their efforts to reduce water footprint has resulted in huge profits for the company and of-course environment along the entire process (Unilever, 2008).

Another good example of an organization implementing sustainable practices is U.S. postal service. They have tried to integrate sustainability into their strategic and operational priorities. Sustainable practices have been a key enabler in driving their financial results. It was noted that from years 2007 to 2009 the U.S postal service avoided over $400 million just by implementing sustainable practices in their operations (Linich, 2008).

Therefore, we can say that areas of application of sustainable practices are not limited. Many organizations have started adopting standards and are making sincere efforts to become sustainable. The examples laid by these huge organizations can be a stepping stone for other organizations. These organizations can also be used for benchmarking purposes in future.

2.9 Alternatives for sustainable supply chain

Reverse logistics: It is one of the least understood and least studied aspects of supply chain. In some businesses, the level of returns is so low that very little time and effort is invested in making it work. However, we know that it plays an important role in achieving sustainability in supply chains. In order to recycle, refurbish and keep track of products throughout their life- cycle, every organization needs reverse logistics.

Green Packaging: In order to minimize wastes or by-products of supply chain processes, it is important to have green packaging. This means use of recycled material, which can be recycled again after use. As we all know use of plastic is hazardous to environment, which raises the need for green packaging to go green.

Shared operations: The willingness of organizations to share operations with others in the supply chain such as sharing of vehicles, information and so on can improve efficiency among other benefits. Sharing of operations can effectively lead to reduction in vehicle utilization, emission from all sources and overall costs.

Sustainable Design: Design building with consideration for traffic flows and neighbours. Strategic location of warehouses and factories is important for strategic design. A lot of research has been carried out in this area to provide solutions to green facility layout and warehouse location problems.

Use of IT and automated systems: In the early days everything was done manually from docking, counting to tracking of goods. But with advancement in technology all is automated nowadays**.** Even though most of the systems are automated, we are still far from fully capitalizing on the benefits of technology**.**

Enriching employee values and self-esteem: Moving from environmental and cost issues, another important practice is focusing on the employees values and self-esteem. As stated by Maslow (1954) there are certain needs that need to be satisfied. These include physiological, safety, love and belonging, self-esteem, and self-actualization.

Adopting Green methodologies: Green Methodologies include a long list of activities including green manufacturing, waste reduction and use of environment friendly fuels.

2.10 Best Practices in Sustainable Supply chains

Case Study 1: Green packaging and reverse logistics – The free pack net (Sood and Emmett, 2010).

A packaging company named Free Pack Net came up with a feasible packaging methodology which was based on research and analysis. They produced materials that met technical, economic, and practical feasibility in packaging industry. They also succeeded in creating a structural and modular packaging that is able to resist lateral and vertical loads. Since these materials were made of modular elements they proved to be beneficial as they could be collapsed when returned after use (Sood and Emmett, 2010).

The total rental costs of reusable packaging are less than the purchase and disposal costs of disposable packaging. "Customers benefited as there was considerable reduction in damages caused during the transportation and handling operations as the damage have been typically reduced from 5% to 0.4%" (Sood and Emmett, 2010).

In the year 2006 Free Pack Net assessed its environmental benefits by comparing its current disposal packaging methodology to new reusable packaging technique. The results showed that benefits which were well over 50% for most of the indicators (Sood and Emmett, 2010).

Case Study 2: The manufacturer/ shared user solution: Griffins (NZBCSD, 2003)

A food manufacturing company (Griffins) in New Zealand produces high volume low weight products such as potato chips and biscuits. Since these products take a lot of space even though they are of a light weigh, it leads to wastage of resources when it comes to transportation and warehousing. In order to overcome this problem and optimize the usage of its resources they came up with a stratergy to share their warehousing operations by hiring a third party logistics provider (Toll Logistics). This strategy included carton configurations, collaborative logistics and identification of pallet heights which eventually led to cost reduction (NZBCSD, 2003).

Case Study 3: Progressive enterprises: The grocery retailer, sustainable design (NZBCSD, 2003)

Progressive Enterprises is a multi-million dollar distribution centre in New Zealand. They operate 24/7 catering 153 supermarkets in southern Auckland. Progressives operations led to congestion and pollution due to their huge fleet of trucks. To optimize their truck utilization and reduce congestion they strategized to have round the clock distributions which included scheduling deliveries at off peak hours, buying directly from the factory. These changes considerably reduced the traffic flows, costs and optimized vehicle utilization (NZBCSD, 2003).

They also adopted a sustainable design and relocated away from residential areas which considerably reduced noise and pollution (NZBCSD, 2003).

Case Study 4: General Merchandise - The warehouse (NZBCSD, 2003)

In this case study benefits of implementing technology in operations is shown. It was found that automation can optimize the results. The Warehouse which is one of the largest mixed retailers in New Zealand operates from two distribution centres. These distribution centres are strategically located and to further reduce transportation costs they implemented automated storage systems consisting of sorting and accumulation conveyors. Automation of processes led to considerable benefits including reduction in arrival and departure of delivery vehicles, reduction in energy costs and elimination of repetitive work (NZBCSD, 2003).

Case Study 5: McDonalds – Employee Program (McDonalds, 2010)

A four- part employee development program was initiated in China by one of McDonald's Supplier (The Marketing Store). The main objective of the program was educating employees and providing well-rounded development opportunities. This program enriched their knowledge in various areas including computers, reading, communications and internet online services. The program resulted in confident and highly productive employees (McDonalds, 2010). From this case it can be noted that enriching employee experience plays an important role in them being productive and giving back to the organization.

Case Study 6: McDonalds - Greening the Restaurants (McDonalds, 2010)

McDonald's has initiated many green programs in Europe which have been successful so far. These include solar panels, windmills, heat recovery systems and recyclable building materials. As part of sustainability drive in "Green City, UK", 11 of McDonald's restaurants dispose their waste at an energy-recovery facility and test environmentally-friendly technologies. Similarly a project is being built in Sweden to conserve natural resources without compromising function or comfort.

Case Study 7: Green reverse supply chain waste and Kodak (Sood and Emmett, 2010)

Kodak introduced disposable film cameras in mid-1980. The product was great, the pricing was great, and the public liked the convenience. But this had its side-effects leading to more garbage, pollution and environmental hazards as plastic used to make these cameras was not disposed safely.

After noticing this problem they eventually came up with a strategy to collect the cameras at end of their life-cycle and then recycle them properly. In order to implement this successfully, they had to restructure their logistics in a reverse direction which had its usual challenges. Reverse logistics was not a well-honed concept at that time but gradually a supply loop was created.

Once, this process started they realized that more and more parts could be recycled which eventually resulted in cost savings. They improvised on this process by redesigning the product itself to maximize the reuse resulting in greater benefits and savings.

2.11 Existing state of research

There has been an increase in research on the topic of sustainability and sustainable supply chains in recent years. As Seuring and Muller (2007) state that there have been 194 papers published on this topic from 1994 to 2007. However most of the papers lay focus on the environmental aspect of sustainability and have ignored economic and social aspects. 140 papers deal with the environment and the rest work on economic and social side.

This literature review provides details on the evolution of supply chain concepts, sustainable supply chain advent, its advantages, enablers, alternatives, metrics, barriers, and case studies in successful implementations for years 2008-2010. A total of 29 papers were published covering these topics during the years 2008-2010.

Chapter 3:

Solution Approach

In this chapter, we present an integration solution approach based on Interpretative structural modeling (ISM) and Analytic network process (ANP) to determine enablers and most appropriate alternative(s) for sustainable supply chain planning. A comprehensive literature review and survey was carried out to identify the enablers. The relationship among the enablers was explored using ISM. The results of ISM were then used as an input for ANP along with potential list of alternatives to generate the best alternative(s) for sustainable supply chain management.

The proposed framework is shown in Figure 3-1 and comprises of four phases. Phase one is data collection where research is carried out to understand sustainable supply chains and determine their enablers. This involves detailed literature review of previous research work on this topic and other related topics. For the purpose of literature review various journals and research papers were referred from search engines such as science direct, emerald insight and inter science wiley.

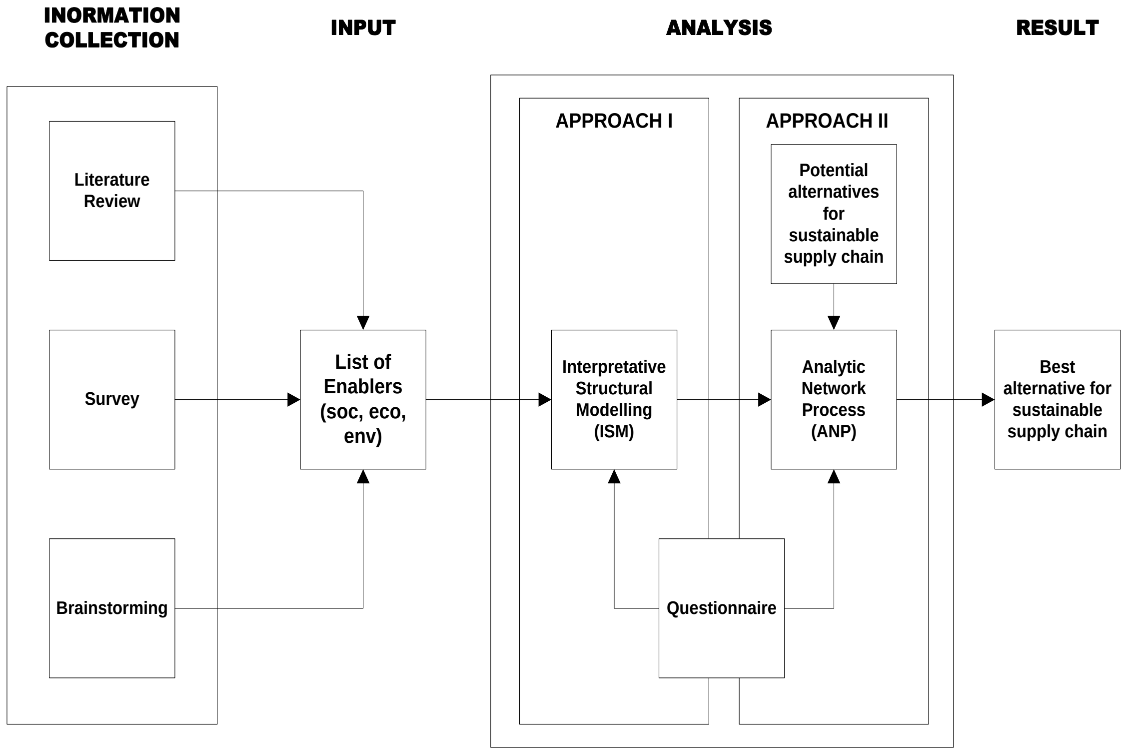


Figure 3-1: Integrated framework for ISM and ANP

Next phase is Input wherein the list of enablers is generated based on the data collection. These enablers are then categorized based on environmental, social and economic aspects of sustainability.

The third phase is Analysis wherein the integrated ISM-ANP approach is implemented. ISM is used to model the enablers and develop a digraph depicting the relationships and priorities amongst the enablers. The results from ISM and the list of potential alternatives are used as an input for ANP which generates prioritized alternatives for final selection. The result of ANP is the best alternative for implementation to make supply chain sustainable.

3.1 Enablers of Sustainable Supply Chains

Sustainable supply chains are more complex to achieve as compared to the traditional supply chains. In this thesis, we have determined 21 enablers for sustainable supply chains that have a major impact in achieving sustainability. These enablers are listed in Table 3-1. The enablers were selected based on literature review and opinions collected from a survey (see Appendix) sent to various supply chain experts.

	Enabler	**Category**	**Reference**
1	Information Sharing	Env, Eco	Hahn et al., 2000; Lee and Whang, 2000
2	Employee Training	Env	Sari; 2009
3	Adoption of Env. Standards	Env	Boiral and Sala, 1998; Rondinelli and Vastag, 2000
4	Strategic Planning	Env, Eco, Soc	Walton et al., 1998
5	Quality Management	Eco, Env	Foster, 2008; Kaynak and Hartley, 2008
6	Risk Management	Eco, Env	Christopher and Lee, 2004; Paulson, 2005
7	Collaborative Partnerships	Env, Eco, Soc	Theyel, 2001
8	Technology Management	Env, Eco, Soc	Tang et al., 2000
9	Governmental Regulations	Env, Soc	Porter et al., 1995; Guenther et al., 2010
10	Adoption of Green Practices	Env	Guenther et al., 2010; Chen et al; 2005
11	Management Commitment	Env	Greer and Bruno, 1996
12	Voice of Customer	Env, Eco, Soc	Kleindorfer et al., 2005
13	Quality of Life	Soc	Zakland et al., 2004
14	Gov. Rewards and Incentives	Env	Guenther et al., 2010
15	Environmental Quality Management	Env	Foster, 2008
16	Adoption of safety standards	Env, Eco, Soc	Guenther et al., 2010
17	Labour equity	Soc	Hutchins et al., 2008
18	Employee Healthcare	Soc	Hutchins et al., 2008
19	Employee Injury Protection	Soc	Hutchins et al., 2008
20	Philanthropy	Soc	Hutchins et al., 2008
21	Freeing of public space	Soc	Hutchins et al., 2008

Table 3-1: Enablers of Sustainable supply chain

The details of the various enablers are presented as follows:

Information Sharing: Information sharing leads to visibility in supply chains which in turn leads to cooperation among supply chain partners. According to Hahn et al. (2000) effective communication and coordination among all elements of supply chain are essential to its success. Lee and Whang (2000) suggested that information is a basic enabler for tight coordination in supply chains.

Employee Training: Helps achieve social sustainability and also provides the employees with expertise to perform their tasks efficiently. Companies' power comes from the physical and mental strength of their workers. Therefore, sustainability of being powerful for an organization is tied to the physical and psychological health of its employees, and their knowledge and skills. Since the importance of human resources on the organizational success has been realized, responsibility and authority of Human Resources Departments have broadened, especially in accommodation sector. Organizing Employee Trainings and maintaining Occupational Safety and Health are among the main functions of Human Resources Management departments (Sari; 2009). These two functions interact and they both serve the aim of protecting employees' physical, psychological and social health.

Adoption of Environmental Standards: ISO 14001 brings the achievement of environmental objectives and cost reductions, as its adoption reduces the firm's environmental impact and improves aspects of operational efficiency and effectiveness. Furthermore, ISO 14001 provides an external benefit through signalling the firm's commitment towards environmental management to its external stakeholders (Boiral and

Sala, 1998; Rondinelli and Vastag, 2000). Therefore, firms adopt ISO 14001 when their expected (long-term) profit with certification is greater than without adoption. In other words, the benefits of ISO 14001 adoption outweigh the cost.

Strategic Planning: Strategic planning is an integral part of every organization and an important phase in successful implementation of supply chain management. As per (Walton et al., 1998) environmental issues are becoming an intrinsic part of strategic planning process in organizations mainly due to governmental regulations and customer pressure for sustainable products and services.

Quality Management: Quality management in context of supply chains is defined as a systems-based approach to performance improvement that leverages opportunities created by upstream and downstream linkages with suppliers (Foster; 2008) and customers. As competition moves beyond a single firm into the supply chain, focus is shifting from management of internal practices alone. Instead, quality managers must integrate their firm's practices with those of customers and suppliers (Kaynak and Hartley; 2008).

Risk Management: Risks are associated with negative consequences or impact of different processes, activities and resources of supply chains (Christopher and Lee, 2004) and supply chain (Paulson, 2005; Spekman and Davis, 2004). The expectation of risk is difficult to define. Should risk event be expected (as supplier has quality deficiencies experienced by Robert Bosch GmbH, Wagner and Bode, 2006) or unexpected. Risk is also sometimes interpreted as presence of unreliable and uncertain resources thereby creating supply chain interruption, whereas uncertainty can be explained as matching risk between supply and demand in supply chain processes. Risk management is very crucial part of supply chain as there can be various kinds of risks varying from financial to operational risks.

Collaborative Partnerships: In an environmental study based on US chemical firms, it was found that firms whose environmental strategy comprises close supply chain relations are likely to be leaders in waste reduction and environmental innovation (Theyel, 2001). Generally, there is lack of trust and commitment in the supply chain due to confidentiality which acts as a barrier. Thereby cooperation among supply chain partners plays a very important role in development of sustainable supply chains.

Technology Management: Use of IT tools to monitor the supply chains and sharing information among the partners leads to visibility in supply chain, thereby providing better cooperation among different levels of the supply chain. Electronic data interchange and internet have enabled partners in supply chains to act upon same data rather than rely on distorted and noisy data that emerges in an extended supply chain (Lee et al., 2000). Swafford et al (2008) emphasize the role of IT integration and flexibility in achieving supply chain agility.

Adoption of green practices: Sustainable production and consumption will be the main characteristics of future societies to provide sustainable development and a sustainable society. The manufacturing industry is one of the main sources of environmental pollution. Therefore, all industries are seeking to minimize their environmental impacts. Green manufacturing, which is an advanced mode of manufacturing, involves application of sustainable science to the manufacturing industry on a very wide range of topics, such as environmental consciousness, life cycle thinking, and sustainable development, which increase the risk (Chen et al; 2005). Green procurement has an independent effect on the whole environmental value chain, whether only one or more companies of the chain choose to implement it (Guenther et al, 2010). According to Guenther et al (2010), Green procurement works together with suppliers, R&D and operations for designing solutions to minimize environmental impacts and address stakeholder concerns. In this capacity, it can serve to control and reduce environmental impacts within the whole life-cycle of a product, and improve life-cycle analyses as well. Awasthi et al (2010) propose a fuzzy multicriteria approach for evaluating environmental performance of suppliers. Bai and Sarkis (2010) propose a grey system and rough sets based methodology for integrating sustainability in supplier selection.

Governmental Regulations: Environmental legislation and regulations can inhibit innovation by prescribing best available techniques and setting unreasonable deadlines (Porter et al., 1995). For example, The EU (European Parliament and the Council, 2003) has made green procurement almost obligatory by various legislations – by means of the Directive on Waste Electrical and Electronic Equipment (WEEE). The aim of this directive is to apply recycling rates, re-usage guidelines, etc., as instruments for waste reduction (Guenther et al, 2010).

Management Commitment: Commitment from management includes an effort and financial backing from the upper management to implement sustainability. The most famous con of green supply chain management is that the companies do not change practice but merely advertise that they do, creating a greenwash (Greer and Bruno, 1996).

Voice of Customer: A trigger for the increased number of ISO 14001 adoptions is the environmental preferences and pressures of stakeholders, especially on the demand side, as they influence firm profits. Firms therefore attempt to satisfy their stakeholders with ISO 14001 adoption, as this indicates their commitment to environmental management. Indeed, many previous studies that have analyzed the determinants of ISO 14001 adoption have found that environmental preferences and pressures of stakeholders influence the firm's decision. In particular, Christmann and Taylor (2001), Nakamura et al. (2001),Welch et al. (2002), Bansal and Hunter (2003), Hibiki et al. (2004), Neumayer and Perkins (2004), Wu et al. (2007), Arimura et al. (2008) and Nishitani (2009) suggest that foreign customers form a significant stakeholder group for encouraging the adoption of ISO 14001. This implies that foreign customers are more likely to consider that the qualities of the supplier's EMS will influence the quality of their EMS in the global supply chain. Community pressures and the threat of liability can also drive companies to improve their environmental performance. Clearly, companies are most likely to improve their environmental performance when public pressure or strong regulations exist. Sometimes, companies themselves lobby for regulations if they have developed an environmentally friendly technology and believe that regulations requiring their technology would give them a competitive advantage (Kleindorfer et al., 2005).

Quality of Life: One of the tiers of sustainability is the social side, which has been neglected by most authors. The parameter to measure social aspect is Quality of life which makes this an important enabler for sustainable supply chains. As Zaklad et al. (2004) have pointed out that people are responsible for driving at least 50 percent of performance and thereby for those of us who care about supply chain efficiency are right to think this inherently human system factor is important. It is important to build the human capabilities needed to sustain an innovative, nimble, collaborative, and integrated supply chain.

Labor equity: Labor equity implies that there is no discrimination of any employee based on any ground (age, sex, race) and all the employees are treated equally. Hutchins (2008) provides a metric to measure this enabler using wage as a base for measurement.

Employee healthcare: Employee healthcare is an important quantifying factor for social sustainability. This may include various medical costs such as surgeries, transplants and so on. Hutchins (2008) suggests health maintenance to be metric to measure healthcare.

Employee injury protection: Precautions need to be taken to ensure employee safety at work. Employee injury protection is another important enabler for social sustainability. Hutchins (2008) also provides a metric to measure social sustainability via employee safety.

Philanthropy: Organizations today participate in numerous social activities including financial roles within the community (Hutchins et al., 2008). These also include charities, funding performance, and providing grants to students.

3.2 Interpretive Structural Modeling (ISM)

"Interpretive structural modelling is an interactive learning process in which a set of different and directly related elements are structured into a comprehensive systematic model (Warfield, 1974; Sage, 1977; Agarwal et al., 2007)". This methodology helps develop the direction of complex relationships among elements in a system (Sage, 1977; Faisal et al., 2006). The model thus obtained by applying this methodology presents a 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 (Faisal et al., 2006). Therefore, we can say that ISM modelling not only provides insights into the relationships between the various enablers but also helps develop the hierarchy based on the importance of each enabler and provides a visual representation of the scenario. The method is interpretative as the judgement of the group decides whether and how the variables are related. It is structural as the basis of relationship is an overall structure that is extracted from a complex set of variables. It is a modelling technique as the specific relationships and overall structure is portrayed in a digraph model. ISM has been applied in various fields. Table 3-2 presents some of them.

Author	**Area of Application of ISM model**
Richard H. Watson, 1977	Technological Forecasting and Social Change
Kannan et al., 2009	Conservation and Recycling
Backus et al., 1995	Agriculture
Shankar et al., 2005	Reverse Logistics
Chen et al., 2010	Automobile Industry

Table 3-2: Areas of application of ISM

The steps to develop ISM are as follows: First of all, the variables or enablers are identified. These variables are found based on literature review and also inputs from the peers of the particular field. Once the variables are identified, a contextual relationship is established among the variables with respect to their influence on each other. Once we have established a contextual relationship among the variables, we develop a Structural self-interaction matrix (SSIM) based on the pair-wise comparison of the variables. The SSIM is then converted into a Reachability matrix and its transitivity is verified. Transitivity states that if variable A is related to B and B is related to C then A is related to C. After we check for transitivities, we get the final Reachability matrix which is then portioned into different levels. Then based on the relationships in the Reachability matrix, a directed graph is drawn and the transitive links are removed which is our final ISM digraph.

3.2.1 Structural Self-Interaction Matrix

For analyzing the relationship between the various enablers of sustainable supply chains, a contextual relationship of “leads to” type is chosen. This means that one variable helps to ameliorate another variable. Based on this, contextual relationship between the variables is developed (Faisal et al., 2006).

After defining contextual relationship for each variable, the relationship between any two sub-variables (*i* and *j*) and the associated direction of relation is questioned. Four symbols are used for the type of the relation that exists between the two sub-variables under consideration (Faisal et al., 2006).

- V: enabler *i* will ameliorate enabler *j*;
- A: enabler *j* will ameliorate enabler *i*;
- X: enabler *i* and *j* will ameliorate each other;
- O: enablers *i* and *j* are unrelated.

The template for SSIM is as show in the Table 3-3:

(j) / (i) Enablers	5	4	3	2
1	A	V	A	X
2	X	O	X	
3	O	X	V	
4	V	A		
5	X			

Table 3-3: Template for SSIM

3.2.2 Reachability Matrix

The SSIM is converted into a Reachability matrix, which is a binary matrix consisting of 1's and 0's. The rules for substitution of 1's and 0's are as mentioned below:

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

(j) (i) ENABLERS	1	2	3	4	5	6	7	8
1	1	1	1	0	0	0	0	0
2	0	1	1	0	0	0	0	0
3	1	1	1	1	1	1	1	0
4	1	1	1	1	1	1	1	0
5	1	1	1	1	1	1	1	0
6	1	1	1	1	1	1	1	0
7	1	1	1	1	1	1	1	0
8	1	1	1	1	1	1	1	1

Table 3-4: Sample Initial reachability matrix

3.2.3 Level partitioning the Reachability matrix

“From the final Reachability matrix, partitioning is done by assessing the reachability and antecedent sets for each variable” (Warfield, 1974). The reachability set consists of the element itself and other elements, which it may help achieve, on the other hand antecedent set consists of the element itself and other elements, which may help achieving it. Then the intersection of these sets is derived for all the elements (Faisal et al., 2006). The elements for which the reachability and intersection sets are same are the top level elements in the ISM hierarchy. “The top level elements in the hierarchy would not help achieve any other element above its own level” (Faisal et al., 2006). Once the top level elements are found they are separated out of other elements. Then this process is continued until the level of each element is found.

3.2.4 Conical Matrix

A conical matrix is developed by clustering variables in the same level, across rows and columns of the final Reachability matrix.

3.2.5 Digraph for ISM based models

From the conical form of the Reachability matrices, the structural model is generated by means of vertices and lines based on the relationship between the variables '*i*' and '*j*'. Then the transitivities are removed to develop the digraph or directed graph. For example, in the conical matrix 1's represent a relation and 0's represent no relation, thereby we find that there is relationship between two elements which are at top level in our diagraph. We add directed arrows in the digraph to depict this relationship. The rest of the elements can be ignored for the moment as they are at a lower level. In the next step we take elements in the next level i.e. level II. This process is carried out till the last level is reached and transitivity's are removed. Thereby, we get a directed graph for list of activities showing the relation among each activity.

3.2.6 MIC MAC Analysis

MICMAC analysis refers to Matrice d'Impacts Croisés Multiplication Appliquée á un Classement (Duperrin, 1973) and involves development of a graph to classify different enablers based on their driving and dependence power. From the conical matrix, driving power and dependence of each variable is determined. This is used as an input to develop a graph to categorize the variables into 4 clusters namely Independent, Linkage, Autonomous and Dependent.

Independent variables: These are most important variables. They have high driving power and low dependence.

Linkage Variables: These variables are of intermediate importance as they have high driving power but also have high dependence. This implies that they can drive the system but are dependent on other variables.

Dependent Variables: These variables have low driving power and high dependence. They are usually driven by independent variables.

Autonomous Variables: These variables are stand-alone. They neither have high driving power nor high dependence but they are still essential part of the system.

3.3 Determining the Alternatives

The alternatives were determined from the literature review, discussions with supply chain experts and questionnaire survey keeping in mind the enablers found previously. Approaches like brainstorming and literature review were used to narrow down to the list of alternatives shown in Table 3-5.

Alternatives
Carbon taxing
Incentives for green certification
Employee training programs on sustainability
Management training for corporate sustainability
IT-enabled process management for sustainability
Community awareness campaigns on sustainability
Implement Environmental Management Systems
Mandatory fair-trade practices in organizations
Employee safety at work programs
Incentives for collaboration on sustainability

Table 3-5: Alternatives for sustainable supply chains

Carbon taxing: The carbon tax is an environmental tax that is levied on the carbon content of fuels. A carbon tax can be implemented by taxing the burning of fossil fuels like coal, petroleum, and natural gas in proportion to their carbon content. It is a known fact the supply chain processes leave a major carbon footprint if not properly controlled. Thereby, stricter rules on carbon taxing are an effective way for achieving environment sustainability.

Incentives for green certification: Giving incentives to organizations that are certified green will encourage the management to do more work towards environmental sustainability.

Employee training programs on sustainability: Employee training programs can play a vital role in improving the lifestyle of employees and also make them more knowledgeable. This alternative can help achieve social sustainability.

Management training for corporate sustainability: Training management for corporate sustainability means educating and spiking interest in the top level executives to be sustainable. Most of the large corporations today are taking up corporate social responsibility, and training the management to do so is an effective way to achieve corporate sustainability.

IT-enabled process management for sustainability: Technology can play an important role in achieving sustainable supply chains. IT-enabled process management will be useful in strategic planning by giving access to real time information.

Community awareness campaigns on sustainability: Community awareness campaigns such as public demos, training camps, monetary rewards for green practices can increase customer’s interest, chances of raising concerns for green products, and preference for green certified organizations.

Implement environmental management systems: It refers to the management of an organization's environmental programs in a comprehensive, systematic, planned and documented manner through environmental management systems such as adoption of ISO 14001.

Mandatory fair-trade practices: Fair-trade is defined as an "organized social movement that aims to help producers in developing countries make better trading conditions and promotes sustainability". This alternative primarily satisfies social sustainability and labour equity. It also provides economic sustainability.

Employee safety at work programs: Employee safety at work is an important concern and should be taken care of by the management. Generally, in the process of supply chains safety of workers at lower levels is ignored. Safety at work programs should be implemented at all levels in supply chain.

Incentives for collaboration on sustainability: Collaboration in a supply chain has shown benefits in terms of reduction in bullwhip effect, forecasting and meeting customer needs. But most of the people in a supply chain are not willing to share information with their partners which leads to lack of collaboration. Incentives for collaborating firms can promote this method which has benefits like economic sustainability.

3.4 Analytic Network Process (ANP)

A few multi-criteria decision making techniques were analyzed before deciding on using ANP. These techniques included TOPSIS, VIKOR and AHP (Cristóbal, 2011). In TOPSIS the chosen alternative should be as close to the ideal solution as possible and as far from the negative-ideal solution as possible (Hwang et al., 1993). The ideal solution is formed as a composite of the best performance values exhibited by any alternative for each attribute. On the other hand VIKOR is used to determine the preference ranking from a set of alternatives in the presence of conflicting criteria. The justification of VIKOR is to use the concept of the compromise programming to determine the preference ranking by the results of the individual and group regrets. However, eventually an advanced from of AHP called ANP was used.

Analytic hierarchy process (AHP) was introduced by Saaty in 1980's for choosing the most suitable alternatives in multi-criteria decision analysis. It is a structured technique for dealing with complex decisions. AHP allows users to find a solution to their problem that best suits their goals and understanding of the problem rather than prescribing a correct decision (Agarwal et al., 2002).

Author	**Area of Application of ANP**
Jharkharia and Shankar, 2004	Selection of logistics service provider
Wu et al., 2008	Partner Selection in strategic alliances
Agarwal and Shankar, 2002	Performance improvement is supply chains
Meade and Sarkis, 1999	Organizational project alternatives for agile manufacturing

Table 3-6: Areas of Application of ANP

Analytic network process (ANP) is a more general form of AHP, incorporating feedback and interdependent relationships among decision attributes and alternatives. This provides a more accurate approach when modelling a complex decision environment (Saaty, 1999; Agarwal et al., 2002). The process is designed to provide a holistic approach in which all the factors are laid out in an AHP or in an ANP system that allows for dependencies. All possible outcomes that can be thought of are joined in these structures and then both judgement and logic are used to estimate the relative influence from which the overall answer is derived (Agarwal et al., 2002). The different steps of ANP are described as follows:

3.4.1 Model Construction and problem structuring

The model was constructed in a hierarchical manner using the beta version of ANP software “Superdecisions”. The top most elements in the hierarchy is goal or the objective and then the criteria, which are then decomposed into sub-criteria and attributes if any. The development of this model requires identification of attributes at each level and definition of their inter-relationships; this is achieved using the results of ISM in our case. The ultimate objective of this hierarchy is to identify the alternatives that will be most significant in implementing sustainable supply chains efficiently.

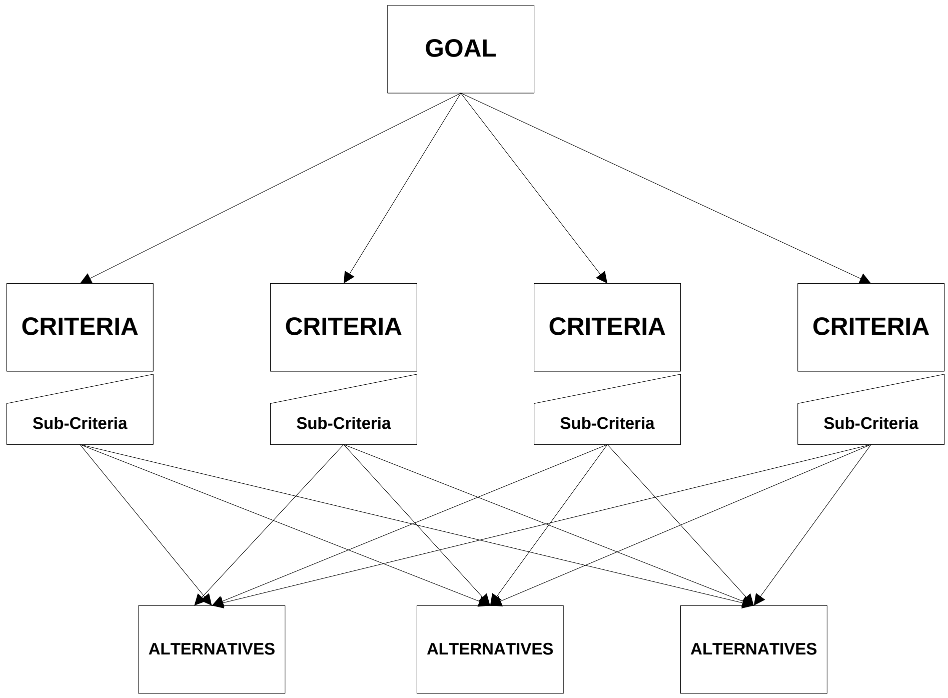


Figure 3-2: Abstract representation of the model

3.4.2 Pair-wise comparison between components/attribute levels

Once the model is developed the next step is to answer a series of pair-wise comparisons. The rating is done on a scale of one to nine with one being equally important and nine being most important. These comparisons are with respect to upper level control criteria in accordance with their relative importance towards the control criteria. In case of interdependencies, the components within the same level are viewed as controlling components for one another. Levels may also be interdependent. Through pair-wise comparisons between the applicable attribute enablers of performance dimension cluster, the weighted priority is calculated (Saaty, 1980). The screenshot of this pair-wise comparison questionnaire is shown in Figure 3-3.

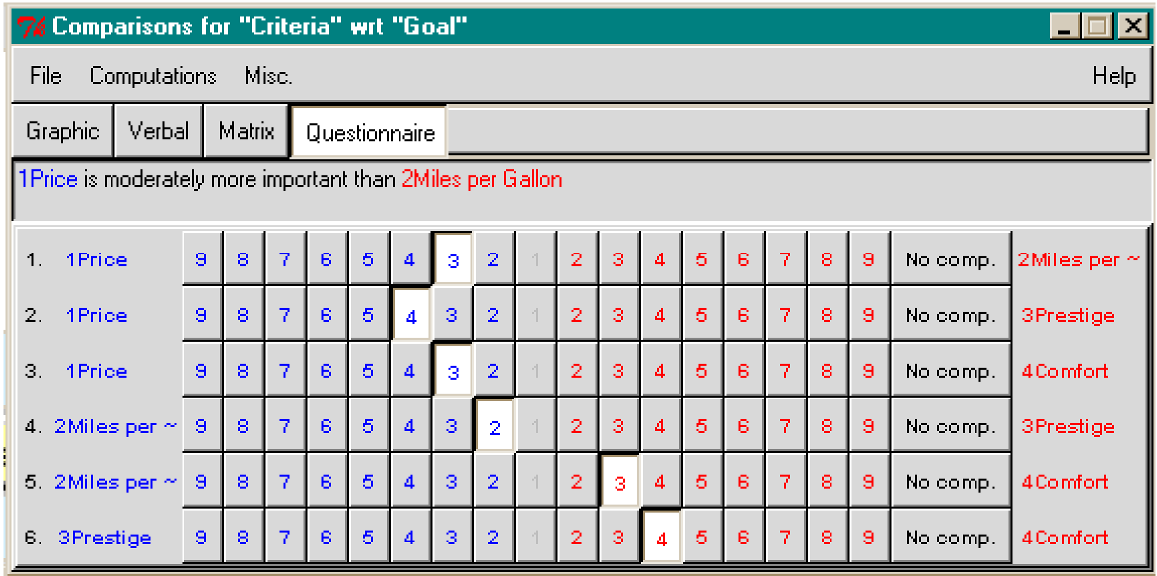


Figure 3-3: Screenshot for pair-wise questionnaire comparison (Saaty, 2003)

3.4.3 Pair-wise comparison matrices of interdependencies

To reflect interdependencies in the network, pair-wise comparisons among all attributes/ enablers are conducted. In the previous step we examined how these sub-factors influenced the main factor. In this step we examine how they influence each other. In simpler words, the interdependencies are measured.

3.4.4 Super-matrix formation

The comparison process is then converted into a super matrix. Super-matrices are arranged with the clusters in alphabetical order across the top and down the left side, and with the elements within each cluster in alphabetical order across the top and down the left side. To change the ordering in a super-matrix, you need only re-name the clusters and/or the elements, so their alphabetical order gets in the order you want. The unweighted super-matrix contains the local priorities derived from the pairwise comparisons throughout the network. The weighted super-matrix is obtained by multiplying all the elements in a component of the unweighted super-matrix by the corresponding cluster weight. A screenshot of a weighted super-matrix is shown below in Figure 3-4 for better understanding. This screenshot has been taken from the tutorial for ANP (Saaty, 2003).

ANP Main Window: bridge.mod: Weighted Super Ma...

Cluster Node Labels		Alternatives		Objectives	
		Bridge A	Bridge B	Aesthetics	Safety
Alternatives	Bridge A	0.000000	0.000000	0.875000	0.333333
	Bridge B	0.000000	0.000000	0.125000	0.666667
Objectives	Aesthetics	0.857143	0.100000	0.000000	0.000000
	Safety	0.142857	0.900000	0.000000	0.000000

Done

Figure 3-4: Screenshot for weighted super-matrix (Saaty, 2003)

3.4.5 Selection of the best alternative

The result for the alternatives in "Superdecisions" is obtained with the Synthesis command in the Main Model. It provides the priorities for the alternatives. A screenshot of the priorities is shown in Figure 3-5 below. The Normals column presents the results in the form of priorities. This is the usual way to report on results. The Ideals column is obtained from the Normals column by dividing each of its entries by the largest value in the column. The Raw column is read directly from the Limit Supermatrix (Saaty, 2003). The alternative with the highest ideal score (column 3) is finally chosen and recommended for implementation.

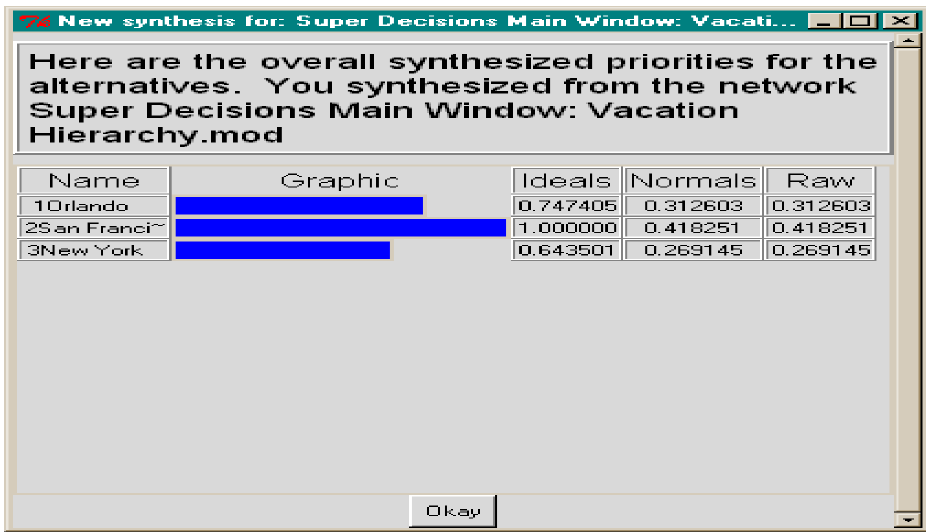


Figure 3-5: Screenshot for overall synthesized priorities (Saaty, 2003)

Chapter 4:

Numerical Application

4.1 Application of Interpretive Structural Modeling

In this section, we present the results of application of ISM on the list of enablers for each of the three social, environmental and economic dimensions.

4.1.1 Structural Self Interaction Matrix

Firstly, the SSIM's are developed for each of the three legs of sustainability. In order to get an unbiased solution to the problem, a survey (see Appendix) was carried out in which opinions of academic experts in sustainable supply chains was taken and the accumulated results were used to develop the final Self Structure Interaction Matrix (SSIM). Tables 4-1 to 4-3 present the SSIM for the economic, environmental and social dimensions.

ENABLERS	Voice of the Customer	Adoption of safety standards	Technology Management	Information Sharing	Collaborative partnerships	Strategic planning	Risk Management
Quality Management	A	A	A	A	A	X	V
Risk Management	A	A	A	A	A	X	
Strategic planning	A	X	X	X	X		
Collaborative partnerships	A	X	X	X			
Information Sharing	A	X	X			**V**	**i->j**
Technology Management	A	X				**A**	**j->i**
Adoption of safety standards	A					**X**	**i<->j**
Voice of the Customer						**O**	**i !=j**

Table 4-1: SSIM Economic dimension

ENABLERS	Adoption of safety standards	Environmental Quality Management	Technology Management	Information Sharing	Collaborative partnerships	Strategic planning	Risk Management	Govt Rewards and Incentives	Employee Training	Management Commitment	Voice of the customer	Adoption of Environmental Standards	Governmental Regulations
Adoption of Green Practices	O	V	A	X	X	X	V	A	A	A	A	A	A
Governmental Regulations	V	V	V	V	V	V	V	O	V	V	O	V	
Adoption of Environmental Standards	O	V	X	X	X	X	V	A	A	A	A		
Voice of the customer	V	V	V	V	V	V	V	O	V	V			
Management Commitment	V	V	V	V	V	A	V	A	V				
Employee Training	V	V	V	V	V	A	V	A					
Govt Rewards and Incentives	V	V	V	V	V	V	V						
Risk Management	A	A	A	A	A	A							
Strategic planning	V	V	X	X	X								
Collaborative partnerships	V	V	V	V									
Information Sharing	V	V	V								**V**	**i->j**	
Technology Management	V	V									**A**	**j->i**	
Environmental Quality Management	A										**X**	**i<->j**	
Adoption of safety standards											**O**	**i !=j**	

Table 4-2: SSIM Environmental dimension

ENABLERS	Collaborative partnerships	Strategic planning	Technology Management	Governmental Regulations	Adoption of safety standards	Voice of the customer	Freeing of public space	Quality of Life	Philanthropy	Employee Injury Protection	Employee Healthcare
Labour equity	A	A	O	A	O	A	O	V	O	O	O
Employee Healthcare	A	A	O	A	A	A	O	V	O	O	
Employee Injury Protection	A	A	O	A	A	A	A	V	O		
Philanthropy	A	A	O	A	O	A	O	V			
Quality of Life	A	A	A	A	A	A	A				
Freeing of public space	A	A	A	A	O	A					
Voice of the customer	V	V	V	O	V						
Adoption of safety standards	X	X	X	A						**V**	**i->j**
Governmental Regulations	V	V	V							**A**	**j->i**
Technology Management	X	X								**X**	**i<->j**
Strategic planning	X									**O**	**i !=j**
Collaborative partnerships											

Table 4-3: SSIM Economic dimension

To understand the interpretation of various elements of SSIM, let us consider the example of enablers 'Quality management' and 'Voice of customer'. In Table 4-1 intersection of the above mentioned variables is 'A' this implies that voice of customer will ameliorate quality management. In Table 4-2 Intersection of 'Management Commitment' and 'Adoption of safety standards' is 'V' this implies that management commitment will ameliorate Adoption of safety standards. Next let us see how we get 'X's in the SSIM's In Table 4-1 the intersection Information sharing and Technology management is 'X' which implies that Information Sharing and Technology Management will ameliorate each other. In all the above tables 'O's imply that there is no relationship between the two enablers. For example in Table 4-3, philanthropy and freeing public space have no relation with each other thereby we have an 'O' at their intersection

4.1.2 Reachability Matrix

Once we have the SSIM, the next step is to obtain the reachability matrix. Based on the rules mentioned in Chapter 3, we obtain an initial reachability matrix for each of the SSIM. These matrices are as shown in the Tables 4-4 to 4-6.

ENABLERS	Quality Management	Risk Management	Strategic planning	Collaborative partnerships	Information Sharing	Technology Management	Adoption of safety standards	Voice of the Customer
Quality Management	1	1	1	0	0	0	0	0
Risk Management	0	1	1	0	0	0	0	0
Strategic planning	1	1	1	1	1	1	1	0
Collaborative partnerships	1	1	1	1	1	1	1	0
Information Sharing	1	1	1	1	1	1	1	0
Technology Management	1	1	1	1	1	1	1	0
Adoption of safety standards	1	1	1	1	1	1	1	0
Voice of the Customer	1	1	1	1	1	1	1	1

Table 4-4: Initial reachability matrix – Economic dimension

ENABLERS	Labour equity	Employee Healthcare	Employee Injury Protection	Philanthropy	Quality of Life	Freeing of public space	Voice of the customer	Adoption of safety	Governmental Regulations	Technology Management	Strategic planning	Collaborative partnerships
Labour equity	1	0	0	0	1	0	0	0	0	0	0	0
Employee Healthcare	0	1	0	0	1	0	0	0	0	0	0	0
Employee Injury Protection	0	0	1	0	1	0	0	0	0	0	0	0
Philanthropy	0	0	0	1	1	0	0	0	0	0	0	0
Quality of Life	0	0	0	0	1	0	0	0	0	0	0	0
Freeing of public space	0	0	1	0	1	1	0	0	0	0	0	0
Voice of the customer	1	1	1	1	1	1	1	1	0	1	1	1
Adoption of safety standards	0	1	1	0	1	0	0	1	0	1	1	1
Governmental Regulations	1	1	1	1	1	1	0	1	1	1	1	1
Technology Management	0	0	0	0	1	1	0	1	0	1	1	1
Strategic planning	1	1	1	1	1	1	0	1	0	1	1	1
Collaborative partnerships	1	1	1	1	1	1	0	1	0	1	1	1

Table 4-5: Initial Reachability Matrix – Social dimension

ENABLERS	Adoption of Green Practices	Governmental Regulations	Adoption of Environmental	Voice of the customer	Management Commitment	Employee Training	Govt Rewards and Incentives	Risk Management	Strategic planning	Collaborative partnerships	Information Sharing	Technology Management	Environmental Quality	Adoption of safety standards
Adoption of Green Practices	1	0	0	0	0	0	0	1	1	1	1	0	1	0
Governmental Regulations	1	1	1	0	1	1	0	1	1	1	1	1	1	1
Adoption of Environmental Standards	1	0	1	0	0	0	0	1	1	1	1	1	1	0
Voice of the customer	1	0	1	1	1	1	0	1	1	1	1	1	1	1
Management Commitment	1	0	1	0	1	1	0	1	0	1	1	1	1	1
Employee Training	1	0	1	0	0	1	0	1	0	1	1	1	1	1
Govt Rewards and Incentives	1	0	1	0	1	1	1	1	1	1	1	1	1	1
Risk Management	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Strategic planning	1	0	1	0	1	1	0	1	1	1	1	1	1	1
Collaborative partnerships	1	0	1	0	0	0	0	1	1	1	1	1	1	1
Information Sharing	1	0	1	0	0	0	0	1	1	0	1	1	1	1
Technology Management	1	0	1	0	0	0	0	1	1	0	0	1	1	1
Environmental Quality Management	0	0	0	0	0	0	0	1	0	0	0	0	1	0
Adoption of safety standards	0	0	0	0	0	0	0	1	0	0	0	0	1	1

Table 4-6: Initial reachability matrix – Environmental dimension

After checking for transitivities of various elements in above Initial reachability matrices we get the final Reachability matrices which are shown in Tables 4-7 to 4-9. The 1* entries represent the transitivity incorporated to fill any gaps in the opinion collected during the development of SSIM.

ENABLERS	Quality Management	Risk Management	Strategic planning	Collaborative partnerships	Information Sharing	Technology Management	Adoption of safety standards	Voice of the Customer
Quality Management	1	1	1	1*	1*	1*	1*	0
Risk Management	1*	1	1	1*	1*	1*	1*	0
Strategic planning	1	1	1	1	1	1	1	0
Collaborative partnerships	1	1	1	1	1	1	1	0
Information Sharing	1	1	1	1	1	1	1	0
Technology Management	1	1	1	1	1	1	1	0
Adoption of safety standards	1	1	1	1	1	1	1	0
Voice of the Customer	1	1	1	1	1	1	1	1

Table 4-7: Final reachability matrix – Economic dimension

ENABLERS	Labour equity	Employee Healthcare	Employee Injury Protection	Philanthropy	Quality of Life	Freeing of public space	Voice of the customer	Adoption of safety	Governmental Regulations	Technology Management	Strategic planning	Collaborative partnerships
Labour equity	1	0	0	0	1	0	0	0	0	0	0	0
Employee Healthcare	0	1	0	0	1	0	0	0	0	0	0	0
Employee Injury Protection	0	0	1	0	1	0	0	0	0	0	0	0
Philanthropy	0	0	0	1	1	0	0	0	0	0	0	0
Quality of Life	0	0	0	0	1	0	0	0	0	0	0	0
Freeing of public space	0	0	1	0	1	1	0	0	0	0	0	0
Voice of the customer	1	1	1	1	1	1	1	1	0	1	1	1
Adoption of safety standards	1*	1	1	1*	1	1*	0	1	0	1	1	1
Governmental Regulations	1	1	1	1	1	1	0	1	1	1	1	1
Technology Management	1*	1*	1*	1*	1	1	0	1	0	1	1	1
Strategic planning	1	1	1	1	1	1	0	1	0	1	1	1
Collaborative partnerships	1	1	1	1	1	1	0	1	0	1	1	1

Table 4-8: Final reachability matrix – Social dimension

ENABLERS	Adoption of Green	Governmenta l Regulations	Adoption of Environmenta	Voice of the customer	Management Commitment	Employee Training	Govt Rewards and	Risk Management	Strategic planning	Collaborative partnerships	Information Sharing	Technology Management	Environmenta l Quality	Adoption of safety
Adoption of Green Practices	1	0	1*	0	1*	1*	0	1	1	1	1	1*	1	1*
Governmental Regulations	1	1	1	0	1	1	0	1	1	1	1	1	1	1
Adoption of Environmental Standards	1	0	1	0	1*	1*	0	1	1	1	1	1	1	1*
Voice of the customer	1	0	1	1	1	1	0	1	1	1	1	1	1	1
Management Commitment	1	0	1	0	1	1	0	1	1*	1	1	1	1	1
Employee Training	1	0	1	0	0	1	0	1	1*	1	1	1	1	1
Govt Rewards and Incentives	1	0	1	0	1	1	1	1	1	1	1	1	1	1
Risk Management	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Strategic planning	1	0	1	0	1	1	0	1	1	1	1	1	1	1
Collaborative partnerships	1	0	1	0	1*	1*	0	1	1	1	1	1	1	1
Information Sharing	1	0	1	0	1*	1*	0	1	1	1*	1	1	1	1
Technology Management	1	0	1	0	1*	1*	0	1	1	1*	1*	1	1	1
Environmental Quality Management	0	0	0	0	0	0	0	1	0	0	0	0	1	0
Adoption of safety standards	0	0	0	0	0	0	0	1	0	0	0	0	1	1

Table 4-9: Final reachability matrix – Environment dimension

4.1.3 Level partitioning

Tables 4-10 to 4-20 present the results of level partitioning for the different enablers from social, economic and environmental dimensions. In the first set (Table 4-10) of iteration of environmental enablers it is found that element Risk Management (8) is on level I as the reachability set and intersection set are the same. Thereby in the next iteration i.e. iteration II (Table 4-11) we separate Risk Management (8) from all the sets giving us the next level element Environmental Quality Management (13) (Table 4-12). These iterations are continued till we find the level of each element.

Environmental Viability

ENABLERS	Reachability Set	Antecedent Set	Intersection Set	Level
Adoption of Green Practices	1,3,5,6,8,9,10,11,12,13,14	1,2,3,4,5,6,7,9,10,11,12	1,3,5,6,9,10,11,12	
Governmental Regulations	1,2,3,5,6,8,9,10,11,12,13,14	2	2	
Adoption of Environmental Standards	1,3,5,6,8,9,10,11,12,13,14	1,2,3,4,5,6,7,9,10,11,12	1,3,5,6,9,10,11,12	
Voice of the customer	1,3,4,5,6,8,9,10,11,12,13,14	4	4	
Management Commitment	1,3,5,6,8,9,10,11,12,13,14	1,2,3,4,5,7,9,10,11,12	1,3,5,9,10,11,12	
Employee Training	1,3,6,8,9,10,11,12,13,14	1,2,3,4,5,6,7,9,10,11,12	1,3,6,9,10,11,12	
Govt Rewards and Incentives	1,3,5,6,7,8,9,10,11,12,13,14	7	7	
Risk Management	8	1,2,3,4,5,6,7,8,9,10,11,12,13,14	8	**I**
Strategic planning	1,3,5,6,8,9,10,11,12,13,14	1,2,3,4,5,6,7,9,10,11,12	1,3,5,6,9,10,11,12	
Collaborative partnerships	1,3,5,6,8,9,10,11,12,13,14	1,2,3,4,5,6,7,9,10,11,12	1,3,5,6,9,10,11,12	
Information Sharing	1,3,5,6,8,9,10,11,12,13,14	1,2,3,4,5,6,7,9,10,11,12	1,3,5,6,9,10,11,12	
Technology Management	1,3,5,6,8,9,10,11,12,13,14	1,2,3,4,5,6,7,9,10,11,12	1,3,5,6,9,10,11,12	
Environmental Quality Management	8,13	1,2,3,4,5,6,7,9,10,11,12,13,14	13	
Adoption of safety standards	8,13,14	1,2,3,4,5,6,7,9,10,11,12,14	14	

Table 4-10:Level Partitioning (Environment) Iteration I

ENABLERS	Reachability Set	Antecedent Set	Intersection Set	Level
Adoption of Green Practices	1,3,5,6,9,10,11,12,13,14	1,2,3,4,5,6,7,9,10,11,12	1,3,5,6,9,10,11,12	
Governmental Regulations	1,2,3,5,6,9,10,11,12,13,14	2	2	
Adoption of Environmental Standards	1,3,5,6,9,10,11,12,13,14	1,2,3,4,5,6,7,9,10,11,12	1,3,5,6,9,10,11,12	
Voice of the customer	1,3,4,5,6,9,10,11,12,13,14	4	4	
Management Commitment	1,3,5,6,9,10,11,12,13,14	1,2,3,4,5,7,9,10,11,12	1,3,5,9,10,11,12	
Employee Training	1,3,6,9,10,11,12,13,14	1,2,3,4,5,6,7,9,10,11,12	1,3,6,9,10,11,12	
Govt Rewards and Incentives	1,3,5,6,7,9,10,11,12,13,14	7	7	
Strategic planning	1,3,5,6,9,10,11,12,13,14	1,2,3,4,5,6,7,9,10,11,12	1,3,5,6,9,10,11,12	
Collaborative partnerships	1,3,5,6,9,10,11,12,13,14	1,2,3,4,5,6,7,9,10,11,12	1,3,5,6,9,10,11,12	
Information Sharing	1,3,5,6,9,10,11,12,13,14	1,2,3,4,5,6,7,9,10,11,12	1,3,5,6,9,10,11,12	
Technology Management	1,3,5,6,9,10,11,12,13,14	1,2,3,4,5,6,7,9,10,11,12	1,3,5,6,9,10,11,12	
Environmental Quality Management	13	1,2,3,4,5,6,7,9,10,11,12,13,14	13	**II**
Adoption of safety standards	13,14	1,2,3,4,5,6,7,9,10,11,12,14	14	

Table 4-11: Level Partitioning (Environment) Iteration II

ENABLERS	Reachability Set	Antecedent Set	Intersection Set	Level
Adoption of Green Practices	1,3,5,6,9,10,11,12,14	1,2,3,4,5,6,7,9,10,11,12	1,3,5,6,9,10,11,12	
Governmental Regulations	1,2,3,5,6,9,10,11,12,14	2	2	
Adoption of Environmental Standards	1,3,5,6,9,10,11,12,14	1,2,3,4,5,6,7,9,10,11,12	1,3,5,6,9,10,11,12	
Voice of the customer	1,3,4,5,6,9,10,11,12,14	4	4	
Management Commitment	1,3,5,6,9,10,11,12,14	1,2,3,4,5,7,9,10,11,12	1,3,5,9,10,11,12	
Employee Training	1,3,6,9,10,11,12,14	1,2,3,4,5,6,7,9,10,11,12	1,3,6,9,10,11,12	
Govt Rewards and Incentives	1,3,5,6,7,9,10,11,12,14	7	7	
Strategic planning	1,3,5,6,9,10,11,12,14	1,2,3,4,5,6,7,9,10,11,12	1,3,5,6,9,10,11,12	
Collaborative partnerships	1,3,5,6,9,10,11,12,14	1,2,3,4,5,6,7,9,10,11,12	1,3,5,6,9,10,11,12	
Information Sharing	1,3,5,6,9,10,11,12,14	1,2,3,4,5,6,7,9,10,11,12	1,3,5,6,9,10,11,12	
Technology Management	1,3,5,6,9,10,11,12,14	1,2,3,4,5,6,7,9,10,11,12	1,3,5,6,9,10,11,12	
Adoption of safety standards	14	1,2,3,4,5,6,7,9,10,11,12,14	14	**III**

Table 4-12: Level Partitioning (Environment) Iteration III

ENABLERS	Reachability Set	Antecedent Set	Intersection Set	Level
Adoption of Green Practices	1,3,5,6,9,10,11,12	1,2,3,4,5,6,7,9,10,11,12	1,3,5,6,9,10,11,12	**IV**
Governmental Regulations	1,2,3,5,6,9,10,11,12	2	2	
Adoption of Environmental Standards	1,3,5,6,9,10,11,12	1,2,3,4,5,6,7,9,10,11,12	1,3,5,6,9,10,11,12	**IV**
Voice of the customer	1,3,4,5,6,9,10,11,12	4	4	
Management Commitment	1,3,5,6,9,10,11,12	1,2,3,4,5,7,9,10,11,12	1,3,5,9,10,11,12	
Employee Training	1,3,6,9,10,11,12	1,2,3,4,5,6,7,9,10,11,12	1,3,6,9,10,11,12	**IV**
Govt Rewards and Incentives	1,3,5,6,7,9,10,11,12	7	7	
Strategic planning	1,3,5,6,9,10,11,12	1,2,3,4,5,6,7,9,10,11,12	1,3,5,6,9,10,11,12	**IV**
Collaborative partnerships	1,3,5,6,9,10,11,12	1,2,3,4,5,6,7,9,10,11,12	1,3,5,6,9,10,11,12	**IV**
Information Sharing	1,3,5,6,9,10,11,12	1,2,3,4,5,6,7,9,10,11,12	1,3,5,6,9,10,11,12	**IV**
Technology Management	1,3,5,6,9,10,11,12	1,2,3,4,5,6,7,9,10,11,12	1,3,5,6,9,10,11,12	**IV**

Table 4-13: Level Partitioning (Environment) Iteration IV

ENABLERS	Reachability Set	Antecedent Set	Intersection Set	Level
Governmental Regulations	2,5	2	2	
Voice of the customer	4,5	4	4	
Management Commitment	5	2,4,5,7	5	**V**
Govt Rewards and Incentives	5,7	7	7	

Table 4-14: Level Partitioning (Environment) Iteration V

ENABLERS	Reachability Set	Antecedent Set	Intersection Set	Level
Governmental Regulations	2	2	2	**VI**
Voice of the customer	4	4	4	**VI**
Govt Rewards and Incentives			7	**VI**

Table 4-15: Level Partitioning (Environment) Iteration VI

Social Viability

ENABLERS	Reachability Set	Antecedent Set	Intersection Set	Level
Labour equity	1,5	1,7,8,9,10,11,12	1	
Employee Healthcare	2,5	2,7,8,9,10,11,12	2	
Employee Injury Protection	3,5	3,6,7,8,9,10,11,12	3	
Philanthropy	4,5	4,7,8,9,10,11,12	4	
Quality of Life	5	1,2,3,4,5,6,7,8,9,10,11,12	5	I
Freeing of public space	3,5,6	6,7,8,9,10,11,12	6	
Voice of the customer	1,2,3,4,5,6,7,8,10,11,12	7	7	
Adoption of safety standards	1,2,3,4,5,6,8,10,11,12	7,8,9,10,11,12	8,10,11,12	
Governmental Regulations	1,2,3,4,5,6,8,9,10,11,12	9	9	
Technology Management	1,2,3,4,5,6,8,10,11,12	7,8,9,10,11,12	8,10,11,12	
Strategic planning	1,2,3,4,5,6,8,10,11,12	7,8,9,10,11,12	8,10,11,12	
Collaborative partnerships	1,2,3,4,5,6,8,10,11,12	7,8,9,10,11,12	8,10,11,12	

Table 4-16: Level Partitioning (Social) Iteration I

ENABLERS	Reachability Set	Antecedent Set	Intersection Set	Level
Labour equity	1	1,7,8,9,10,11,12	1	**II**
Employee Healthcare	2	2,7,8,9,10,11,12	2	**II**
Employee Injury Protection	3	3,6,7,8,9,10,11,12	3	**II**
Philanthropy	4	4,7,8,9,10,11,12	4	**II**
Freeing of public space	3,6	6,7,8,9,10,11,12	6	
Voice of the customer	1,2,3,4,6,7,8,10,11,12	7	7	
Adoption of safety standards	1,2,3,4,6,8,10,11,12	7,8,9,10,11,12	8,10,11,12	
Governmental Regulations	1,2,3,4,6,8,9,10,11,12	9	9	
Technology Management	1,2,3,4,6,8,10,11,12	7,8,9,10,11,12	8,10,11,12	
Strategic planning	1,2,3,4,6,8,10,11,12	7,8,9,10,11,12	8,10,11,12	
Collaborative partnerships	1,2,3,4,6,8,10,11,12	7,8,9,10,11,12	8,10,11,12	

Table 4-17: Level Partitioning (Social) Iteration II

ENABLERS	Reachability Set	Antecedent Set	Intersection Set	Lev el
Freeing of public space	6	6,7,8,9,10,11,12	6	**III**
Voice of the customer	6,7,8,10,11,12	7	7	
Adoption of safety standards	6,8,10,11,12	7,8,9,10,11,12	8,10,11,12	
Governmental Regulations	6,8,9,10,11,12	9	9	
Technology Management	6,8,10,11,12	7,8,9,10,11,12	8,10,11,12	
Strategic planning	6,8,10,11,12	7,8,9,10,11,12	8,10,11,12	
Collaborative partnerships	6,8,10,11,12	7,8,9,10,11,12	8,10,11,12	

Table 4-18: Level Partitioning (Social) Iteration III

ENABLERS	Reachability Set	Antecedent Set	Intersection Set	Lev el
Voice of the customer	7,8,10,11,12	7	7	**V**
Adoption of safety standards	8,10,11,12	7,8,9,10,11,12	8,10,11,12	**IV**
Governmental Regulations	8,9,10,11,12	9	9	**V**
Technology Management	8,10,11,12	7,8,9,10,11,12	8,10,11,12	**IV**
Strategic planning	8,10,11,12	7,8,9,10,11,12	8,10,11,12	**IV**
Collaborative partnerships	8,10,11,12	7,8,9,10,11,12	8,10,11,12	**IV**

Table 4-19: Level Partitioning (Social) Iteration IV

Economic Viability

ENABLERS	Reachability Set	Antecedent Set	Intersection Set	Level
Quality Management	1,2,3,4,5,6,7	1,2,3,4,5,6,7,8	1,2,3,4,5,6,7	**I**
Risk Management	1,2,3,4,5,6,7	1,2,3,4,5,6,7,8	1,2,3,4,5,6,7	**I**
Strategic planning	1,2,3,4,5,6,7	1,2,3,4,5,6,7,8	1,2,3,4,5,6,7	**I**
Collaborative partnerships	1,2,3,4,5,6,7	1,2,3,4,5,6,7,8	1,2,3,4,5,6,7	**I**
Information Sharing	1,2,3,4,5,6,7	1,2,3,4,5,6,7,8	1,2,3,4,5,6,7	**I**
Technology Management	1,2,3,4,5,6,7	1,2,3,4,5,6,7,8	1,2,3,4,5,6,7	**I**
Adoption of safety standards	1,2,3,4,5,6,7	1,2,3,4,5,6,7,8	1,2,3,4,5,6,7	**I**
Voice of the Customer	1,2,3,4,5,6,7,8	8	8	**II**

Table 4-20: Level Partitioning (Economic) Iteration I

4.1.4 Conical Matrix

Once the level partitioning is done we have the hierarchy in which the elements are arranged, thereby we can now prepare a conical matrix. As mentioned previously a conical matrix is formed by clustering the variables in same levels across rows and columns. Tables 4-21 to 4-23 show the conical matrix for different enablers for each of the factors of sustainability dimensions.

Enablers	Risk management	Environmenta l Quality	adoption of safety	Adoption of green	Adoption of environmenta	Employee Training	Strategic Planning	Collaborative partnerships	Information sharing	Technology management	Management commitment	voice of customer	Governmenta l regulations	Govt. Rewards and
risk management	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Environmental Quality Management	1	1	0	0	0	0	0	0	0	0	0	0	0	0
adoption of safety standards	1	1	1	0	0	0	0	0	0	0	0	0	0	0
Adoption of green practices	1	1	1	1	1	1	1	1	1	1	1	0	0	0
Adoption of environmental standards	1	1	1	1	1	1	1	1	1	1	1	0	0	0
Employee Training	1	1	1	1	1	1	1	1	1	1	0	0	0	0
Strategic Planning	1	1	1	1	1	1	1	1	1	1	1	1	0	0
Collaborative partnerships	1	1	1	1	1	1	1	1	1	1	1	0	0	0
Information sharing	1	1	1	1	1	1	1	1	1	1	1	0	0	0
Technology management	1	1	1	1	1	1	1	1	1	1	1	0	0	0
Management commitment	1	1	1	1	1	1	1	1	1	1	1	0	0	0
voice of customer	1	1	1	1	1	1	1	1	1	1	1	1	0	0
Governmental regulations	1	1	1	1	1	1	1	1	1	1	1	0	1	0
Govt. Rewards and incentives	1	1	1	1	1	1	1	1	1	1	1	0	0	1

Table 4-21: Conical for of reachability matrix – Environment dimension

Enablers	Quality of Life	Labour equity	Employee Healthcare	Employee Injury	Philanthropy	Freeing public space	Adoption of safety	Technology management	Strategic Planning	Collaborative partnerships	Voice of customer	governmental regulations
Quality of Life	1	0	0	0	0	0	0	0	0	0	0	0
Labour equity	1	1	0	0	0	0	0	0	0	0	0	0
Employee Healthcare	1	0	1	0	0	0	0	0	0	0	0	0
Employee Injury protection	1	0	0	1	0	0	0	0	0	0	0	0
Philanthropy	1	0	0	0	1	0	0	0	0	0	0	0
Freeing public space	1	0	0	1	0	1	0	0	0	0	0	0
Adoption of safety standards	1	1	1	1	1	1	1	1	1	1	0	0
Technology management	1	1	1	1	1	1	1	1	1	1	0	0
Strategic Planning	1	1	1	1	1	1	1	1	1	1	0	0
Collaborative partnerships	1	1	1	1	1	1	1	1	1	1	0	0
Voice of customer	1	1	1	1	1	1	1	1	1	1	1	0
governmental regulations	1	1	1	1	1	1	1	1	1	1	0	1

Table 4-22: Conical for of reachability matrix – Social dimension

ENABLERS	Quality Management	Risk Management	Strategic planning	Collaborative partnerships	Information Sharing	Technology Management	Adoption of safety standards	Voice of the Customer
Quality Management	1	1	1	1	1	1	1	0
Risk Management	1	1	1	1	1	1	1	0
Strategic planning	1	1	1	1	1	1	1	0
Collaborative partnerships	1	1	1	1	1	1	1	0
Information Sharing	1	1	1	1	1	1	1	0
Technology Management	1	1	1	1	1	1	1	0
Adoption of safety standards	1	1	1	1	1	1	1	0
Voice of the Customer	1	1	1	1	1	1	1	1

Table 4-23: Conical for of reachability matrix – Economic dimension

It can be seen from Tables 4-21 to 4-23 that the highest level enablers are placed on the top of the digraph. The remaining columns are filled with other enablers in the decreasing order of levels.

4.1.5 Results

4.1.5.1 Diagraphs for ISM

Environmental ISM: Figure 4-1 presents the results of ISM for the environment dimension. It can be seen from the digraph the most important enablers that will drive other enablers in achieving environmental aspect of sustainability are Governmental Regulations, Voice of Customer and Governmental Rewards and Incentives. The next level consists of Management Commitment. It can be said that once management is committed to taking up sustainability and avoiding green-wash one can start implementing the “going green” campaign. The next level “Management Commitment” in our digraph consists of a bunch of enablers including Employee Training, Technology management, Information Sharing, Collaborative partnerships and so on. Most of these elements are related to each other and are strongly dependent on commitment from management and other enablers of lower levels. Successful implementation of these enablers leads to adoption of safety standards, Environmental Quality Management and Risk Management in decreasing order of hierarchy.

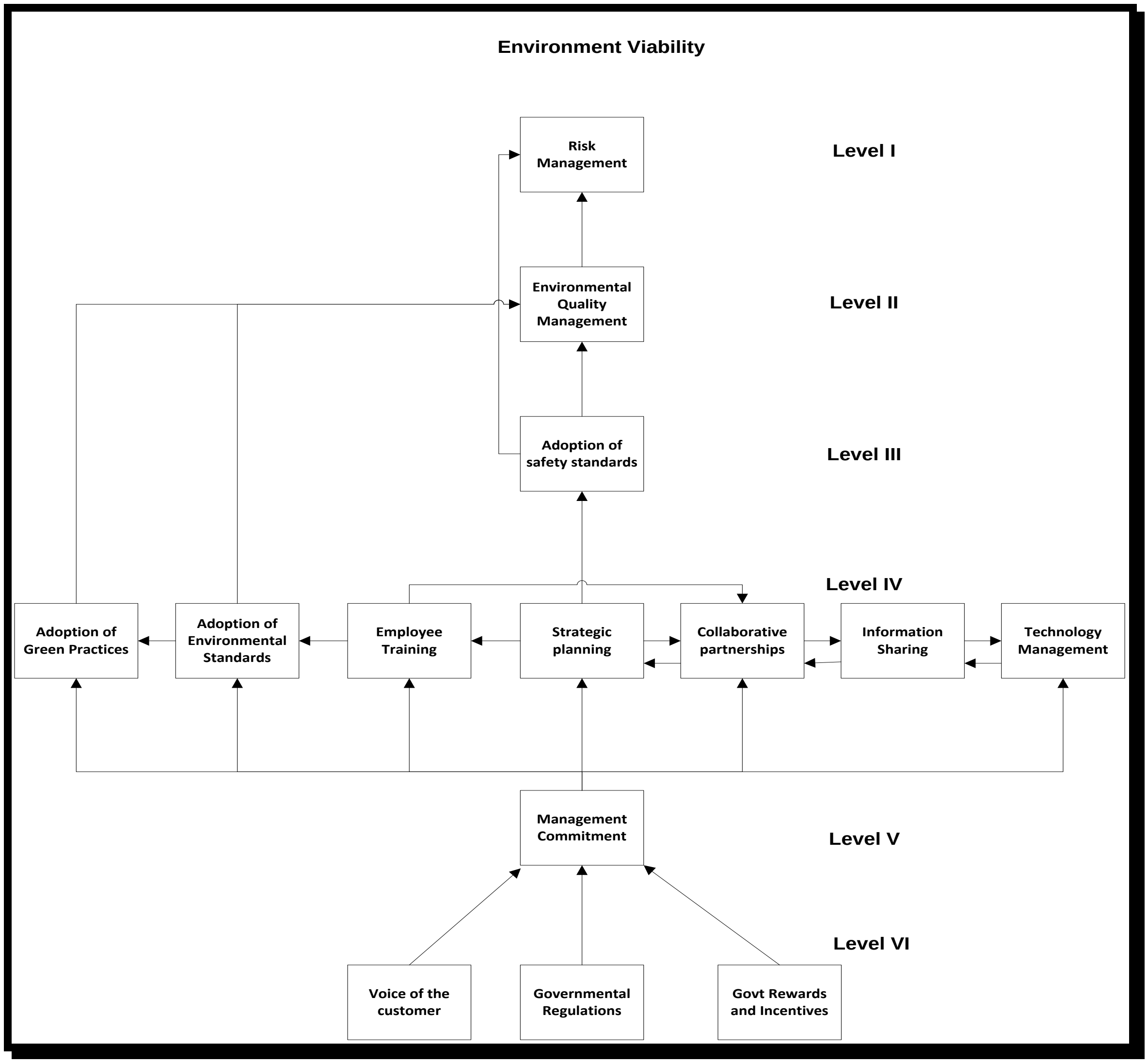


Figure 4-1: Diagraph for ISM model – Environmental dimension

Social ISM: Figure 4-2 presents the results of ISM for social dimension. It can be seen from the digraph that Governmental Regulations and Voice of Customer are the most important enablers for attaining social sustainability. These two enablers can help achieve the next level of enablers that consist of Technology Management, Strategic Planning, Collaborative Partnerships and adoption of safety standards, which have one to one relationship with each other and ameliorate each other. Adoption of these practices can help achieve Labour equity, Employee Health care, Employee injury protection and Philanthropy at the next level. Attaining these enablers will eventually lead to a better Quality of Life which is the enabler at the top most level.

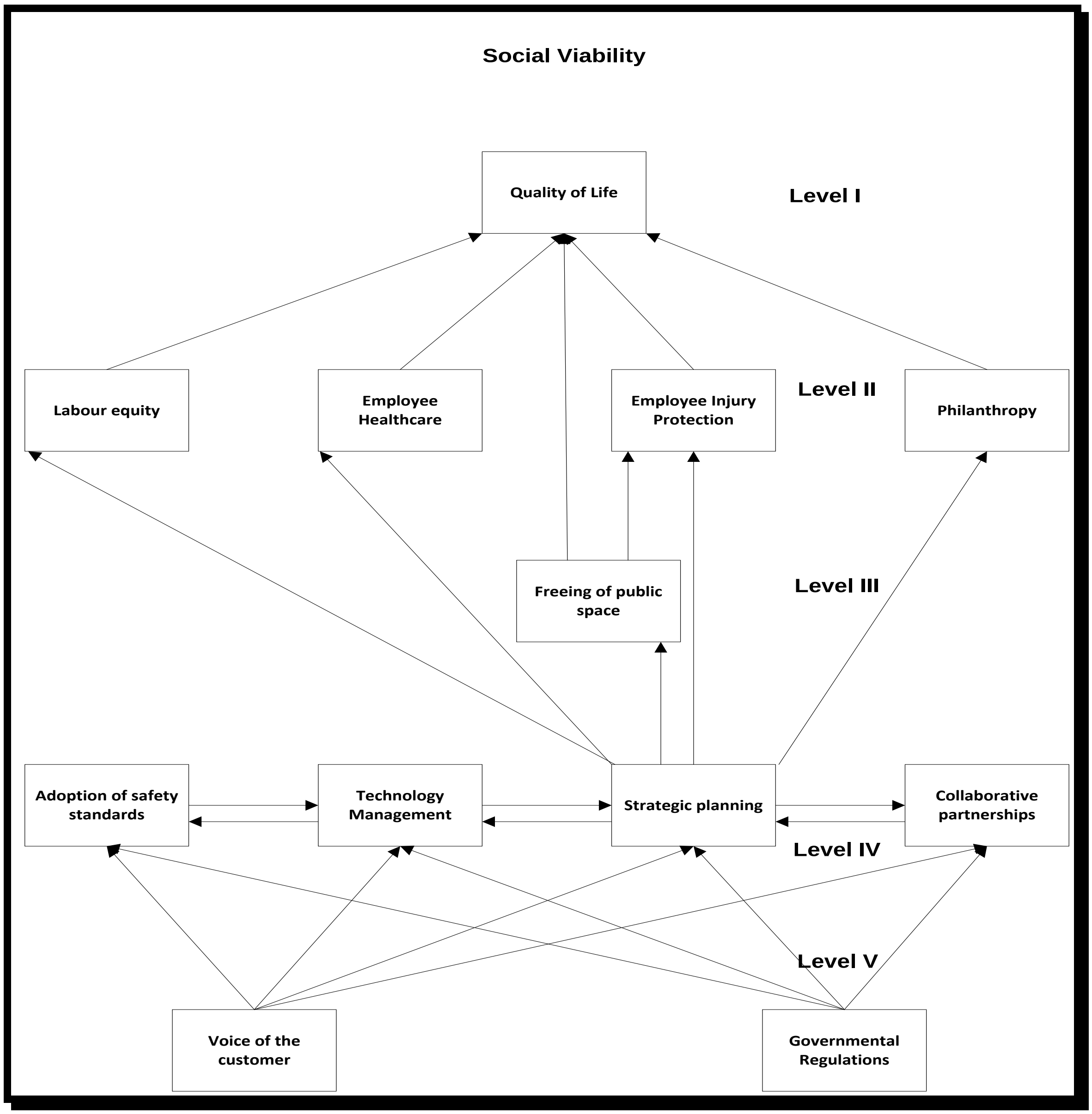


Figure 4-2: Diagraph for ISM model – Social dimension

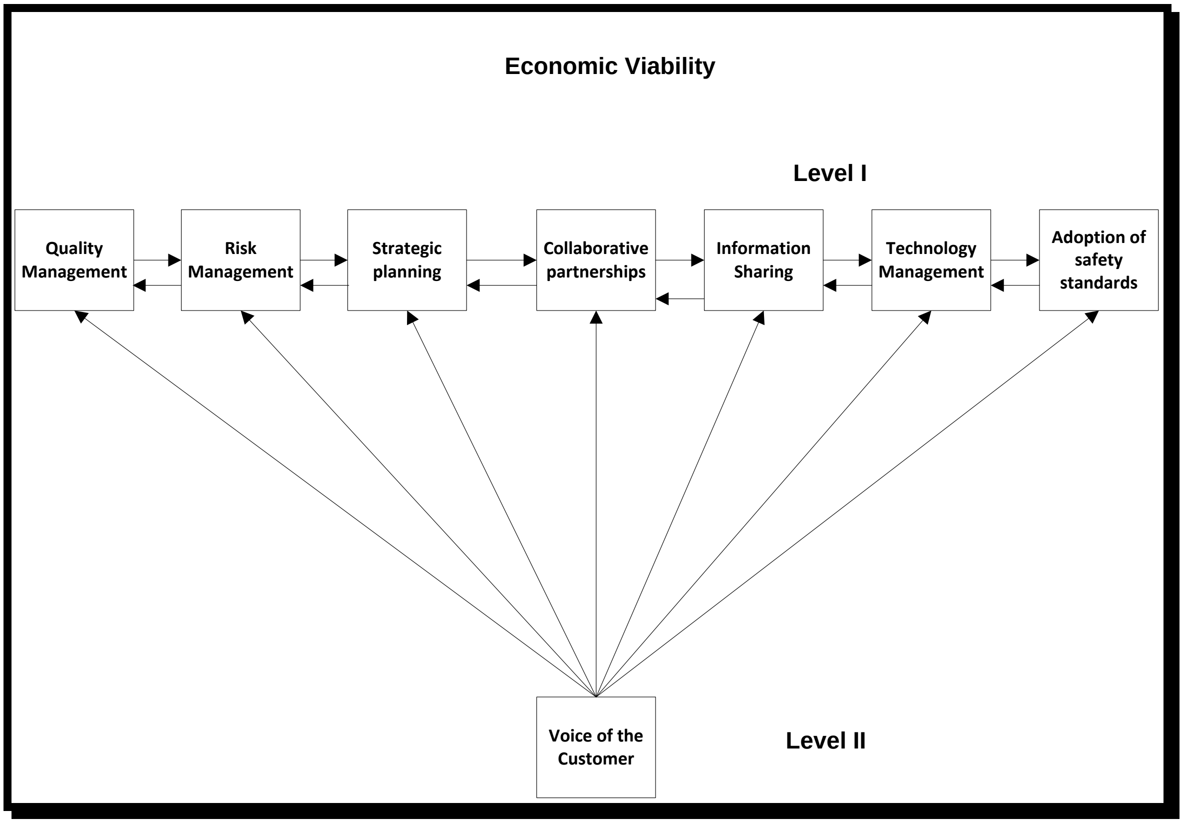


Figure 4-3: Diagraph for ISM model – Economic dimension

4.1.5.2 MICMAC ANALYSIS

Tables 4-24 to 4-26 represent matrices used for conducting MICMAC analysis. The matrices contain the driving power and dependence for each of the enabler. The enablers with high driving power and low dependence fall in the cluster Independent variables. The enablers with low driving power and high dependence fall in cluster for dependent variables. The enablers with high driving power and high dependence fall in the cluster for linkage variables. Lastly, the enablers with low driving power and low dependence fall in the cluster for autonomous variables.

Enablers	Risk management	Environmental Quality	adoption of safety	Adoption of green	Adoption of environmenta	Employee Training	Strategic Planning	Collaborative partnerships	Information sharing	Technology management	Management commitment	voice of customer	Governmental regulations	Govt. Rewards and	Driving
Risk management	1	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Environmental Quality Management	1	1	0	0	0	0	0	0	0	0	0	0	0	0	**2**
Adoption of safety standards	1	1	1	0	0	0	0	0	0	0	0	0	0	0	**3**
Adoption of green practices	1	1	1	1	1	1	1	1	1	1	1	0	0	0	**11**
Adoption of environmental standards	1	1	1	1	1	1	1	1	1	1	1	0	0	0	**11**
Employee Training	1	1	1	1	1	1	1	1	1	1	0	0	0	0	**11**
Strategic Planning	1	1	1	1	1	1	1	1	1	1	1	1	0	0	**11**
Collaborative partnerships	1	1	1	1	1	1	1	1	1	1	1	0	0	0	**11**
Information sharing	1	1	1	1	1	1	1	1	1	1	1	0	0	0	**11**
Technology management	1	1	1	1	1	1	1	1	1	1	1	0	0	0	**11**
Management commitment	1	1	1	1	1	1	1	1	1	1	1	0	0	0	**11**
Voice of customer	1	1	1	1	1	1	1	1	1	1	1	1	0	0	**12**
Governmental regulations	1	1	1	1	1	1	1	1	1	1	1	0	1	0	**12**
Govt. Rewards and incentives	1	1	1	1	1	1	1	1	1	1	1	0	0	1	**12**
Dependence	**14**	**13**	**12**	**11**	**11**	**11**	**11**	**11**	**11**	**11**	**10**	**2**	**1**	**1**	

Table 4-24: Driving power and dependence in reachability matrix – Environmental dimension

Enablers	Quality of Life	Labour equity	Employee Healthcare	Employee Injury	Philanthropy	Freeing public space	Adoption of safety	Technology management	Strategic Planning	Collaborative partnerships	Voice of customer	governmental regulations	Driving Power
Quality of Life	1	0	0	0	0	0	0	0	0	0	0	0	**1**
Labour equity	1	1	0	0	0	0	0	0	0	0	0	0	**2**
Employee Healthcare	1	0	1	0	0	0	0	0	0	0	0	0	**2**
Employee Injury protection	1	0	0	1	0	0	0	0	0	0	0	0	**2**
Philanthropy	1	0	0	0	1	0	0	0	0	0	0	0	**2**
Freeing public space	1	0	0	1	0	1	0	0	0	0	0	0	**2**
Adoption of safety standards	1	1	1	1	1	1	1	1	1	1	0	0	**10**
Technology management	1	1	1	1	1	1	1	1	1	1	0	0	**10**
Strategic Planning	1	1	1	1	1	1	1	1	1	1	0	0	**10**
Collaborative partnerships	1	1	1	1	1	1	1	1	1	1	0	0	**10**
Voice of customer	1	1	1	1	1	1	1	1	1	1	1	0	**11**
governmental regulations	1	1	1	1	1	1	1	1	1	1	0	1	**11**
Dependence	**12**	**7**	**7**	**8**	**7**	**7**	**6**	**6**	**6**	**6**	**1**	**1**	

Table 4-25: Driving power and dependence in reachability matrix – Social dimension

ENABLERS	Quality Management	Risk Management	Strategic planing	Collaborative partnerships	Information Sharing	Technology Management	Adoption of safety standards	Voice of the Customer	Driving Power
Quality Management	1	1	1	1	1	1	1	0	**7**
Risk Management	1	1	1	1	1	1	1	0	**7**
Strategic planning	1	1	1	1	1	1	1	0	**7**
Collaborative partnerships	1	1	1	1	1	1	1	0	**7**
Information Sharing	1	1	1	1	1	1	1	0	**7**
Technology Management	1	1	1	1	1	1	1	0	**7**
Adoption of safety standards	1	1	1	1	1	1	1	0	**7**
Voice of the Customer	1	1	1	1	1	1	1	1	**8**
Dependence	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**1**	

Table 4-26: Driving power and dependence in reachability matrix - Economic dimension

Figures 4-4 to 4-6 present graphically the results of MICMAC analysis. From the results of environmental dimension (Figure 4-4) it is found that governmental regulations, governmental rewards and incentives and voice of the customer have a strong driving power and fall in the cluster IV which is cluster of independent variables. Management commitment, Adoption of green standards and all the variables at level 4 falls under cluster III which stands for linkage variables. Lastly we have Safety standards, Environmental Quality management and Risk management under cluster II which is the cluster for dependent variables. We do not have any autonomous variables.

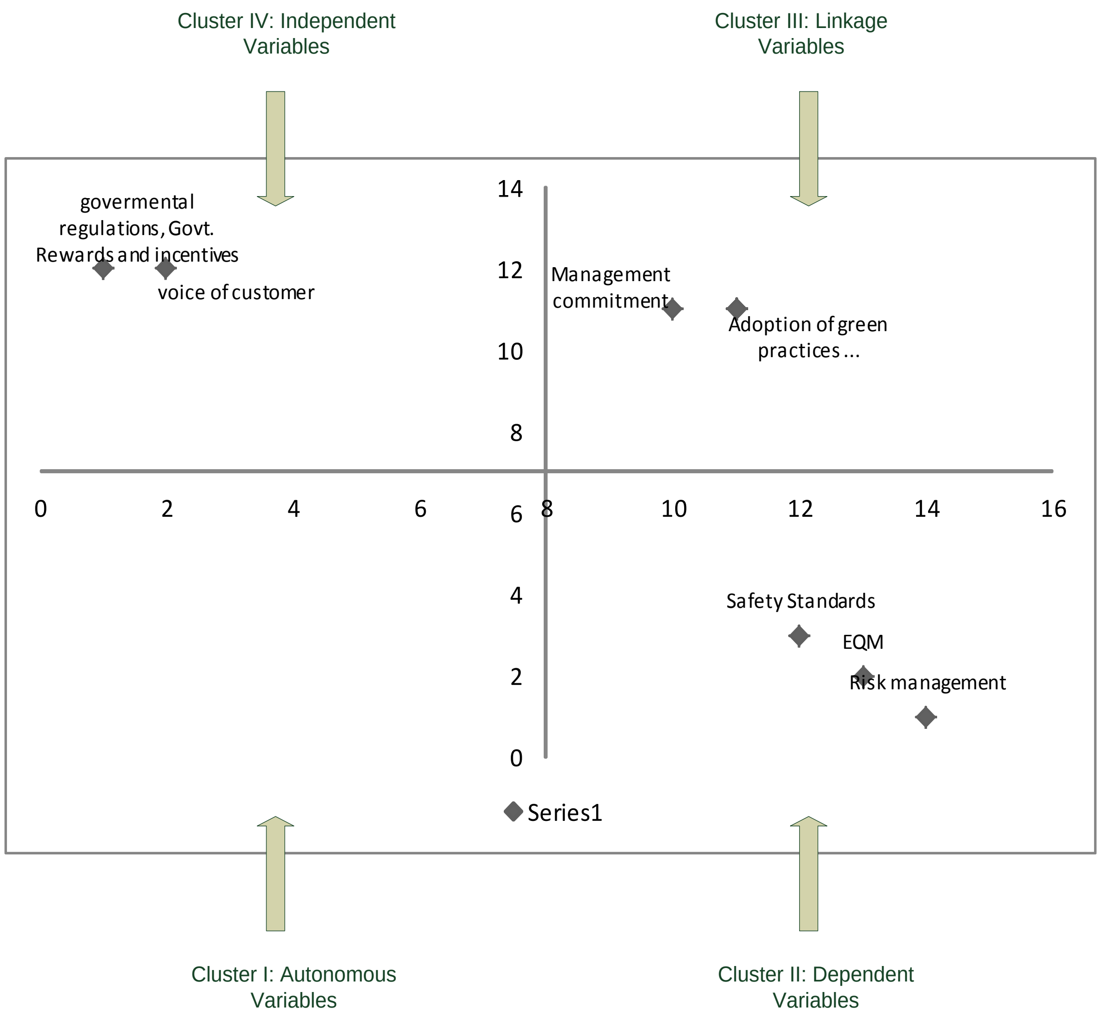


Figure 4-4: Cluster of variables (MICMAC analysis) – Environmental dimension

From the results of economic dimension (Figure 4-5) we see that voice of customer is the only independent variable for economic viability. Risk management, Strategic planning, Collaborative partnerships, Information sharing, Technology management, Quality management and Adoption of safety standards are all Linkage variables. There are no autonomous and dependent variables.

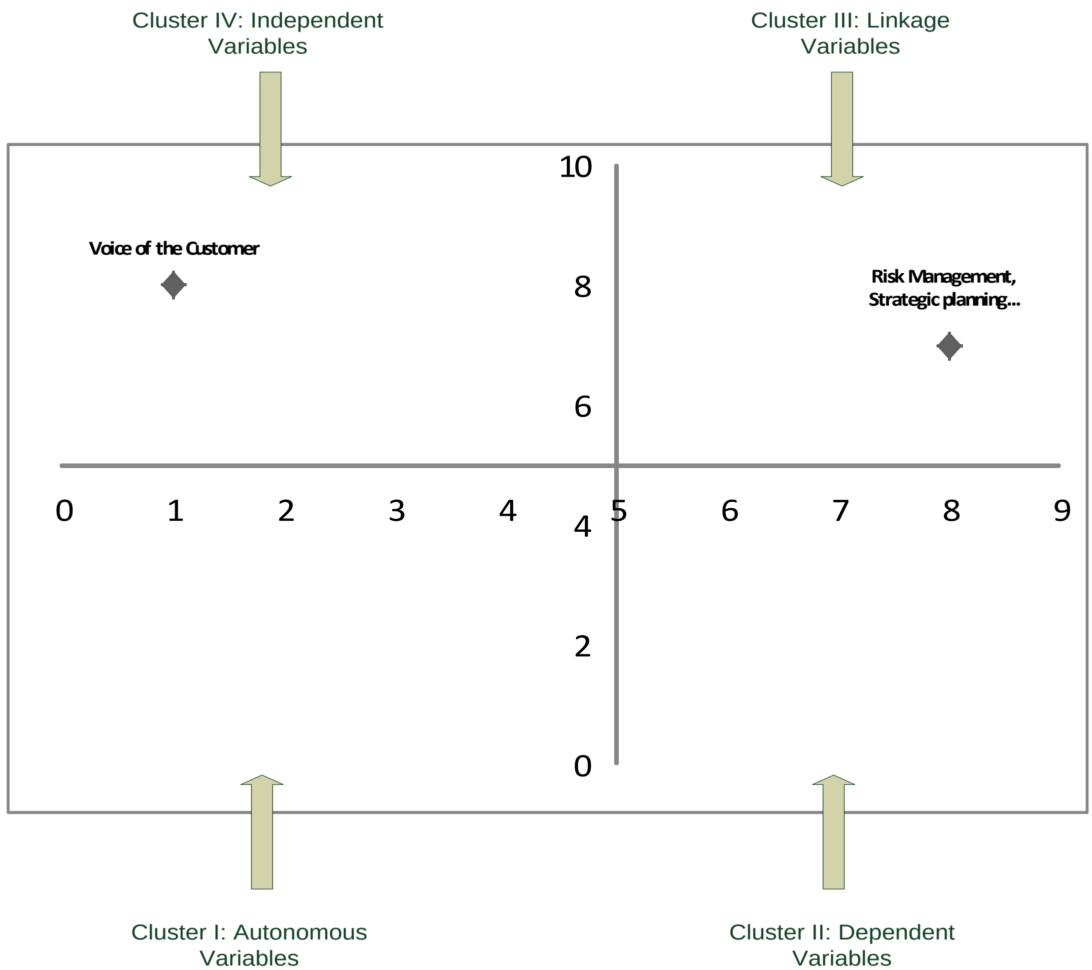


Figure 4-5: Cluster of variables (MICMAC analysis) – Economic dimension

From the results of social dimension (Figure 4-6) we can see that 'Voice of customer' and 'governmental regulations' are found to be independent variables. 'Strategic planning' is the only linkage variable. 'Freeing public spaces, Philanthropy, Quality of life, Employee injury protection, Employee healthcare and labour equity' are the dependent variables. There are no autonomous variables. It is observed that the variables with strong driving power are key variables. In this case we have Governmental regulations, Voice of customer, and Governmental rewards and incentives to be the key variables.

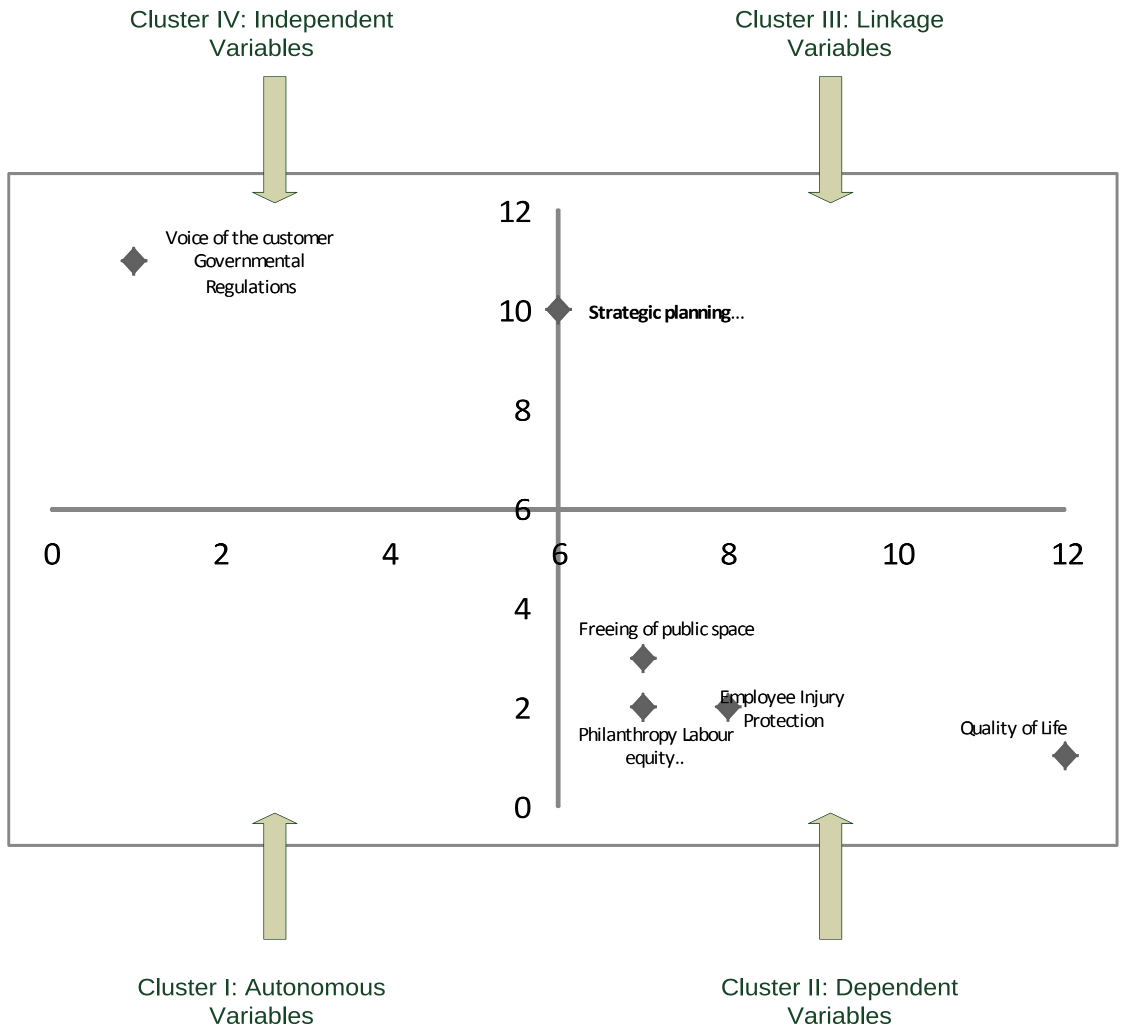


Figure 4-6: Cluster of variables (MICMAC analysis) – Social dimension

4.2 Application of ANP

4.2.1 Model construction and problem structuring

The results produced from ISM provided the interrelationship between the enablers and based on these relationships and the list of potential alternatives we constructed the ANP model using "Super decisions" software.

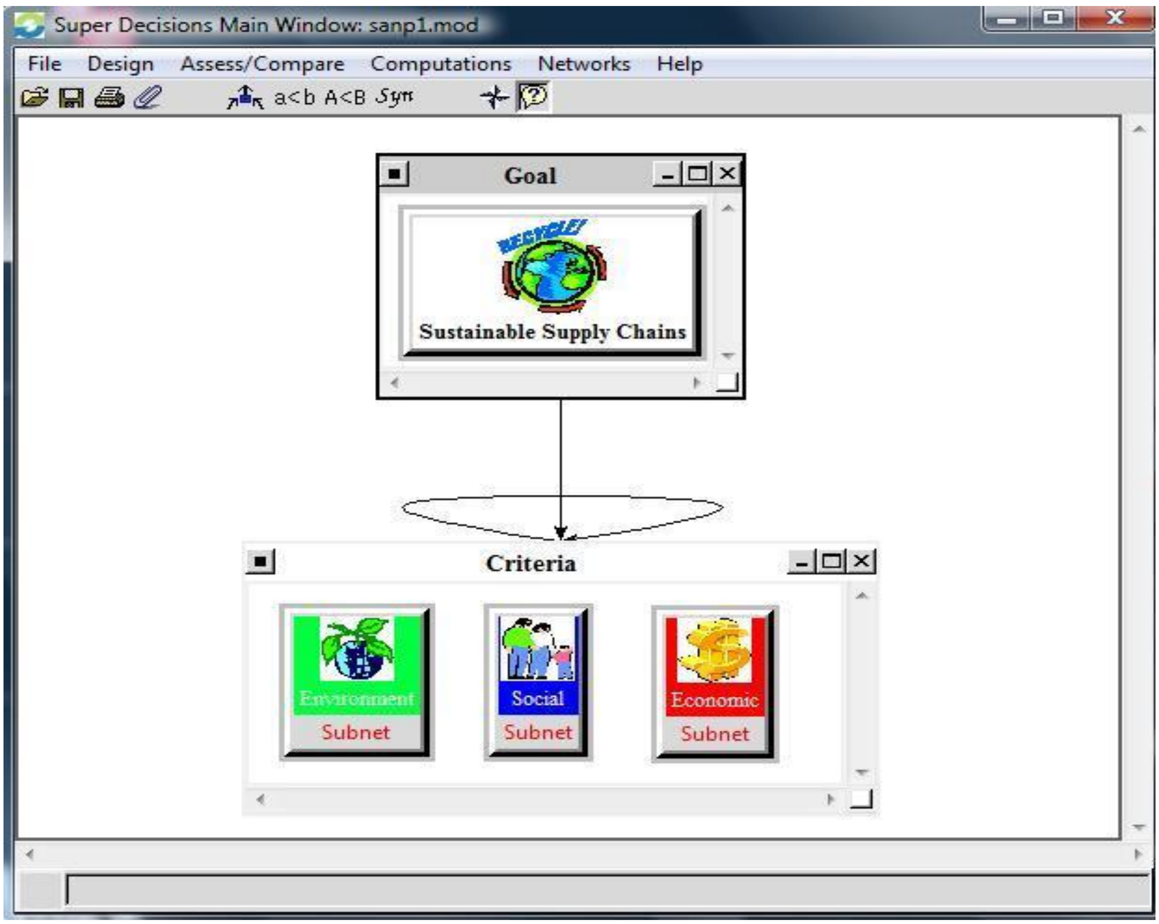


Figure 4-7: Screenshot of the sustainable supply chain model

The model consists of two clusters namely Goal and Criteria (Figure 4-7). The goal is to find best alternative(s) for sustainable supply chains based on the interrelationships between enablers. The three main criteria for achieving sustainability are environmental, social and economic viability. Each of the criteria can have several sub-criterions.

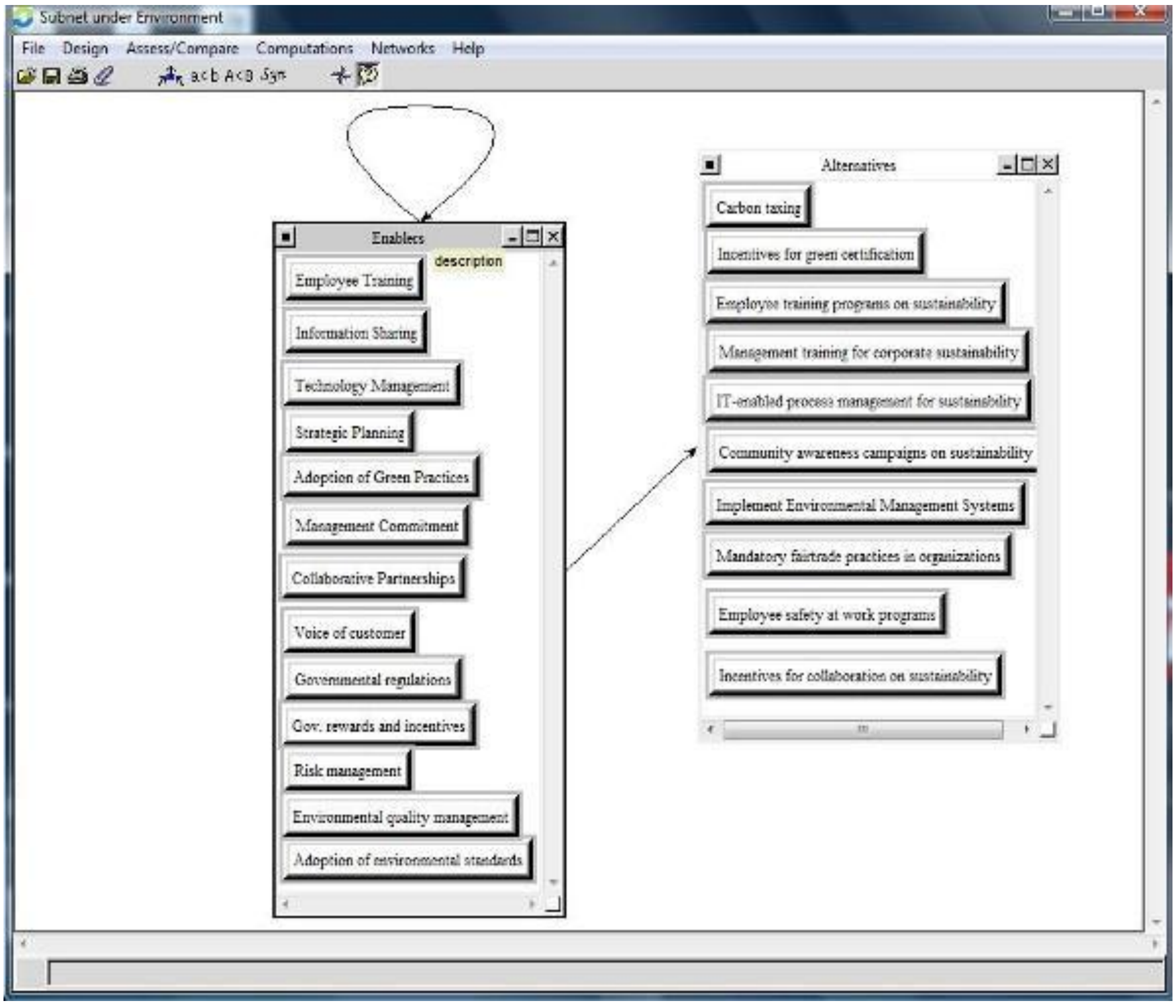


Figure 4-8: Screenshot of Environmental sub-network model

Environmental sub-network: The sub-network for “Environment” criteria is shown in Figure 4-8. It consists of two clusters namely enablers and alternatives. The interactions amongst the enablers are based on ISM methodology and the alternatives listed are a result of brainstorming and literature review.

Social sub-network: This sub-network like environmental sub-network consists of two clusters namely enablers and alternatives. Enablers clusters consists of nodes for each of the enabler previously found. Their interaction is again based on the results of ISM. This sub-network is shown in Figure 4-9.

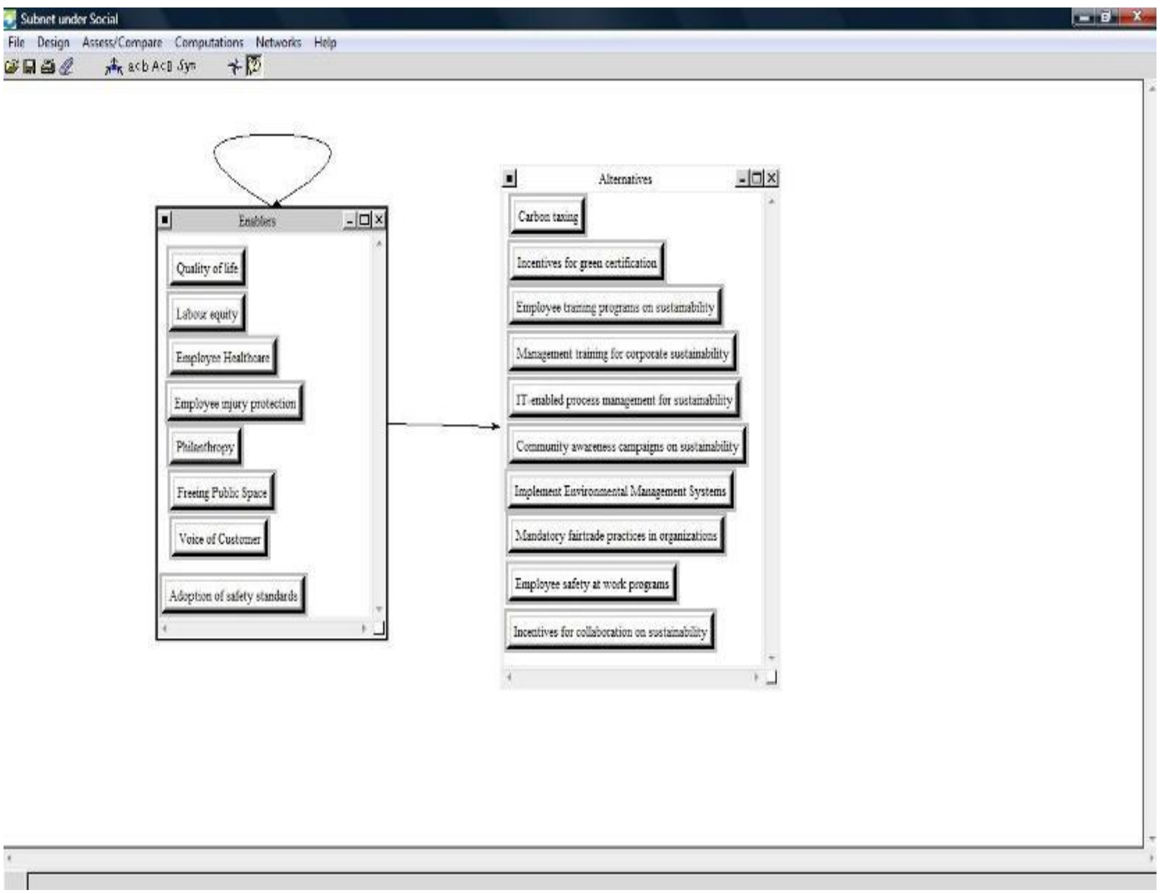


Figure 4-9: Screenshot of Social sub-network model

Economic sub-network: The model for this sub-network is as shown in Figure 4-10. It consists of two clusters just like the other two sub-networks and shows interaction between the enablers and alternatives.

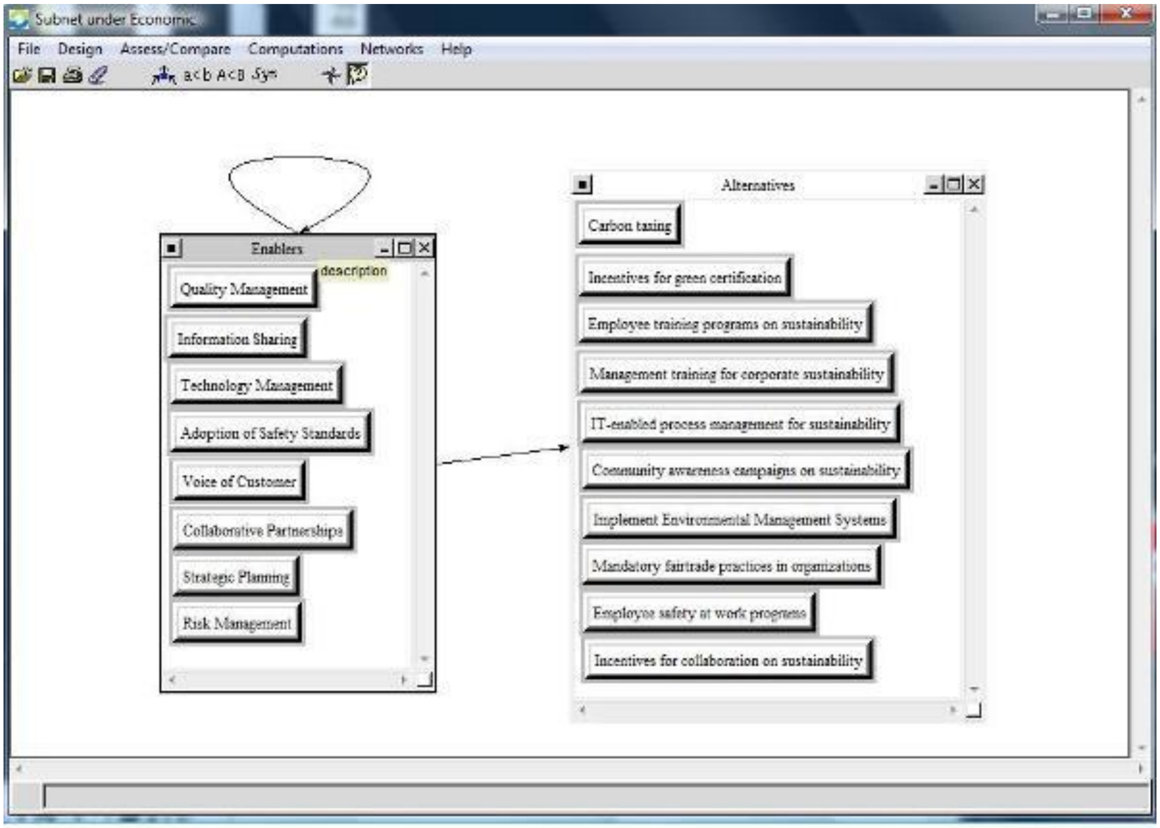


Figure 4-10: Screenshot of Economic sub-network

4.2.2 Pair-wise comparison between components

The pair-wise comparisons are carried out first at the primary level to check the importance of each criterion with respect to other criterion. Since each of the three criteria is equally important for sustainability we rate them as equally important.

Screenshot of comparison between Social and Economic with respect to Environment is shown in Figure 4-11.

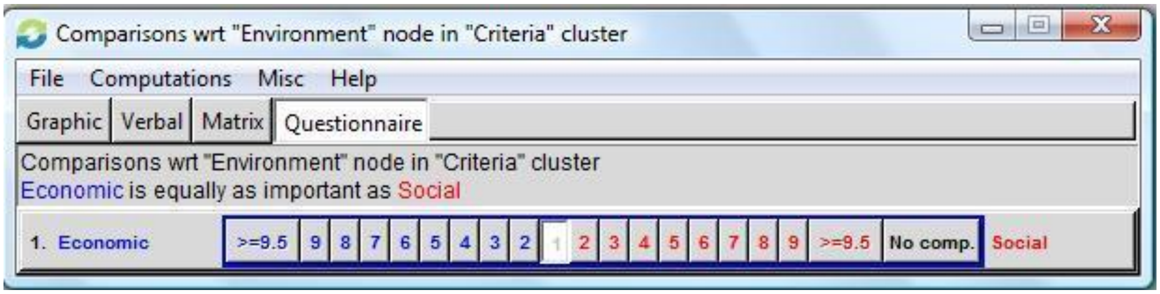


Figure 4-11: Comparisons with respect to Environment node in "criteria" cluster

The inputs to these questionnaires are based on opinion of academia experts in sustainable supply chain management. These comparisons are carried out for each and every node in the cluster it has a relationship with. In Superdecisions software it is possible to perform these comparisons in form of questionnaire, matrix, verbal or graphically. Each of these methods has been show below (Figure 4-12 to Figure 4-15) for comparisons with respect to Voice of customer node in "Enablers" cluster in Environment sub-network.

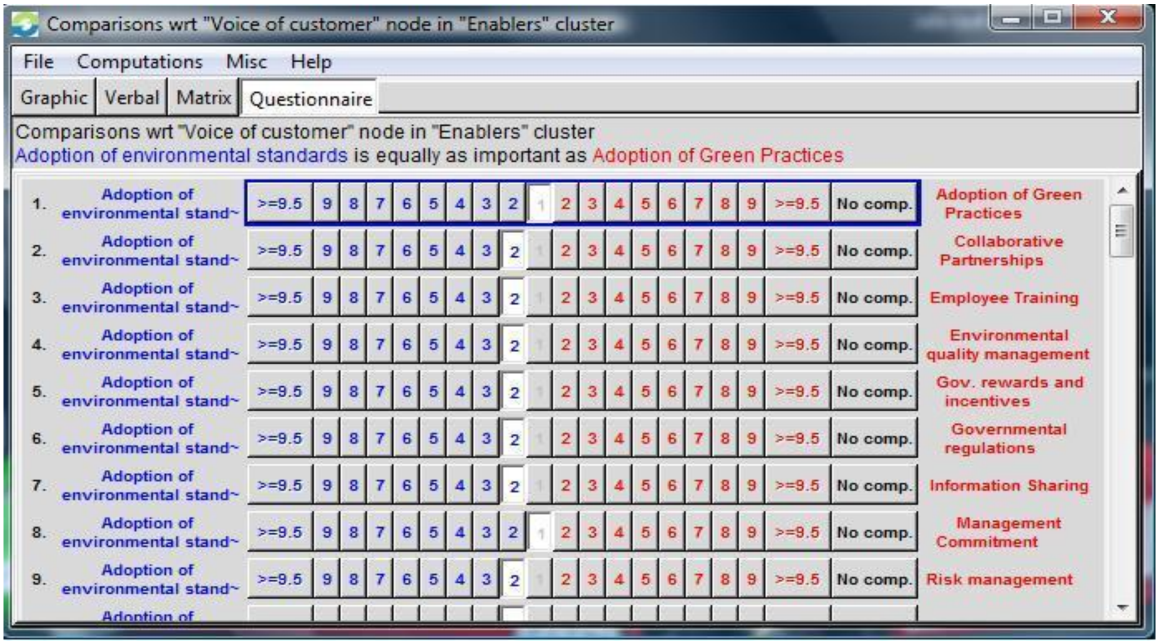


Figure 4-12: Questionnaire for comparisons with respect to “Voice of customer” node in "Enablers"

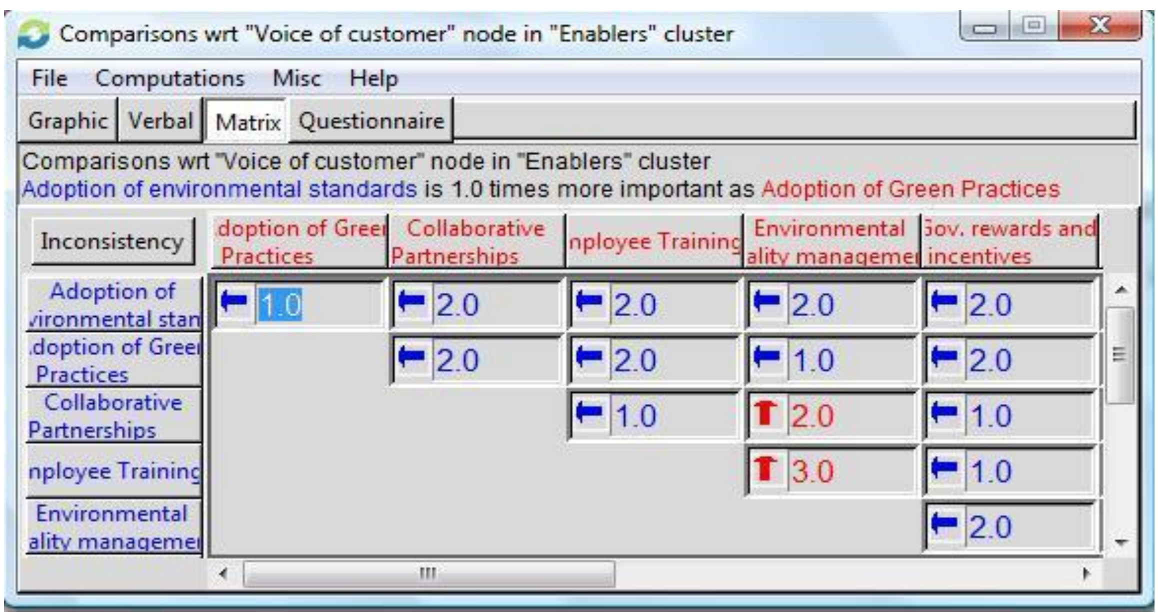


Figure 4-13: Matrix representation for comparisons with respect to “Voice of customer” node in "Enablers"

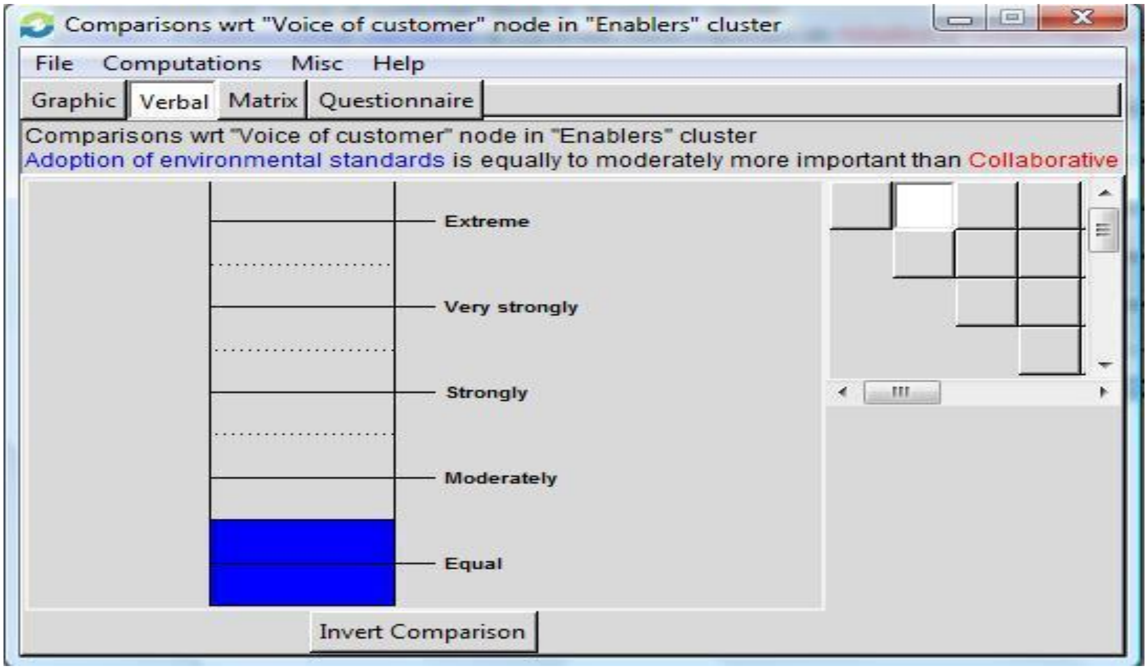


Figure 4-14: Verbal representation for comparisons with respect to “Voice of customer” node in "Enablers"

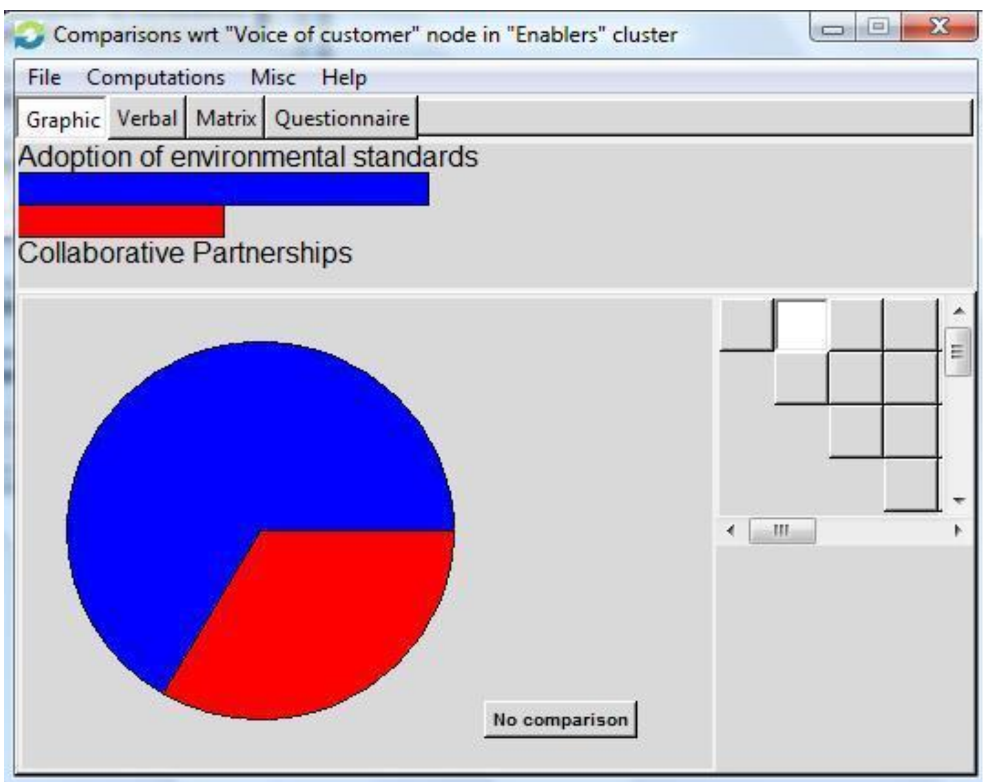


Figure 4-15: Graphical representation for comparisons with respect to “Voice of customer” node in "Enablers"

4.2.3 Super- matrix formation

The relative values obtained from pair-wise comparisons can now be synthesized to establish unweighted supermatrix. The unweighted supermatrix will be further normalized to obtain the weighted supermatrix. This is done by multiplying all the elements in a component of the unweighted supermatrix by the corresponding cluster weight. The three clusters in our network, which are economic, environment and social have been given equal weights as they are all equally important for sustainable supply chain. The results of these matrices for the model and each of the sub-networks are shown in Figures 4-16 to 4-23.

Super Decisions Main Window: sanp1.mod: Unweighted ...

Cluster Node Labels		Criteria			Goal
		Economic	Environment	Social	Sustainable Supply Chains
Criteria	Economic	0.000000	0.500000	0.500000	0.333333
	Environment	0.500000	0.000000	0.500000	0.333333
	Social	0.500000	0.500000	0.000000	0.333333
Goal	Sustainable Supply Chains	0.000000	0.000000	0.000000	0.000000

Done

Figure 4-16: unweighted super matrix for the model

Super Decisions Main Window: sanp1.mod: Weighted S...

Cluster Node Labels		Criteria			Goal
		Economic	Environment	Social	Sustainable Supply Chains
Criteria	Economic	0.000000	0.500000	0.500000	0.333333
	Environment	0.500000	0.000000	0.500000	0.333333
	Social	0.500000	0.500000	0.000000	0.333333
Goal	Sustainable Supply Chains	0.000000	0.000000	0.000000	0.000000

Done

Figure 4-17: Weighted super matrix for the model

Subnet under Environment: Unweighted Super Matrix

Cluster Node Labels		Enablers							
		Employee Training	Environmental quality management	Gov. rewards and incentives	Governmental regulations	Information Sharing	Management Commitment	Risk management	Strategic Planning
Alternatives	Carbon taxing	0.000000	0.000000	0.000000	0.490361	0.000000	0.000000	0.000000	0.000000
	Community awareness campaigns on sustainability	0.000000	0.231030	0.000000	0.000000	0.249981	0.000000	0.000000	0.164606
	Employee safety at work programs	0.000000	0.000000	0.000000	0.000000	0.000000	0.110597	0.000000	0.123734
	Employee training programs on sustainability	0.500000	0.000000	0.000000	0.000000	0.000000	0.099026	0.250000	0.123734
	Implement Environmental Management Systems	0.000000	0.490091	0.000000	0.000000	0.000000	0.141348	0.000000	0.206595
	Incentives for collaboration on sustainability	0.000000	0.000000	0.249981	0.122176	0.000000	0.000000	0.000000	0.000000
	Incentives for green certification	0.000000	0.115516	0.750019	0.132496	0.000000	0.000000	0.000000	0.000000
	IT-enabled process management for sustainability	0.000000	0.163363	0.000000	0.000000	0.750019	0.177565	0.500000	0.254221

Figure 4-18: Unweighted super matrix for Environment Sub-criteria

Subnet under Environment: Weighted Super Matrix

Cluster	Node Labels	Enablers: Employee Training	Environmental quality management	Gov. rewards and incentives	Governmental regulations	Information Sharing	Management Commitment	Risk management	Strategic Planning
Alternatives	Carbon taxing	0.000000	0.000000	0.000000	0.245181	0.000000	0.000000	0.000000	0.000000
	Community awareness campaigns on sustainability	0.000000	0.115515	0.000000	0.000000	0.124991	0.000000	0.000000	0.082303
	Employee safety at work programs	0.000000	0.000000	0.000000	0.000000	0.000000	0.055299	0.000000	0.061867
	Employee training programs on sustainability	0.250000	0.000000	0.000000	0.000000	0.000000	0.049513	0.250000	0.061867
	Implement Environmental Management Systems	0.000000	0.245046	0.000000	0.000000	0.000000	0.070674	0.000000	0.103298
	Incentives for collaboration on sustainability	0.000000	0.000000	0.124991	0.061088	0.000000	0.000000	0.000000	0.000000
	Incentives for green certification	0.000000	0.057758	0.375009	0.066248	0.000000	0.000000	0.000000	0.000000
	IT-enabled process management for sustainability	0.000000	0.081682	0.000000	0.000000	0.375009	0.088782	0.500000	0.127110

Figure 4-19: Weighted super matrix for Environment Sub-criteria

Subnet under Social: Unweighted Super Matrix

Cluster	Node Labels	Enablers: Adoption of safety standards	Employee Healthcare	Employee injury protection	Freeing Public Space	Labour equity	Philanthropy	Quality of life	Voice of Customer
Alternatives	Community awareness campaigns on sustainability	0.000000	0.000000	0.000000	0.333333	0.333333	0.000000	0.259921	0.244679
	Employee safety at work programs	1.000000	1.000000	1.000000	0.000000	0.000000	1.000000	0.327477	0.185432
	Employee training programs on sustainability	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	Implement Environmental Management Systems	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.140531
	Incentives for collaboration on sustainability	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.106503
	Incentives for green certification	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	IT-enabled process management for sustainability	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	Management training for corporate sustainability	0.000000	0.000000	0.000000	0.666667	0.000000	0.000000	0.000000	0.000000

Figure 4-20: Unweighted super matrix Social sub-criteria

Subnet under Social: Weighted Super Matrix

Cluster	Node Labels	Enablers							
		Adoption of safety standards	Employee Healthcare	Employee injury protection	Freeing Public Space	Labour equity	Philanthropy	Quality of life	Voice of Customer
Alternatives	Carbon taxing	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	Community awareness campaigns on sustainability	0.000000	0.000000	0.000000	0.166667	0.166667	0.000000	0.129961	0.122339
	Employee safety at work programs	0.500000	0.500000	0.500000	0.000000	0.000000	0.500000	0.163738	0.092716
	Employee training programs on sustainability	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	Implement Environmental Management Systems	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.070266
	Incentives for collaboration on sustainability	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.053251
	Incentives for green certification	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	IT-enabled process management for sustainability	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

Figure 4-21: Weighted super matrix Social sub-criteria

Subnet under Economic: Unweighted Super Matrix

Cluster	Node Labels	Enablers							
		Adoption of Safety Standards	Collaborative Partnerships	Information Sharing	Quality Management	Risk Management	Strategic Planning	Technology Management	Voice of Customer
Alternatives	Carbon taxing	0.000000	0.000000	0.000000	0.000000	0.239018	0.000000	0.000000	0.000000
	Community awareness campaigns on sustainability	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	Employee safety at work programs	1.000000	0.000000	0.000000	0.000000	0.168172	0.000000	0.000000	0.000000
	Employee training programs on sustainability	0.000000	0.000000	0.000000	0.259927	0.197603	0.000000	0.000000	0.000000
	Implement Environmental Management Systems	0.000000	0.000000	0.000000	0.327476	0.000000	0.000000	0.000000	0.000000
	Incentives for collaboration on sustainability	0.000000	0.666667	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	Incentives for green certification	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	IT-enabled process management for sustainability	0.000000	0.333333	1.000000	0.412597	0.395207	0.000000	1.000000	0.000000

Figure 4-22: Unweighted Super matrix for Economic sub-network

Subnet under Economic: Weighted Super Matrix

Cluster Node Labels		Enablers							
		Adoption of Safety Standards	Collaborative Partnerships	Information Sharing	Quality Management	Risk Management	Strategic Planning	Technology Management	Voice of Customer
Alternatives	Carbon taxing	0.000000	0.000000	0.000000	0.000000	0.119509	0.000000	0.000000	0.000000
	Community awareness campaigns on sustainability	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	Employee safety at work programs	0.500000	0.000000	0.000000	0.000000	0.084086	0.000000	0.000000	0.000000
	Employee training programs on sustainability	0.000000	0.000000	0.000000	0.129963	0.098802	0.000000	0.000000	0.000000
	Implement Environmental Management Systems	0.000000	0.000000	0.000000	0.163738	0.000000	0.000000	0.000000	0.000000
	Incentives for collaboration on sustainability	0.000000	0.333333	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	Incentives for green certification	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	IT-enabled process management for sustainability	0.000000	0.166667	0.500000	0.206298	0.197603	0.000000	0.500000	0.000000

Figure 4-23: weighted Super matrix for Economic sub-network

4.2.4 Selection of the best alternative

Using the synthesize command in super decisions software we obtain the prioritized results for alternatives. The Normals column presents the results in the form of priorities. This is the usual way to report on results. The Ideals column is obtained from the Normals column by dividing each of its entries by the largest value in the column. The Raw column is read directly from the Limit Supermatrix.

For the environment subnet (Figure 4-24), we can see that IT-enabled processes have the highest priority, followed by implementation of environmental management systems, management training for corporate sustainability, and Employee training programs on sustainability and community awareness programs.

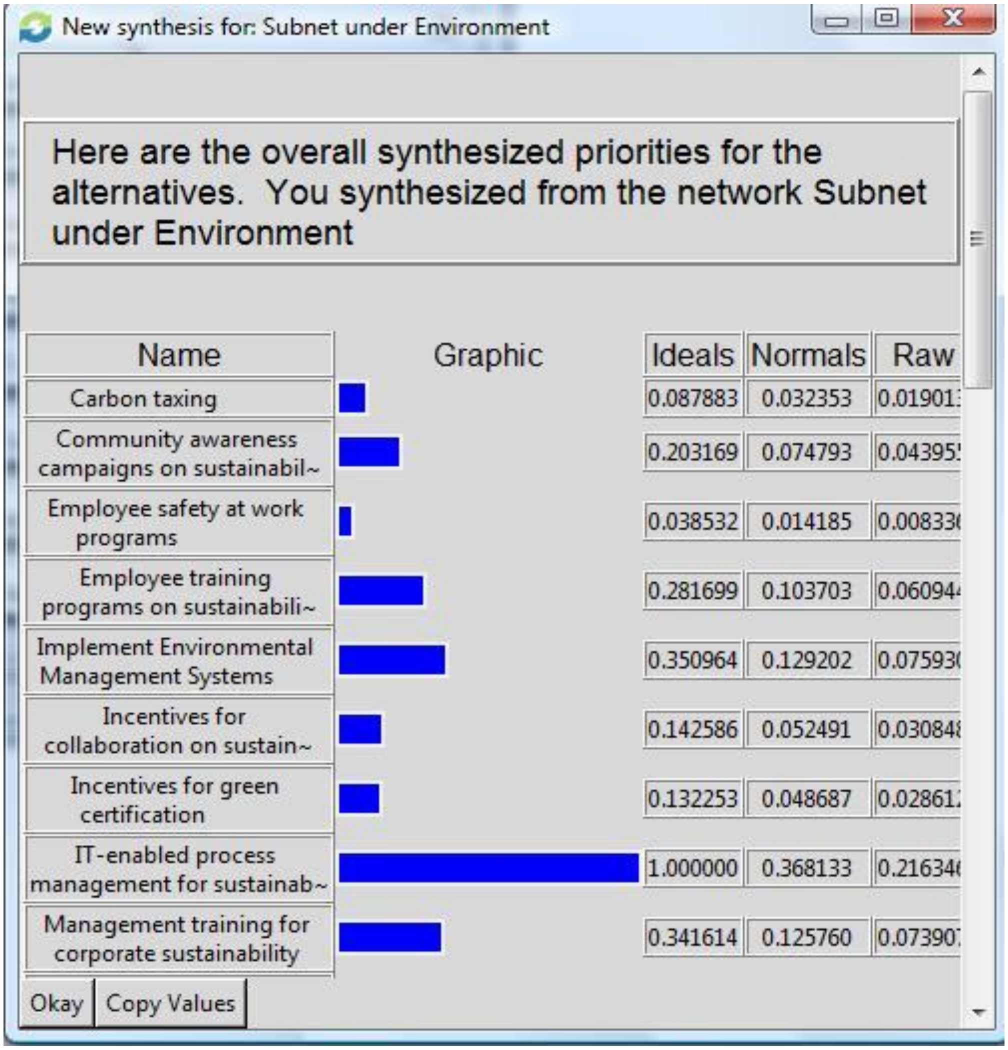
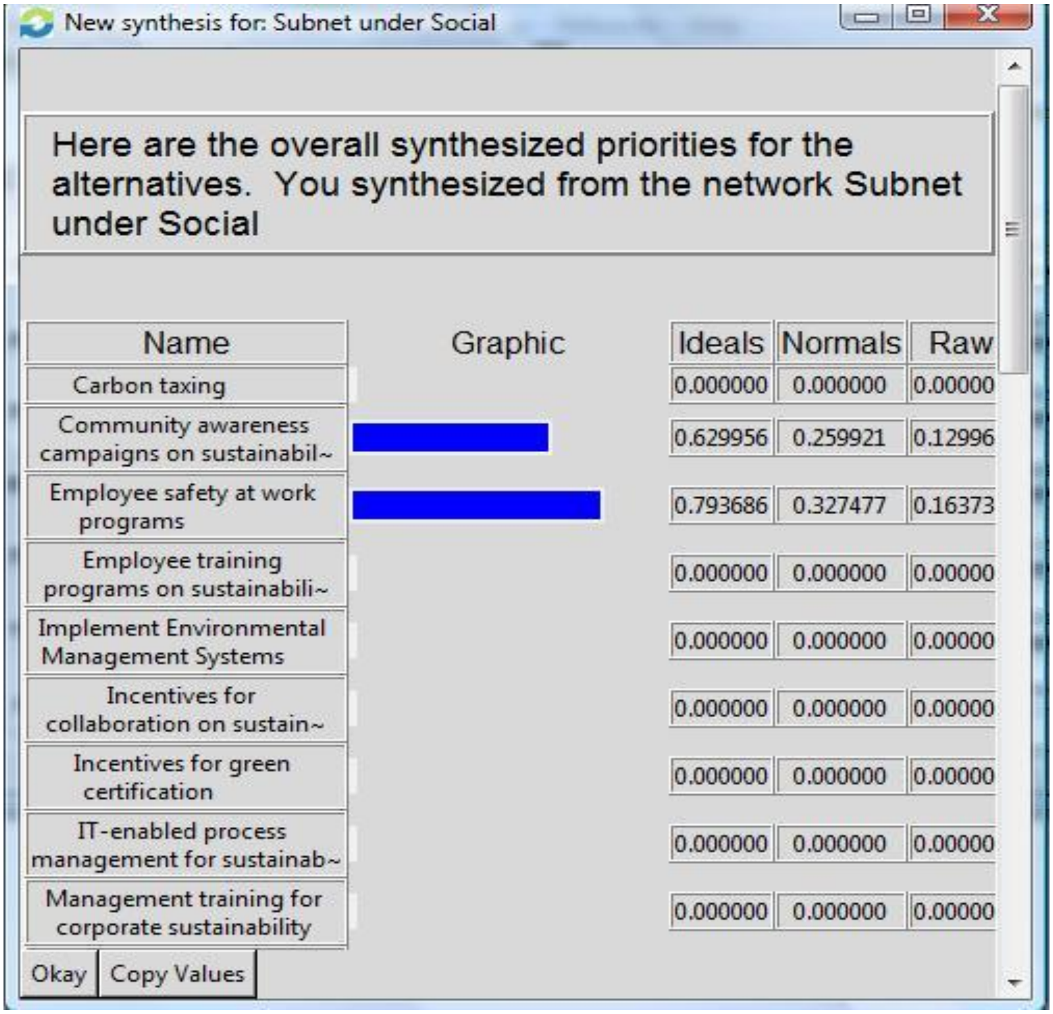


Figure 4-24: Synthesized priorities for the alternatives - Environment subnet

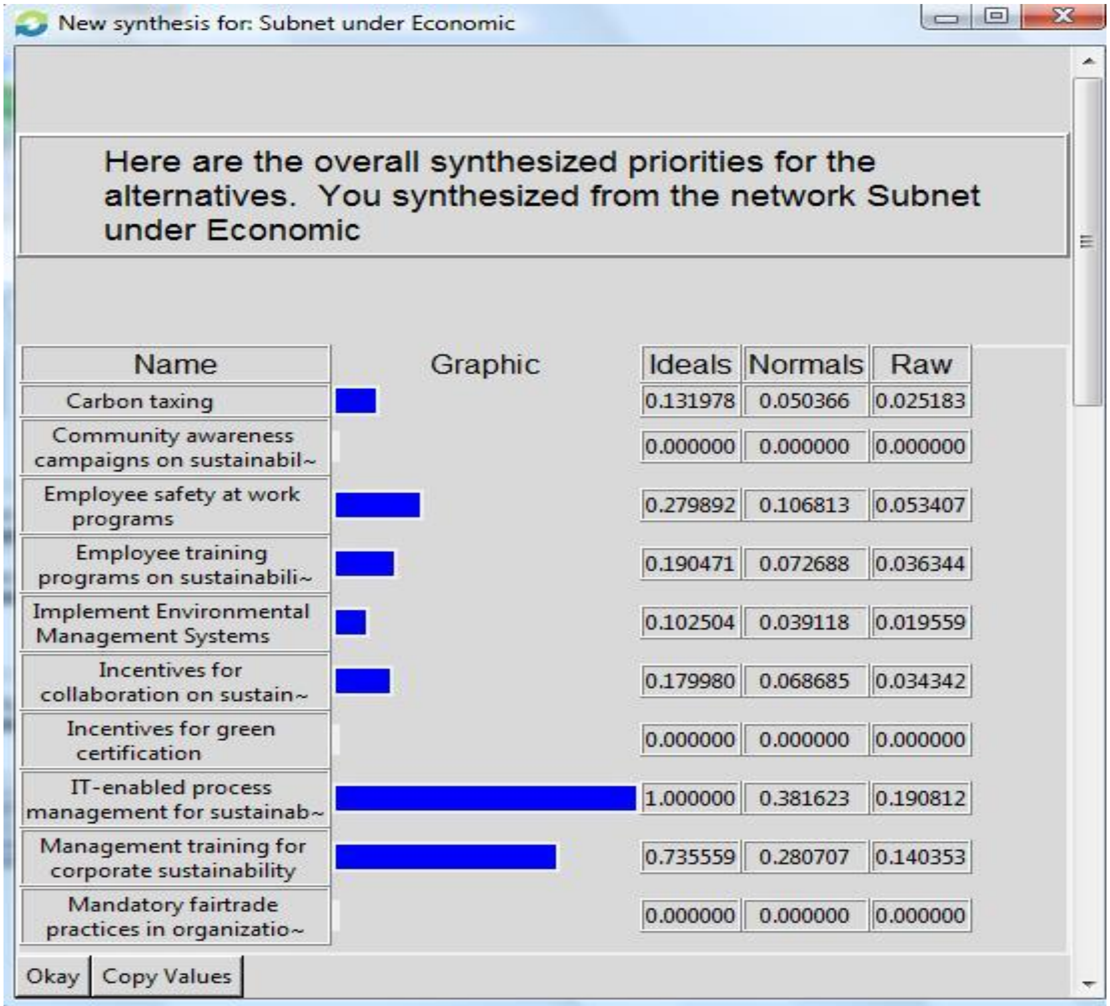
The synthesized results for Social subnet are shown in the Figure 4-25. Employee safety at work has the highest rating. This is followed by Community awareness campaigns for sustainability. This shows that the other alternatives are not relevant to the social subnet. Thereby the values for the rest of the alternatives are zero indicating low or no interaction among enablers and alternatives. Please note that these alternatives are highly dependent on the input data. Our purpose here is to demonstrate the usage of reported techniques than generalizing results for sustainability.



Name	Graphic	Ideals	Normals	Raw
Carbon taxing		0.000000	0.000000	0.00000
Community awareness campaigns on sustainabil~		0.629956	0.259921	0.12996
Employee safety at work programs		0.793686	0.327477	0.16373
Employee training programs on sustainabili~		0.000000	0.000000	0.00000
Implement Environmental Management Systems		0.000000	0.000000	0.00000
Incentives for collaboration on sustain~		0.000000	0.000000	0.00000
Incentives for green certification		0.000000	0.000000	0.00000
IT-enabled process management for sustainab~		0.000000	0.000000	0.00000
Management training for corporate sustainability		0.000000	0.000000	0.00000

Figure 4-25: Synthesized priorities for the alternatives -Social subnet

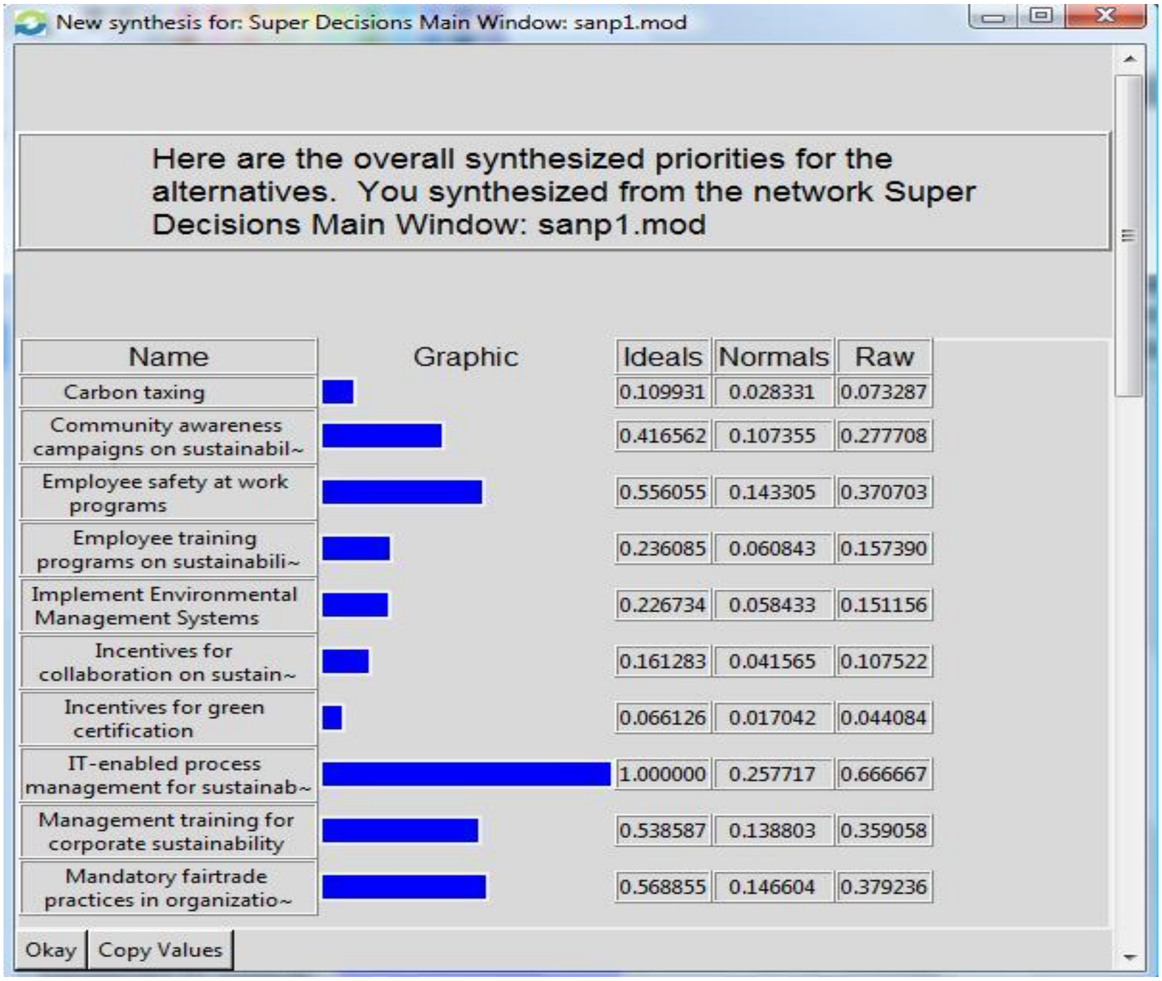
The results for economic (Figure 4-26) subnet indicate that IT-enabled process for sustainability have the highest priority, followed by Management training for corporate sustainability, Employee safety at work, Employee training programs on sustainability, and Incentives for collaboration on sustainability.



Name	Graphic	Ideals	Normals	Raw
Carbon taxing		0.131978	0.050366	0.025183
Community awareness campaigns on sustainabil~		0.000000	0.000000	0.000000
Employee safety at work programs		0.279892	0.106813	0.053407
Employee training programs on sustainabili~		0.190471	0.072688	0.036344
Implement Environmental Management Systems		0.102504	0.039118	0.019559
Incentives for collaboration on sustain~		0.179980	0.068685	0.034342
Incentives for green certification		0.000000	0.000000	0.000000
IT-enabled process management for sustainab~		1.000000	0.381623	0.190812
Management training for corporate sustainability		0.735559	0.280707	0.140353
Mandatory fairtrade practices in organizatio~		0.000000	0.000000	0.000000

Figure 4-26: Synthesized priorities for the alternatives - Economic subnet

The final result of ANP (Figure 4-27) based on the three dimensions of sustainability are presented in Figure 4.27. It can be seen that IT enabled process management is the most important alternative for achieving sustainability (25.77%), followed by Mandatory fair trade practices in organizations (14.66), Employee safety at work programs (14.33%), Management training for sustainability (13.88%), Community awareness campaigns on sustainability (10.73%), Employee training programs on sustainability (6.08%), Implement environmental management systems (5.84%), Incentives for collaboration on sustainability (4.1%), Carbon taxing (2.83%), and Incentives for green practices (1.70%).



Name	Graphic	Ideals	Normals	Raw
Carbon taxing		0.109931	0.028331	0.073287
Community awareness campaigns on sustainabil~		0.416562	0.107355	0.277708
Employee safety at work programs		0.556055	0.143305	0.370703
Employee training programs on sustainabili~		0.236085	0.060843	0.157390
Implement Environmental Management Systems		0.226734	0.058433	0.151156
Incentives for collaboration on sustain~		0.161283	0.041565	0.107522
Incentives for green certification		0.066126	0.017042	0.044084
IT-enabled process management for sustainab~		1.000000	0.257717	0.666667
Management training for corporate sustainability		0.538587	0.138803	0.359058
Mandatory fairtrade practices in organizatio~		0.568855	0.146604	0.379236

Figure 4-27: Synthesized priorities for the alternatives

Chapter 5:

Conclusions and Future Work

5.1 Conclusion

The demand for sustainable supply chains has been growing in the last few decades. People are becoming more aware of the hazards of the supply chain processes and its effects on people, environment and economy. In this thesis, we present a two-step approach based on ISM and ANP for determining enablers and alternatives for sustainable supply chain management.

In the first step, Interpretative structural modeling was used to determine the inter-relationships among the enablers. A detailed literature review was conducted to determine enablers for sustainable supply chain. These enablers were later categorized into environmental, social, and economic dimensions. The results of ISM show that voice of customer, governmental regulations, and governmental rewards and incentives are the driving factors in order to achieve sustainable supply chains. It was also found that enablers including strategic planning, quality management, employee training, management commitment, information sharing, collaborative partnerships, adoption of environmental standards, adoption of green practices, labor equity, philanthropy, quality management play a very important role as linkage variables. Employing these enablers would eventually lead to a better quality of life, adoption of safety standards, and environmental quality management.

In the second step, Analytical Network Process (ANP) was used to evaluate the potential alternatives using the enablers obtained from ISM to select the best one(s) for implementation. "Super Decisions" software was used to develop the ANP model. The results show that IT-enabled process management is the most important alternative followed by mandatory fair-trade practices in organizations. Community awareness programs were also a considerably important alternative, considering the three dimensions of sustainability.

The findings of our study suggest that sustainable supply chains can be achieved by IT-enabled process management. Fair-trade practices will lead to social sustainability and making people aware of the environmental hazards and training them will eventually drive them to raise their voice for sustainable organizations and products in-turn driving the organizations to adopt sustainable practices. The role of governmental regulations, rewards and incentives in achieving sustainable supply chain practices was further confirmed through our study. Please note that these results may change with the change in the number of participants responding the survey study or if specific industries are targeted for survey study. In this thesis, we have limited ourselves to academic experts and graduate students at Concordia University with supply chain background, hence, the results should not be generalized for all industries or all supply chains. Rather, emphasis should be laid on applicability of the proposed approach in determining enablers and alternatives for sustainable supply chain management than on generalizing the results

5.2 Future works

The research presented in this thesis provides a list of enablers for sustainable supply chain management and an integrated ISM - ANP framework for evaluating alternatives for sustainable supply chain planning. The results of ANP in our study are solely based on inputs from a few academic experts in supply chain. In general the results can vary depending on people's opinion and therefore the results can vary marginally or enormously if the number and type of participants increased. In general, the more the participants, the more reliable the results are. Therefore, as future work, we plan to extend this study with a wider audience from multiple disciplines.

We tried our best to capture all the possible enablers in this thesis. However, as time will progress new enablers and alternatives will possibly emerge leaving room for their integration in the present framework.

There is also possibility of quantifying the correlation between different enablers using structural equation modeling (SEM).

Finally, the results of proposed ISM-ANP approach can be compared with other existing approaches for similar datasets as part of future works.

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Appendix

Questionnaire on enablers for sustainable supply chains

This questionnaire is part of a study to evaluate the enablers of sustainable supply chains. The questionnaire is entirely anonymous.

A sustainable supply chain is a system of aligned business activities throughout the lifecycle of products that creates value to stakeholders, ensures ongoing commercial success, and improves the wellbeing of people and the environment.

Please Fill out following details and complete the questionnaire: Age: ☐ Sex: ☐

1 being the least important and 6 most important

	1	2	3	4	5	6.
How important is **commitment from management** to achieve Sustainability in supply chains?	☐	☐	☐	☐	☐	☐
How important is it for top management to avoid greenwash? (Just portray they are green but not in reality)	☐	☐	☐	☐	☐	☐
How important are **Governmental Regulations** to achi sustainability in supply chains?	☐	☐	☐	☐	☐	☐
To what extent do international agreements help achieve this cause? (CDP, ISO 14001, UNEP FI etc)	☐	☐	☐	☐	☐	☐
Do domestic and environmental policies have a major impact in companies adopting sustainable practices (Co2 tax..)?	☐	☐	☐	☐	☐	☐
How important role does **Reverse Logistics** play in sustainab supply chains?	☐	☐	☐	☐	☐	☐
How important is reverse logistics in the process of recycling/refurbish?	☐	☐	☐	☐	☐	☐

To what extent does **Customer Pressure** have an impact on ☐ ☐ ☐ ☐ ☐ ☐

If customers are aware of the benefits of sustainability will it have an impact on Sustainability? ☐ ☐ ☐ ☐ ☐ ☐

How much impact do you think use of IT tools can in achieving sustainability? ☐ ☐ ☐ ☐ ☐ ☐

RFID is useful in improving the supply chains. ☐ ☐ ☐ ☐ ☐ ☐

DSS/EDI systems can improve supply chain processes ☐ ☐ ☐ ☐ ☐ ☐

ERP systems help in better distribution of resources and hence improve the supply chain ☐ ☐ ☐ ☐ ☐ ☐

The Impact of Information Sharing on Sustainable Supply Chains is going to be: ☐ ☐ ☐ ☐ ☐ ☐

Information sharing can help reduce bullwhip effect ☐ ☐ ☐ ☐ ☐ ☐

How much impact can cooperation among supply chains partners have on sustainable supply chains? ☐ ☐ ☐ ☐ ☐ ☐

To what extent can cooperation among supply chain partners impact Information Sharing? ☐ ☐ ☐ ☐ ☐ ☐

Cooperation among supply chain partners leads to more visibility: ☐ ☐ ☐ ☐ ☐ ☐

How effective would lean Processes and cutting of wastes be in achieving Sustainable supply chain? ☐ ☐ ☐ ☐ ☐ ☐

How important a role does Green Production and Development play in achieving Sustainability? ☐ ☐ ☐ ☐ ☐ ☐

Green Procurement helps in making the supply chain more sustainable ☐ ☐ ☐ ☐ ☐ ☐

Adopting lean processes helps reduce waste: ☐ ☐ ☐ ☐ ☐ ☐

Would minimizing demand uncertainty play a role in sustainable Supply Chains if yes then : ☐ ☐ ☐ ☐ ☐ ☐

How important is it to minimize cost in order to achieve sustainability? ☐ ☐ ☐ ☐ ☐ ☐

Open-ended comments

Would you like to comment on any of the enablers in the questionnaire above?

Are there any other enablers or relationships that you may want to suggest and rate on a scale of 1 to 6?

Thank you for taking the time to complete this questionnaire