Evaluation of Drivers and Barriers for Sustainability in Indian Marble Industries

MASTER OF TECHNOLOGY

DISSERTATION REPORT

BY

VISHNU JANGID

(2015PIE5317)

DEPARTMENT OF MECHANICAL ENGINEERING

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

JUNE 2017

A

DISSERTATION REPORT

ON

Evaluation of Drivers and Barriers for Sustainability in Indian Marble Industries

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

MASTER OF TECHNOLOGY
IN
INDUSTRIAL ENGINEERING

BY

VISHNU JANGID
(2015PIE5317)

UNDER THE GUIDANCE OF
Dr. GUNJAN SONI

DEPARTMENT OF MECHANICAL ENGINEERING
MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

JUNE 2017

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR
JAIPUR – 302017 (RAJASTHAN), INDIA

CERTIFICATE

This is to certify that the dissertation entitled "**Evaluation of Drivers and Barriers for Sustainability in Indian Marble Industries**" being submitted by **Vishnu Jangid (2015PIE5317)** is a bonafide work carried out by him under my supervision and guidance, and hence approved for submission to the **Department of Mechanical Engineering, Malaviya National Institute of Technology, Jaipur** in partial fulfillment of the requirements for the award of the degree of **Master of Technology (M.Tech.)** in **Industrial Engineering.** The matter embodied in this dissertation report has not been submitted anywhere else for award of any other degree or diploma.

Dr. Gunjan Soni
Assistant Professor,
Department of Mechanical Engineering,
MNIT Jaipur
Place: Jaipur
Dated: June 2017

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR
JAIPUR – 302017 (RAJASTHAN), INDIA

CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in this dissertation entitled **"Evaluation of Drivers and Barriers for Sustainability in Indian Marble Industries"** in partial fulfilment of the requirements for the award of the degree of **Master of Technology (M.Tech.)** in **Industrial Engineering**, and submitted to the **Department of Mechanical Engineering, Malaviya National Institute of Technology, Jaipur** is an authentic record of my own work carried out by me during a period of two year from July 2015 to June 2017 under the guidance and supervision of **Dr. Gunjan Soni,** Department of Mechanical Engineering, Malaviya National Institute of Technology, Jaipur.

The matter presented in this dissertation embodies the results of my own work and has not been submitted anywhere else for award of any other degree or diploma.

Vishnu Jangid
(2015PIE5317)

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Place: Jaipur
Dated: June 2017

Dr. Gunjan Soni
Supervisor

PLAGIARISM REPORT

Evaluation of Drivers and Barriers of Sustainability in Indian Marble sector

ORIGINALITY REPORT

%20	%16	%13	%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	www.tex.unipi.gr Internet Source	%2
2	academicjournalscenter.org Internet Source	%1
3	Bhanot, Neeraj, P. Venkateswara Rao, and S.G. Deshmukh. "An integrated approach for analysing the enablers and barriers of sustainable manufacturing", Journal of Cleaner Production, 2016. Publication	%1
4	T. Raj. "An ISM approach for modelling the enablers of flexible manufacturing system: the case for India.", International Journal of Production Research/00207543, 20081215 Publication	%1
5	Rajesh K. Singh. "Interpretive structural modelling for selection of best supply chain practices", International Journal of Business Performance and Supply Chain Modelling, 2010 Publication	%1

ACKNOWLEDGEMENTS

With great delight, I acknowledge my indebted thanks to my guide and mentor **Dr. Gunjan Soni,** who has always been a source of inspiration and encouragement for me. His stimulated guidance and unwavering support always motivated me to reach out for and achieve higher levels of excellence. This dissertation could not have attained its present form, both in content and presentation without his active interest, direction and help. I am grateful to him for keeping trust in me in all circumstances. I thank him for being big-hearted with any amateurish mistakes of mine.

I express my sincere gratitude to **Prof. G.S. Dangayach (HOD), Prof. Ajay Pal Singh Rathore, Prof. Rakesh Jain, Prof. Gopal Agrawal, Prof. Awadhesh Bhardwaj, Dr. M.L. Mittal** and **Dr. M.L. Meena** for their support and guidance throughout the course of study at MNIT Jaipur.

I highly acknowledge and duly appreciate the support extended by my seniors, colleagues-friends and juniors at various industries for assistance with the collection of data for my research work. I sincerely thank all the industry professionals who, despite of their busy schedule, cheerfully responded to my queries and made this research task possible.

I am thankful to my senior research scholars especially **Om Ji Shukla, Gaurav Kumar Badhotiya** and **Avanish Singh Chauhan** at MNIT Jaipur for their support and guidance. I extend my heartiest thanks to my colleagues-friends for their help & support in accomplishment of this work during my stay at MNIT Jaipur.

Final thanks goes to almighty God, my parents **Sh. Satya Narayan Jangid** and **Smt. Prem Jangid** for their continuous support, encouragement and blessings.

- Vishnu Jangid

ABSTRACT

Indian Stone and marble are the oldest ornamental and building materials that has history dating back from 3200 BC. These dimensional stones have left deep imprints in the architectural heritage of country. A number of temples, forts, and places of ancient Indian civilisation have been carved out locally. These stone architecture has even contributed to the present era with modern buildings like the Presidential house, Parliamentary house and Supreme Court made from a high quality marble from Rajasthan. The increasing fame of Indian marble has forced the demand for its extraction, these stones are also been exported to many countries like USA, Germany, France, etc. Due to its high demand and extraction at the same time has led to tons of waste deposits. Due to the lack of proper waste management techniques the waste is being dumped on open lands and is causing severe threat to the environment in Rajasthan and in nearby areas of the state. Other important aspects being the poor working environment for workers as not much emphasis is given to worker health and safety. So these issues increase the importance of adopting safe and sustainable development approach.

The present work highlights the important drivers and barriers of sustainability in marble processing industries and provides a view of the relative importance of critical drivers and barriers of sustainability. ISM technique is used to develop a complex system comprising all the important drivers and barriers separately and showing the interdependency. MICMAC analysis is done to classify the drivers and barriers based upon their driving and dependency power. The outcome of the results will play a significant role for underlying and enhancing the critical motivating factors as well as to lower the impact of barriers which will hinder the implementation of sustainability. The research shows some drivers and barriers have high driving power and low dependency requiring maximum attention and of strategic importance, and some are having high dependence and low driving power and are resultant effects of other drivers and barriers respectively. The knowledge of dominating drivers and barriers of sustainability would help managers, decision makers, and practitioners in better understanding and to focus on major drivers and barriers of its implementation while undertaking projects in their organizations.

This study focuses on the evaluation of environmental, economic, and social factors of sustainability implementation in marble industries of north western region of India and presents a case study of three marble processing plants by evaluating the extent of sustainability of these plants. Rating and a comparative study has been done for these firms on the basis of various sustainability criterions by using Grey based MCDM approach. A detailed questionnaire was sent to three marble processing firms and based on the received responses the analysis is done. The implications from this research, therefore, are rather obvious, and companies should be able to easily identify the areas in which focus is needed in the future.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

SM	Sustainable Manufacturing
SMC	Sustainable manufacturing Concepts
AHP	Analytical Hierarchical Process
ANP	Analytical Network Process
ISM	Interpretive Structural Modeling
MCDM	Multi Criteria Decision Making
MICMAC	Matriced' Impacts croises-multiplication applique' and classment
R&D	Research & Development
SCC	Self-compacting concrete
SC	Sustainability concepts

Chapter 1
INTRODUCTION

The recent research and growth of knowledge about sustainable development have increased interest in sustainable development terminology, which has gained prominence over the past decade. It embraces terms such as cleaner production, pollution prevention, pollution control, and minimization of resource usage, waste minimization, eco-design (design of a product or process considering the environmental, social and economic impact) in a review presented by Glavic et al., (2007) the basic idea of sustainable manufacturing, a hierarchical classification and its terminology has been demonstrated. For manufacturing applications, the definition of sustainability requires refinement. Companies have developed and applied numerous approaches for integrating sustainability into industrial operations, including people planet profits, sustainable management, ecological sustainability, and the "Triple bottom line" method. The latter method is described by Elkington in his studies, (Elkington, 1998) as a business case for sustainability. In order to adumbrating, understanding and applying sustainability, it is important to have knowledge of sustainability and indicators for it. These topics are explained in this section.

1.1 Sustainability: An introduction

Sustainability is a concept that has been defined in many ways and has different meanings to different people. Sustainable development was introduced in a widespread way by the Brundtland Commission, which defined it as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (Rosen et al., 2012). According to the report presented by the Brundtland Commission sustainability is the combination of three very important factors and theses are highlighted briefly in the following figure:

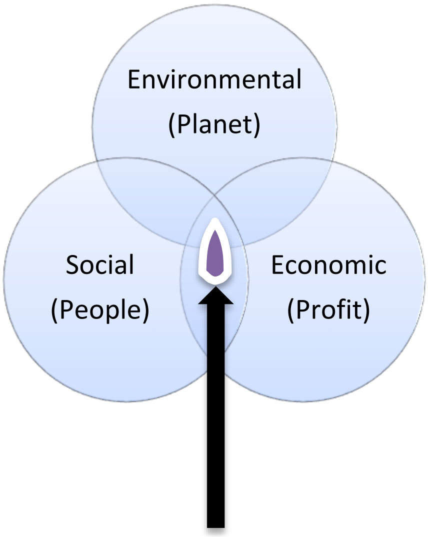


Figure 1.1: Sustainability concept and its elements

This "Triple bottom line" involves a holistic approach relying on the principles of economic prosperity, environmental stewardship and corporate responsibility. According to which it is the intersection of three approaches as environment, social and economic. Sustainability has been illustrated in several different ways, it depends on the context of the particular type of industries, applications and different objectives. The following table shows various sustainability definitions:

Table 1.1: Sustainability definitions

Sr. no.	Authors	Definition of Sustainability
1	Koplin et al. (2007)	A framework to show responsibility towards environmental, economic and social behavior into business practices
2	Bhanot et al. (2015)	Ability to sustain
3	Amrina et al. (2011)	Manufacturing with minimum negative impact on environment
4	Bhanot et al. (2016)	Developing and practicing technologies to transform materials into finished products with reduction in energy consumption, greenhouse gases and waste
5	Garg et al. (2014)	Manufacturing using renewable sources
6	Gupta et al. (2015)	Sustainability is a three dimensional approach
7	The World Commission on Environment and Development (WCED)	Development that meets the needs of the present without compromising the ability of future generations to meet their own needs

To achieve complete sustainability following points should be considered

- A company should focuses on 3 aspects to be truly sustainable i.e. **social, environmental and economic**
- Another common way of saying this is "people, planet, and profit" Sustainability is the intersection of these three concepts.
- It is also called the **Triple Bottom Line** this can be understood clearly by the following figure.

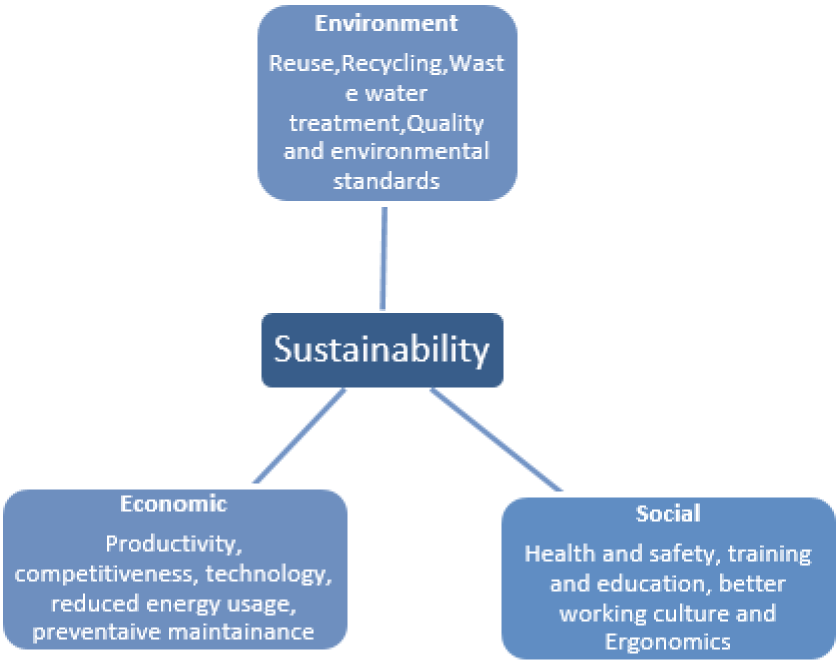


Figure 1.2: Relationship between social, environmental and economic aspects of sustainability

1.2 Introduction to Marble Processing Plant

The following figure 1.3 shows the basic layout of a marble processing plant and various stages where waste is generated. The main task of the quarrying is to cut/slice the stones load it on to the trucks and transport it to the cutting site. Here, in quarrying skill work is required in order to minimize the waste generated at quarry. After that stones go to cutting workshops for cutting and resizing from there it goes to the processing plants which are responsible for shaping, cutting and transporting the dimensional slabs to the distributers. Both quarrying and processing of marble produce wastes and need some means to reduce, reuse and recycle this produced waste. The stone waste from cutting site is sent for further processing to get crushed and transported in different sizes to construction and concrete factories in order to keep the environment safe from non-degradable waste. The marble dust is collected through a water treatment method where concept of gravity is used in stepped tanks as marble dust is heavy so this dust is collected at bottom of tank and remaining waste water is collected in a downward side tank and then again reused for next cycles. This dust is dumped in dumping yard and scrap marble pieces are further processed.

1.3 Motivation for Research

Sustainability is an important function in any manufacturing and processing organization, and its proficiency can largely alter the success of the organization. A number of literatures are available on investigation of drivers and barriers of SM in various areas like automobile industries, green supply chain management and electrical panel industries that have a very strong impact in any organization. Therefore, this research is carried out to provide a detailed insight about the critical factors that can largely affect the success of sustainability projects and also the drivers and barriers of implementation of these factors in practice within the Indian marble processing industries. Also, the ISM approach is used with the aim to understand the mutual interaction of these drivers and barriers and identify the 'driving variables' (i.e. which influence other variables) and the 'dependent variables' (i.e. which are influenced by others).

Hence, the purpose of this research is to explore critical drivers and barriers of sustainability in Indian marble processing industries to find out the importance of various drivers and barriers and develop a structured relationship model providing their driving power and dependence power.

Further a case study of three marble processing plants is presented in the present work and these firms are compared for the extent of sustainability rating & are compared on the basis of sustainability criterion by using Grey based MCDM approach to know which firm is implementing sustainability in best way. A detailed questionnaire was sent to some marble processing firms and based on the received responses the analysis is done.

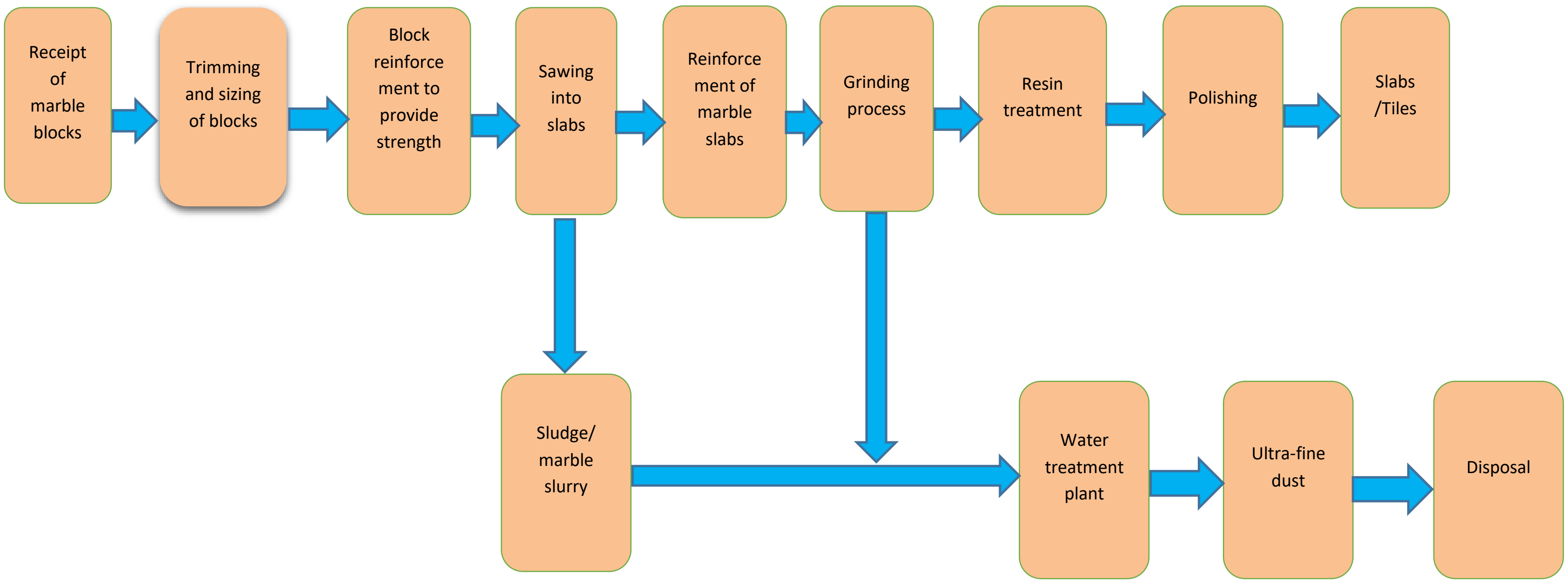


Figure 1.3: Introduction to marble processing plant (adapted from Prajwal et al., 2016)

A detailed questionnaire was sent to some marble processing firms and based on the received responses the analysis is done. Moreover, the research also reveals which factors have been implemented and which have not. The implications from this research, therefore, are rather obvious, and companies should be able to easily identify the areas in which focus is needed in the future.

1.4 Objectives of the Dissertation

The key objectives of this dissertation are as follows:

- To identify the drivers for sustainability and analyse the relationship among them for marble processing industries.
- To identify the barriers for sustainability and analyse the relationship among them for marble processing industries.
- To compare three marble processing industries on the basis of identified drivers and barriers.

1.5 Structure of the Dissertation

This dissertation report is organized into seven chapters as shown in the Figure 1.4. *Chapter 1* discusses the topic of the study, its motivation and need of study, introduction to sustainability and marble processing plant. It outlays the objectives of the research. Finally, the layout and content of the chapters is described.

Chapter 2 provides literature review on sustainability and various areas of sustainability such as environmental, economic, and social aspects. A detailed qualitative analysis is done in this part to gather in-depth information and summarized it in tabular form representing the critical sustainability drivers and barriers.

Chapter 3 gives a detailed research methodology that how the work has been carried out and what steps are being followed during the research work.

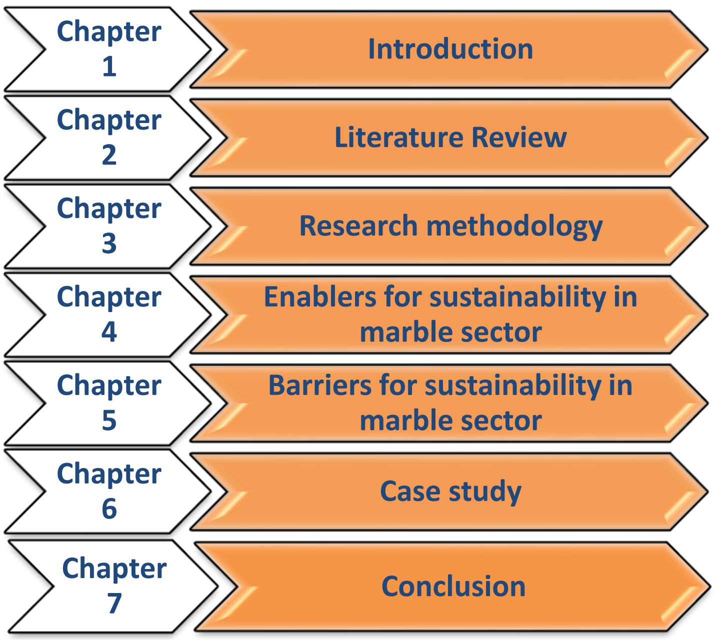
Chapter 4 consists of the description of ten important drivers for sustainable manufacturing in marble sector which justifies and promote its implementation. Using expert's opinion from academia and industry professionals an ISM model is formed and MICMAC principle is also discussed in fourth chapter.

Chapter 5 consists of the detailed description of nine barriers for sustainable manufacturing in marble sector which justify and promote its implementation. Using expert's opinion from academia and industry professionals the ISM model is formed and MICMAC analysis is done in the same way as done in fourth chapter.

Chapter 6 contains a case study of three marble processing plants and these plants are compared for the extent of sustainability. Rating & comparison is done on the basis of various factors of sustainability by using Grey based MCDM approach to know which plant is implementing sustainability in best way.

Chapter 7 contains the conclusion of this research work and lists the limitations of this research. Suggestions are made to show path for future research scope.

Figure 1.4: Outline of the dissertation



Chapter 2
LITERATURE REVIEW

In order to formulate an answer to any research question, a literature review is of significant importance to gather in-depth information on the topic so that a better understanding of the problem can be achieved. The literature review is the basis for a study and contributes to the formulation of answer to the proposed research question (Cooper and Schindler, 2008).

In the present research work the whole literature is divided into two parts of which first being the drivers of sustainability are reviewed then barriers are described with suitable literature. In chapter 6 a case study of three marble processing plants is presented by using Grey based MCDM approach. In chapter 4 and 5 the divers and barriers of sustainability are evaluated using ISM technique.

2.1 Application of Sustainability in Marble industries

A lot of research has done in the field of sustainability but a very few literature is available about sustainability in marble sector specifically. Some authors have described the problem related to the quarrying area like in the study presented by Nicola et al. (2011), the main environmental impact factors such as noise, vibration, fumes, dust, vehicle traffic etc. those are associated with marble quarrying and processing area and their effects have been demonstrated. Traverso et al. (2010) conducted a study to analyze the life cycle assessment of environmental performance of Sicilian marble. In this study the impact of marble processing wastes is highlighted on environment in terms of waste water and energy wastage. The analysis of the whole production process of Perlato di Sicilia illustrates the environmental performance and the hot spots of the entire production cycle of marble. So in order to understand the applications of sustainability in marble processing industries first we should know the important factors of SM which are listed and described below.

2.2 Sustainability drivers extracted from literature

A very detailed and extensive study carried out to find out the drivers in implementing sustainability through literature survey. In this chapter a list of total ten potential critical drivers (available in table 2.1) which are the major driving force behind the successful implementation of SM are shown.

Table 2.1: List of sustainability drivers identified through literature

Sr. no.	Drivers	Description	Literature support
D1	Market pressure	Trade and Commercial Practices, Competitors, Customer Satisfaction.	Kulatunga et al. (2013); Amrina and Yusof (2012), Zhu, & Sarkis (2006)
D2	Financial benefits	Recurring & Long-Term Financial Yields.	Kulatunga et al. (2013); Amrina and Yusof (2012); Mittal et al. (2013); Garg et al. (2014)
D3	Government policy	Law Enforcement and Judicial Regulations, Private-Public Participation and Social accountability. pollution control, landfill taxes, emissions trading, eco-label, etc.	Kulatunga et al. (2013); Amrina and Yusof (2012); NMCC (2006); Garg et al. (2014)
D4	Top management support	Social accountability and management, owner or investors are highly committed to enhance environmental performance, ethics, social values	Kulatunga et al. (2013); Mittal et al. (2013); Koho et al. (2011)
D5	Adoption of innovative and advanced technology	Advance Technological Initiatives for Performance Enhancement.	Mittal et al. (2013), n Azapagic (2006), NMCC (2006)
D6	Lowering manufacturing cost	Efficient Process Management With Minimum Waste outputs.	Azapagic (2006), NMCC (2006)
D7	Quality enhancement	Innovative Process, Product Quality, Enhanced Production.	NMCC (2006)
D8	Training and education of workers	Inducting periodical deployment of workers training and upgraded technological Education.	NMCC (2006),
D9	Worker motivation	Concern towards worker health & safety policies make a positive impact	Beriha et al. (2011), Aukour et al. (2008), Georgiadis & Besiou (2010)
D10	Safeguarding environment	Using the concepts of recycling and reuse of waste marble dust and sludge	Hanieh et al. (2014), Topcu et al. (2009), Kishore, & Chowdary (2015), Glavic & lukman (2007), Hanieh et al. (2014), Topcu et al. (2009), C. Vaidevi (2013)

1. Market pressure

As the study presented by Bhanot et al. (2017) pressure from market for a company is a motivating factor that will increase the company's ability to become competitive and to sustain in market. Competition from competitors of same segment in same product category also contribute towards total market competitiveness. Sometimes the customer or public concerns, insurance companies, various NGOs also put this pressure on manufacturers to practice it and go for green materials, safe processes and good working environment as described by Mittal et al. (2014) and Haapala et al. (2013).

2. Financial benefits

Any new concept that is incorporated by some organization is driven by the need to meet long term financial goals. Low manufacturing costs and improved product quality are the important outcome of implementation of sustainability concepts that will ultimately reduce the cost of the products so does to company's profit share. By implementing such concepts the trust of a customer is regained in company as the company is paying special concerns towards the safety of environmental and health. From the study done by Bhanot et al.(2016) it is very clear that by adopting sustainability concept a firm can improve product quality and also can enjoy an increased market-share that will ultimately increases the profit.

3. Government policy

It may feel that it is a barrier but according to Garg et al. (2014) the government promotions and policies are a strong motivation for many manufacturing firms as by abiding the government policies organizations can publicize their products to be standard and safe that will enhance the image of organization and improve its market share. It is very good and safe for consumers as well as for safeguarding of environment. As described by Bhanot et al. (2015) that the conformance to law enforcement and judicial regulations is essential to maintain proactive environmental strategies to enhance environmental performance. By following the standard Government policies and regulation a firm can keep the wastes and emissions to a minimum level and can enhance the customer and community satisfaction. Government should also need to maintain a strict control over emissions-wastes and should promote green materials (preferably indigenous) and methods.

4. Top management support

Environmental management leadership is very important factor in an organization's efforts towards achieving sustainability. Resource allocation and policy implementation is done by top management so commitment towards policy making based upon market analysis due to market pressure and responsibility towards society and to increase profitability by reducing the costs they can take decisions on implementation of SMC in their organization so they play a very crucial role in implementing it as described by Zhu et al. (2013). Top managements' viewpoints act as favorable and motivating.

5. Adoption of innovative and advanced technology

According to report presented by The National Manufacturing Competitiveness Council (NMCC) that by investing capital in advanced technology and innovative ideas, productivity is improved. Organization become technological sound this led to higher growth & profits along with improved working standard for workers also. Use of new technological perspective make the organization easy to maintain the minimum emissions level and cost of manufacturing reduces as wastes are reduced and lower cost incurred in manufacturing as presented by Bhanot et al.(2016).

6. Lowering manufacturing cost

Based upon the report presented by The National Manufacturing Competitiveness Council (NMCC) it was stated that low cost of manufacturing is always a motivating factor for any organization as it would increase their customer segments. In countries like India where customers are price sensitive it would definitely increase the market share if companies offer less price for a product. But at the same time it is very challenging to maintain the quality of product and safeguarding the environment and society from the negative impact of poor quality product. To maintain both low cost of product and quality is difficult according to Bhanot et al. (2016). Cost savings due to cleaner production methods is a major driving force according to study presented by Azapagic (2006) in mining and marble sector.

7. Quality enhancement

As stated by Nambiar (2010) that one of the most difficult thing is to maintain high quality standards without compromising with environmental safety. Quality drive the future of any organization as it is the most important criteria of development as well as company policy. If by adopting SMC the quality is enhanced then the companies will definitely go to adopt this concept. Quality ensures competitiveness not only in local market but also in foreign markets. Reducing environmental, health and safety impacts of a firm are part of a good business strategy and social responsibility. By doing so corporate image of a firm becomes better and quality of product becomes superior

8. Training and education of workers

As in today's time where possessing a true skill is very essential. Taking the example of lakhs of engineering graduated across the country who doesn't have skills required by the industry and needs proper training before starting working. Sustainability comes with additional advantage of proper training and education about the new methods of product design, process design, various waste reduction techniques, emissions standards, social responsibility and public accountability. It ensures proper use and handling of tools, process parameters, working environments etc. That made SMC truly essential for implementation.

9. Worker motivation

This driver solely based upon the social factor of sustainability as providing proper and adequate facilities to a worker and showing concern towards worker health & safety policies make a positive impact and it is a big boost for his confidence and his loyalty quotient will get enhanced. All this led to higher his confidence and motivate him to do his work with greater efficiency and accuracy in the company.

10. Safeguarding environment

This is a very important driver as saving the environment from further degradation not only helpful for future generations but it also saves cost. Waste marble dust can be recycled and reused in self-compacting concrete (SCC) as a filler material as analyzed by Topcu et al. (2009) in a study to find out the ways of conversion of waste material into some usable form.

2.3 Sustainability barrier extracted from literature

A very detailed and extensive study carried out to find out the barrier in implementing SM through literature survey. In this chapter a list of total nine potential critical barriers (available in table 2.2) which are the major factors which hinder the implementation of sustainability are shown.

Table 2.2: List of sustainability barriers identified through literature

Sr. no.	Barriers	Description	Literature support
B1	Lack of awareness of sustainability concepts and if someone is conducting locally	No or limited access to Sustainability literature.	Gupta et al. (2015), Ghazilla et al.(2015), Mittal et al. (2013)
B2	Negative attitudes towards sustainability concepts	Insignificant knowledge of Sustainability concepts and methods of waste reduction and safeguarding of environment	Herrmann et al. (2013), Bhanot et al. (2017)
B3	Lack of funds for green Projects	Neglected approach for Funds distribution.	Sangwan et al. (2013), Ghazilla et al.(2015)
B4	Lack of standardized metrics or performance benchmarks	Absence of specific Guidelines and parameters. Lack of standard module and methods	Haapala et al. (2013)
B5	Cost too high	Initial high costs for sustainable technology implementation, cost of skill development program, costs of additional tools and equipment	Bhanot et al. (2015) Azapagic (2006)
B6	Lack of cooperation from senior leaders	Total neglect by concerned top Brass.	Mittal et al. (2013), Bhanot et al. (2017)
B7	Fear of not taking risk	Fear of failure when introducing a new concept like focus on waste reduction	Koho et al. (2011)
B8	Uncertain benefits	Due to long payback periods and hidden nature of benefits the uncertainties arises	Herrmann et al. (2013), Bhanot et al. (2017
B9	Lack of skilled staff	Improper way of work handling increases wastes due to lack of skilled workforce	Mittal et al. (2013), Bhanot et al. (2017)

1. Lack of awareness of sustainability concepts

This is a very important barrier as one knows that to implement any concept one must have adequate knowledge about it. Knowledge should be in the form of written or in visual form. No or very few available information is the very basic and primary reason for the lack of awareness of sustainability concepts in the manufacturing organizations (Bhanot et al., 2015).

2. Negative attitudes towards sustainability concepts

If a believe is made about something even before it is done or given a try then one can't help it out. Insignificant knowledge of Sustainability concepts and methods of waste reduction and safeguarding of environment are those barriers in the way of successful implementation of sustainable development. The primary reason for negative attitudes towards sustainability concepts is the lack of proper knowledge and resistance in adopting such practices following which manufacturing organizations can become sustainable. Government institutions need to set up a suitable framework by which they can set up a legal machinery for retention of effective laws and enactment of growth oriented bye-laws (Bhanot et al., 2015).

3. Lack of funds for green Projects

In a company to accomplish any task availability of proper distributed funds should be ensured. The main reason for lack of funds for green projects is the ignorance towards environmental norms and lack in the ability of foreseeing the impact of waste generation on environment (Bhanot et al., 2017). Return on investment period is also long after implementing sustainable technologies which makes it tough for small and medium enterprises to invest in it considering the higher initial cost of investment (Mathiyazhagan et al., 2013). Most of the organizations do not have even enough funds for undertaking research on remanufacturing technologies (Xia et al., 2015). However, government norms can be framed for incentive schemes and even for strict implementation of suitable policies.

4. Lack of standardized metrics or performance benchmarks

For a manufacturing firm it is very difficult to assess their sustainable performance and identify their underperforming domains without having fixed practical guidelines and parameters. Hence, suitable sustainability assessment frameworks can only be framed until and unless both industry professionals and academicians collaborate with each other so that real issues can be identified and worked upon to implement sustainability considering the unique set of operations in each of the manufacturing sector (Bhanot et al., 2015).

5. Cost too high

Out of the all hindrances the cost of initiatives for improvements in the products or processes has always been one of the most critical factors for any manufacturing organization considering initiatives for improvements in the products or processes (Amrina and Yusof, 2012). High initial costs of implementing the sustainable technology constrain the industry practitioners from investing in it especially when return-on-investment is low (Mathiyazhagan et al., 2013). Joint efforts from government, industries and academicians are required to make it feasible for the manufacturers to implement sustainable technologies at an effective cost (Bhanot et al., 2015).

6. Lack of cooperation from senior leaders

The total neglect towards very primary issues such as bringing a change to the existing working environment along with the absence of information systems and a negative approach by the concerned top brass towards implementation of sustainability concepts degrades the motivation for middle management and workers in the organization in pursuing the change (Mathiyazhagan et al., 2013). However, there is a need for top management to understand the importance of pursuing sustainable initiatives and hence, should provide full support regarding infrastructure and resources necessary such as waste treatment facilities, promotion of strategies like reuse, recycle, worker health and safety, preventive maintenance for cost reduction and resource savings and for the implementation of sustainable manufacturing (Amrina and Yusof, 2012).

7. Fear of not taking risk

There is always some risk is associated with bringing every new concept and manufacturing phenomena such as sustainable manufacturing as the cost involved in system improvement is high and long term pay back made it even worse. That is why a new concept is not appreciated due to lack of knowledge, investment issues, lack of funds etc. all make this issue even worse.

8. Uncertain benefits

Uncertain or insignificant economic advantage, slow return on investment, long payback periods and hidden nature of benefits are the main class of barriers that arises when a firm wishes to go green and applying sustainability concepts.

9. Lack of skilled staff

Skilled labor is needed in order to implement and install new system, new tools and techniques at plant level. Skilled labor requires proper training and updated information to accomplish tasks.

2.4 Interpretive Structural Modeling (ISM)

ISM methodology is an interactive learning process and helps to improve order and direction on the complex relationships among variables of a system (Sage, 1977). In this, a set of different and directly related variables affecting the system under consideration is structured into a comprehensive systemic model. The model so formed portrays the structure of a complex issue, a system of a field of study, in a carefully designed pattern employing graphics as well as words (Singh et al., 2003; Ravi and Shankar, 2005; Faisal et al., 2006, 2007).

The basic idea of ISM is to use experts' practical experience and knowledge to decompose a complicated system into several sub-systems (elements) and construct a multilevel structural model. ISM methodology helps impose order and direction on the complexity of relationships among elements of a system (Warfield, 1974; Sage, 1977). Saxena et al. (1990) developed direct relationship matrices of key factors, objectives, and activities for energy conservation in the Indian cement industry by the application of ISM. Mandal and Deshmukh (1994) used the ISM methodology to analyze some of the important criteria on vendor selection and have shown the inter-relationships of criteria and their levels. Singh et al. (2003) used ISM to categorize variables for implementing knowledge management in manufacturing industries. Sharma et al. (1995) used the ISM methodology to develop a hierarchy of action required to achieve the future objective of waste management in India. Ravi et al. (2005) used ISM to model the reverse logistics variables typically found in computer hardware supply chains. The main objectives were: to identify and rank the variables of reverse logistics activities in the computer hardware industry; to find out the interaction among identified variables; and to understand the managerial implications of this research.

Ravi and Shankar (2005) identified 11 factors of reverse logistics in automobile industries and used ISM methodology to analyze the interaction among these factors. Huang et al. (2005) proposed a method by integrating ISM and ANP to analyze subsystems' interdependence and feedback relationships. Kannan and Haq (2007) used the ISM methodology to analyze the interactions among the criteria and sub-criteria, which influences the supplier selection for the built-in-order supply chain environment. Kannan et al. (2008) analyzed the interaction of criteria that was used to select the green suppliers who addressed the environmental performance using ISM, and the effectiveness of the model was illustrated using an automobile company. Kannan et al. (2009) used ISM and fuzzy TOPSIS as a hybrid approach for the analysis and selection of third-party reverse logistics provider. Diabat and Govindan (2011) used the same ISM methodology to analyze the driving affecting the implementation of green supply chain management. Singh and Kant (2008) used ISM methodology to evolve mutual relationships among the identified knowledge management factors. Raj et al. (2010) used ISM approach to understand the mutual interaction of the drivers that help in the implementation of flexible manufacturing systems (FMS) and identify the driving drivers and the dependent drivers.

Some of the important characteristics of ISM as observed by Raj et al. (2010) are:

1. This methodology is interpretive as the judgment of the group decides whether and how the different elements are related.
2. It is structural, too, on the basis of relationship; an overall structure is extracted from the complex set of variables.
3. It is a modeling technique, as the specific relationships and overall structure are portrayed in a digraph model.
4. It helps to impose order and direction on the complexity of relationships among various elements of a system.
5. It is primarily intended as a group learning process, but individuals can also use it.

2.5 Grey based decision approach

A lot of research have done using the grey approach in the situations when there are uncertainties in decisions. Textile manufacturing firms are compared using grey matrix on the basis of 6 sustainability criteria's after categorizing 66 suppliers into 3 groups in a study presented by Baskaran et al. (2012). Mishra et al. (2013) developed a grey-based and fuzzy TOPSIS MCDM model to develop an agility evaluation approach to determine the most suitable agile system for implementing mass customization (MC) strategies. In a detailed study proposed by Govindan et al. (2013) for the selection of suppliers considering the triple bottom approach of people, planet and profit integrating with Fuzzy TOPSIS is studied for reference. A study proposed in the field of selection of manufacturing system by Shukla et al. (2014) using grey based decision making approach in order to meet the dynamic and uncertain market changes is also a good example of application of grey theory. Grey system theory has been used as a tool in analyzing an economic system by Li et al. (2008) in order to get rid of the uncertainties of market. Grey-Entropy Analytical Network Process is used by Tseng et al. (2012) in order to decide which agile system is better of the all available strategies for the implementation of mass customization strategies.

Chapter 3
RESEARCH METHODOLOGY

The methodology followed for conducting this research work is explained in the following sections:

3.1 Collection of Literature

In order to find relevant articles concerning the research objectives a systematic literature review was conducted. Using a broad range of sources resulted in the sufficient literature to conduct this study. Online databases of technical & management publishers were used, viz. Science Direct, Emerald Insight, Taylor and Francis, IEEE online, Google Scholar, etc.

With the purpose of finding relevant literature for this study key words were used based on preliminary readings and logical thinking. As the research context was described, the main concepts are new sustainable development, critical factors, Indian marble sector and manufacturing industries and interpretive structural modeling. Using these as a guideline a list of the key words that are related to the main concepts was drawn. The key words used are presented below. The articles found in preliminary search based on the key words were filtered by grounding on the relevance in title and abstract of the articles. In the second phase, another selection took place by using other criterion so that the most relevant articles would remain for further review. The keywords used for finding relevant articles were:

- Sustainable manufacturing concepts
- Sustainability manufacturing concepts Indian marble sector
- Factors of Sustainable manufacturing implementation
- Drivers of Sustainable manufacturing
- Barriers of Sustainable manufacturing
- Challenges in marble processing industries
- Interpretive structural modeling
- ISM Approach

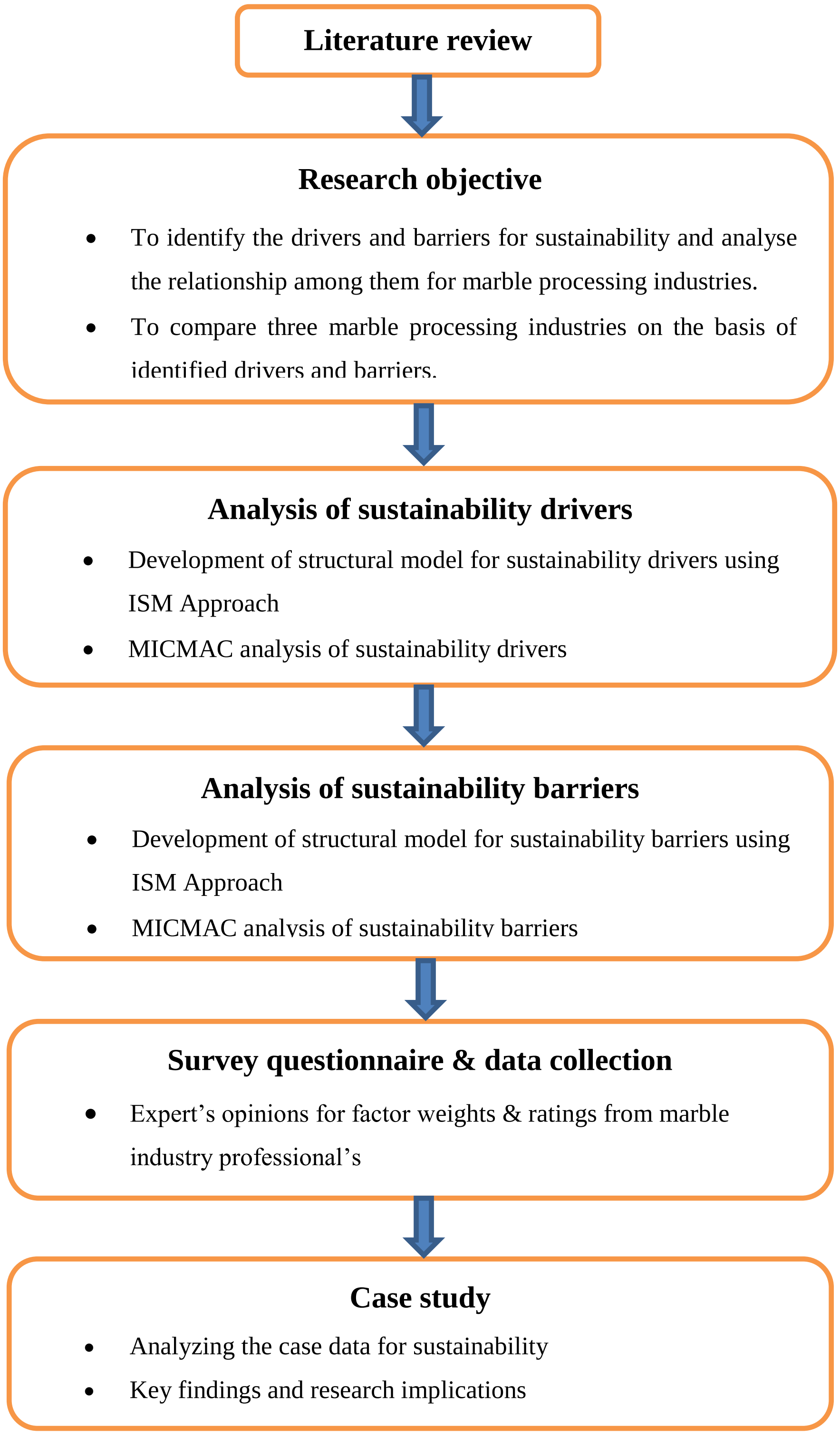


Figure 3.2: Flow diagram for research methodology

The complete research work is carried out into two parts first is the Identification of important drivers and barriers of implementation of sustainability in marble industries. For this work to be effective in stating only manufacturing sector was considered then specifically focus shifted to marble industries.

3.2 ISM framework

In analyzing and setting a contextual relationship between drivers and barriers of the sustainability implementation ISM approach is used here. It is a subjective approach and Delphi technique is used for preparing the SSIM matrix with the help pf experts.

3.2.1 ISM Methodology

The various steps involved in the ISM methodology are given below (Kannan et al., 2009; Talib et al., 2011; K. Mathiyazhagan et al., 2013) as depicted in Figure 3.1.

I. Variables (drivers & barriers) considered for the system under consideration are listed.

II. From the variables identified in step I, a contextual relationship is established among the variables in order to identify as to which pairs of variables should be examined.

III. A structural self-interaction matrix (SSIM) is developed for variables, which indicates pairwise relationships among variables of the system under consideration.

IV. Initial reachability matrix is developed from the SSIM and the matrix is checked for transitivity to obtain final reachability matrix. The transitivity of the contextual relation is a basic assumption made in ISM. It states that if a variable A is related to B and B is related to C, then A is necessarily related to C.

V. The final reachability matrix obtained in step IV is partitioned into different levels on the basis of the reachability and antecedent sets for each of the variable and through a series of iterations.

VI. On the basis of the levels of partitions obtained from step VI and final reachability matrix, a conical matrix is constructed.

VII. A directed graph or digraph is drawn based on partition levels and transitive links are removed.

VIII. The resultant digraph is converted into an ISM-based model, by replacing variable nodes with statements.

IX. Finally, the ISM-based model developed in step VIII is reviewed for inconsistency and necessary modifications are incorporated through expert opinions.

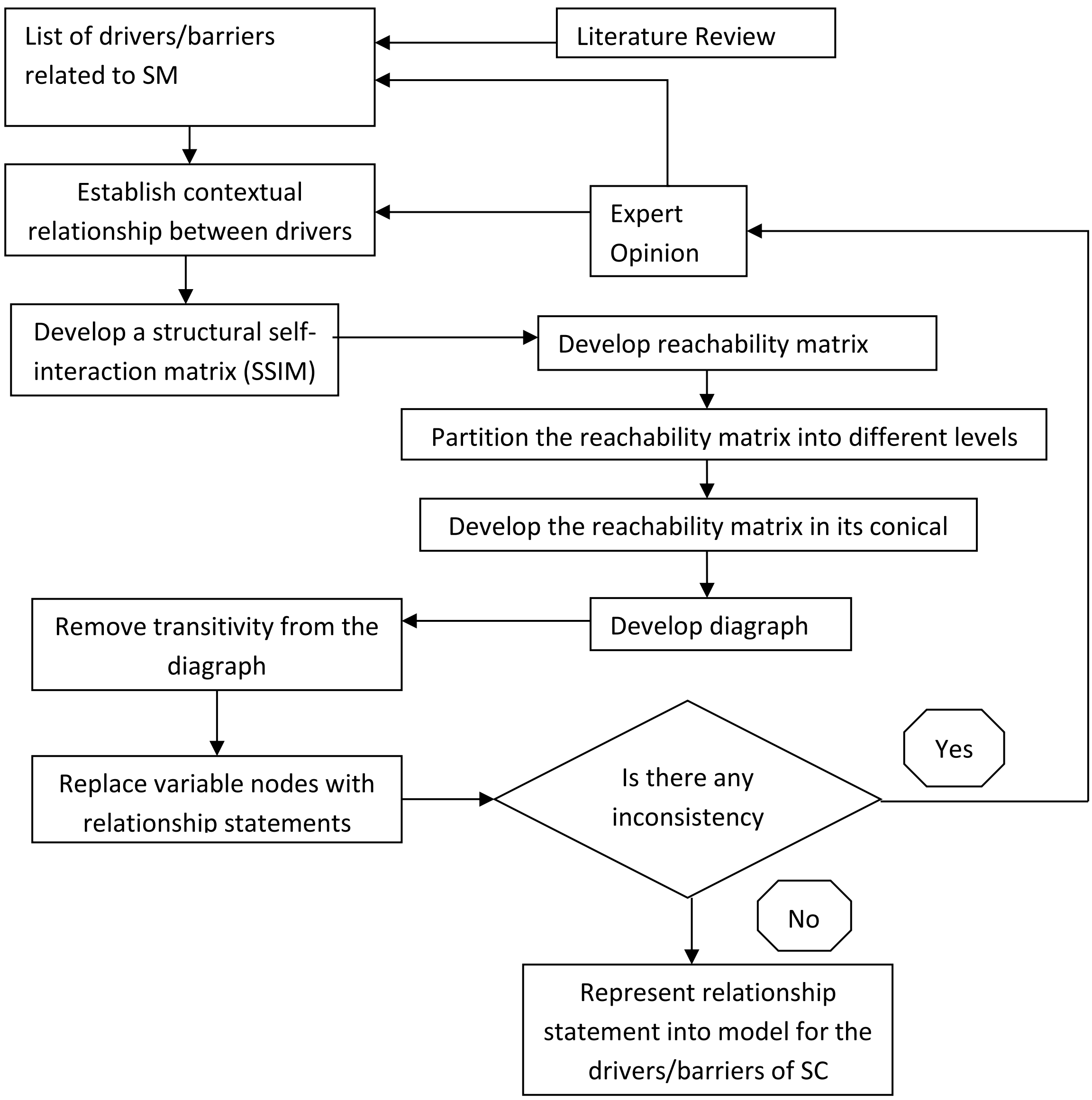


Figure 3.1: Flow diagram for preparing ISM model (adapted from K. Mathiyazhagan et al., 2013)

3.3 MICMAC Principle

Matriced' Impacts croises-multiplication applique' and classment is abbreviated as MICMAC. The MICMAC principle, also known as cross-impact matrix multiplication applied to classification, is based on multiplication properties of matrices (Sharma et al., 1995). The purpose of MICMAC analysis is to analyze the driving power and dependence of variables (Mandal and Deshmukh, 1994). MICMAC analysis is done by plotting a graph between the driving power and dependence power of the factors derived from final reachability matrix.

3.4 Grey Approach framework

Grey approach was first proposed and described by Deng (1989) as a technique of studying and analyzing the situations where uncertainty in available information is more. It is a technique which is used to solve the complex MADM problems which is having a lower degree of information availability and it uses grey sets (Deng et al., 2000). In this approach help of decision makers and experts from industry and academia is taken to apply and evaluate the alternatives by designing a proper and detailed questioner. Following are the steps involved in GREY methodology are given below (Mishra et al., 2013; Shukla et al., 2014 ;).

I. Listing all the factors considered for the system under consideration.
II. Deciding criterion weights with the help of industry professional and academicians.
III. Responses are received from industry professionals from marble processing plants and factor rating are received.
IV. Establishing grey decision matrix with the help of criterion rating received through survey questionnaire.
V. Normalizing the establishing grey decision matrix
VI. Weighted normalized grey decision matrix normalized matrix is formed to give consideration and importance to each criteria.
VII. Listing all the ideal referential alternatives and these are those with maximum values of each criterion in Grey weighted normalized decision matrix
VIII. Calculation of actual alternatives to find out the grey possibility degrees and compare all the three alternatives and rank them.

3.4.1 Variables & Design of questioner for using Grey MCDM technique

The candidate factors chosen as variables for the questioner are identified by brainstorming through previous literature and conformity of marble sector. This research is based on the Delphi method which involves obtaining responses from engineers and managers, working in different functions of marble processing industries, who are directly involved in various phases of marble processing. The assumption considered in questioner is that we believe the respondents know the process of SC better than anybody else, as they are working in the practical field on daily basis.

3.4.2 Questionnaire Design

The draft of questionnaire is prepared based on the factors identified through literature review & brainstorming with sustainability practitioners analyzing the work done by previous researchers. All the factors are listed & grouped into following three categories.

i. Environmental factors
ii. Economic factors
iii. Social factors

The questionnaire is divided into two parts:

1. The first part enquires basic information concerning the respondent, such as his/her name, organization, job position, and function/department, involvement in SM and work experience.
2. Second part deals with the criterions of sustainability. The respondents were asked about the importance rating they perceive to each factor for SM success. They were also required to provide the extent of implementation of that factor in their organization. For this a Yes/No type questioner was prepared and for every factor three to four sub questions were asked. It was ensured that if direct rating is not possible then still the factor can be rated efficiently by considering the number of responses received.

A pilot study was conducted to check the draft questionnaire that the candidate criterions are relevant to practical work of sustainability, and whether the factors are easily understood & explained. The pilot study was carried out with a group of three industry professionals from three different automotive organizations. The internal survey was used to prepare the final questionnaire which addresses the issues that came up during pilot study. Some factors that were not clearly described and some terms that can't be easily or fully comprehended were altered. Some factors were tailored to suit the marble industry, and the factors not relevant to auto industry were removed. Some criterions were clubbed together as they represent similar function. Provision for providing additional relevant comments was given as open ended question in the final questionnaire.

3.4.3 Organization of the questionnaire

The final questionnaire was sent to industry professionals and people of managerial positions in 3 marble processing plants in north western region of India. The companies chosen for conducting the questionnaire survey are renowned marble processing industries of western India. The method used for gathering data was personal interviews. This method was chosen due to the advantage that the designed questionnaire could be conveniently sent to a number of candidate respondents and gather responses in a limited time. The intended respondents were those managers & engineers involved in implementation of SC in the domain of marble processing at any stage.

A total of 3 companies were approached for this questionnaire survey and 3 decision maker from each company were asked to rate the criterions of sustainability based on their experience in the field of implementation of SC in marble processing industries. A total of 12 responses were received in two weeks duration from the respondents. Based on the responses received further analysis was done.

Chapter 4

ANALYSIS OF DRIVERS FOR SUSTAINABILITY

4.1 Overview

In order to implement any new concept in an industry there should be enough reasons which drives, supports, validate and motivates its implementation and justifies the importance of the particular new concept. In the present research sustainability issue is addressed with suitable literature that supports its implementation and all these motivating factors are called sustainability drivers and these are described below.

4.2 Sustainability drivers

A very detailed and extensive study carried out to find out the drivers in implementing sustainability through literature survey. In this chapter a list of total ten potential critical drivers (available in table 4.1) which are the major driving force behind the successful implementation of sustainability are shown here and a complete description of each driver have been provided in chapter two.

Table 4.1: List of sustainability drivers

Sr. no.	Drivers
D1	Market pressure
D2	Financial benefits
D3	Government policy
D4	Top management support
D5	Adoption of innovative and advanced technology
D6	Lowering manufacturing cost
D7	Quality enhancement
D8	Training and education of workers
D9	Worker motivation
D10	Safeguarding environment

4.3 Application of ISM approach

The ISM technique for development of relationship model follows a systematic approach. The various steps involved in ISM approach which are as follows:

4.3.1 Data Collection

The ISM methodology suggests the use of the expert opinions based on management techniques like brain storming, in developing the contextual relationship among the variables. Thus, in this research for identifying the contextual relationship among the drivers, experts from marble industries and academia have been consulted in developing the contextual relationship among the factors.

4.3.2 Structural Self-Interaction Matrix

After identifying and enlisting 10 sustainability drivers through literature review and experts' opinion, their analysis is carried out. First of all, a contextual relationship of "leads to" type is chosen. This means that one factor leads to another factor. Based on this principle, a contextual relationship is developed.

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

V: Drivers *i* will lead to driver *j*;
A: Drivers *j* will lead to driver *i*;
X: Drivers *i* and *j* will influence each other; and
O: Drivers *i* and *j* are unrelated.

The following statements explain the use of symbols V, A, X, and O in the SSIM:

- Market pressure leads to the improved level environment safeguarding, so the relationship between Driver D1 and D10 is denoted by 'V' in the SSIM.
- Quality enhancement will lead to the financial benefits to the company, so the relationship between Driver D2 and D7 is denoted by 'A' in the SSIM
- Government policy and safeguarding environment will lead to each other, so the relationship between Driver D3 and D10 is denoted by 'X' in the SSIM
- No relationship exists between low manufacturing cost and safeguarding environment, so the relationship between Driver D6and D10 is denoted by 'O' in the SSIM

Table 4-2: Structural self-interaction matrix

Drivers	10	9	8	7	6	5	4	3	2	1
D1	V	O	O	V	V	X	A	O	O	X
D2	O	A	O	A	A	A	A	A	X	
D3	X	O	O	O	V	O	V	X		
D4	V	V	V	V	V	V	X			
D5	V	V	V	V	V	X				
D6	O	A	O	A	X					
D7	O	A	O	X						
D8	V	V	X							
D9	V	X								
D10	X									

Based on the contextual relationship between factors, the SSIM has been developed. The SSIM is discussed with the experts. Based on their responses, SSIM has been finalized and is presented in Table 4.2.

4.3.3 Reachability Matrix

In this step, the reachability matrix is developed from SSIM. The SSIM table is converted into the reachability matrix by transforming the information of each cell of SSIM into binary digits (i.e. 1 or 0) in the initial reachability matrix.

The rules for the transformation are as follows:

- If the entry in the cell (*i, j*) in the SSIM is 'V', then the cell (*i, j*) entry becomes 1 and the cell (*j, i*) entry becomes 0 in the reachability matrix.
- If the entry in the cell (*i, j*) in the SSIM is 'A', then the cell (*i, j*) entry becomes 0 and the cell (*j, i*) entry becomes 1 in the reachability matrix.
- If the entry in the cell (*i, j*) in the SSIM is 'X', then the entries in both the cells (*i, j*) and (*j, i*) become 1 in the reachability matrix.
- If the entry in the cell (*i, j*) in the SSIM is 'O', then the entries in both the cells (*i, j*) and (*j, i*) become 0 in the reachability matrix.

Following the above rules, the reachability matrix is constructed as shown in Table 4.3

Table 4-3: Reachability matrix

Drivers	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
D1	1	0	0	0	1	1	1	0	0	1
D2	0	1	0	0	0	0	0	0	0	0
D3	0	1	1	1	0	1	0	0	0	1
D4	1	1	0	1	1	1	1	1	1	1
D5	1	1	0	0	1	1	1	1	1	1
D6	0	1	0	0	0	1	0	0	0	0
D7	0	1	0	0	0	1	1	0	0	0
D8	0	0	0	0	0	0	0	1	1	1
D9	0	1	0	0	0	1	1	0	1	1
D10	0	0	1	0	0	0	0	0	0	1

The reachability matrix will be used to find out the driving power and dependence of each factor are also shown along with the ranking of the drivers is also done. The driving power of a particular sustainability driver is the total number of drivers (including it) which it may help achieve. The dependence is the total number of drivers which may help achieving it. These driving power and dependencies will be used in the MICMAC analysis, where the sustainability drivers will be categorized into four clusters: autonomous (cluster I), dependent (cluster II), linkage (cluster III), and independent also called driving factors (cluster IV).

4.3.4 Level Partitions

Based on the suggestions of Warfield (1974) and Farris and Sage (1975), the reachability set and antecedent set for each factor is found out from reachability matrix. The reachability set for a particular driver consists of the driver itself and the other driver, which it may help achieve. The antecedent set consists of the driver itself and the other drivers which may help in achieving it. After finding the reachability set and antecedent set for each driver, the intersection for these sets is derived for all the drivers. The drivers for which the reachability and the intersection sets are the same is given the level-I driver in the ISM hierarchy, which would not help achieve any other driver above their own level. From Table 4.4, it is seen that driver D2 and D10 are found at level I. Thus, it would be positioned at the top of the ISM model.

After the identification of the level-I drivers, it is removed from the other remaining drivers. This iteration is continued till the level of each driver is determined. Here, level partitioning process of these sustainability drivers is completed in eight iterations giving eight levels. The levels so determined help in building the digraph and the final relationship model of ISM. The iteration steps having sustainability drivers along with their reachability set, antecedent set, intersection set, and the different levels, are shown in Table 4.4 to Table 4.11.

4.3.5 Conical Matrix

Conical matrix is achieved from level-partitioned reachability matrix by rearranging the drivers according to their level, which means all the drivers having same levels are clubbed together. A summary of drivers at various levels is shown in Table 4.12. After rearranging, the conical matrix is obtained, which is depicted in Table 4.13. The conical matrix helps in the generation of the digraph and later on structural model.

Table 4.4: Level-I iteration

Drivers (Di)	**Reachability sets R(Di)**	**Antecedent sets A(Di)**	**Intersection sets R(Di) ∩ A(Di)**	**Level**
1	1,5,6,7,10	1,4,5	1,5	
2	2	2,3,4,5,6,7,9	2	I
3	2,3,4,6	3,10	3	
4	1,2,4,5,6,7,8,9,10	3,4	4	
5	1,2,5,6,7,8,9,10	1,4,5	1,5	
6	2,6	1,3,4,5,6,7,9	6	
7	2,6,7	1,4,5,7,9	7	
8	8,9,10	4,5,8	8	
9	6,7,9,10	4,5,8,9	9	
10	3,10	1,3,4,5,8,9,10	3,10	I

Table 4.5: Level-II iteration

Drivers (Di)	Reachability sets R(Di)	Antecedent sets A(Di)	Intersection sets R(Di) ∩ A(Di)	Level
1	1,5,6,7	1,4,5	1,5	
3	3,4,6	3	3	
4	1,4,5,6,7,8,9	3,4	4	
5	1,5,6,7,8,9	1,4,5	1,5	
6	6	1,3,4,5,6,7,9	6	II
7	6,7	1,4,5,7,9	7	
8	8,9	4,5,8	8	
9	6,7,9	4,5,8,9	9	

Table 4.6: Level-III iteration

Drivers (Di)	Reachability sets R(Di)	Antecedent sets A(Di)	Intersection sets R(Di) ∩ A(Di)	Level
1	1,5,7	1,4,5	1,5	
3	3,4	3	3	
4	1,4,5,7,8,9	3,4	4	
5	1,5,7,8,9	1,4,5	1,5	
7	7	1,4,5,7,9	7	IIII
8	8,9	4,5,8	8	
9	7,9	4,5,8,9	9	

Table 4.7: Level-IV iteration

Drivers (Di)	Reachability sets R(Di)	Antecedent sets A(Di)	Intersection sets R(Di) ∩ A(Di)	Level
1	1,5	1,4,5	1,5	IV
3	3,4	3	3	
4	1,4,5,8,9	3,4	4	
5	1,5,8,9	1,4,5	1,5	
8	8,9	4,5,8	8	
9	9	4,5,8,9	9	IV

Table 4.8: Level-V iteration

Drivers (Di)	Reachability sets R(Di)	Antecedent sets A(Di)	Intersection sets R(Di) ∩ A(Di)	Level
3	3,4	3	3	
4	4,5,8	3,4	4	
5	5,8	4,5	5	
8	8	4,5,8	8	V

Table 4.9: Level-VI iteration

Drivers (Di)	Reachability sets R(Di)	Antecedent sets A(Di)	Intersection sets R(Di) ∩ A(Di)	Level
3	3,4	3	3	
4	4,5	3,4	4	
5	5	4,5	5	VI

Table 4.10: Level-VII iteration

Drivers (Di)	Reachability sets R(Di)	Antecedent sets A(Di)	Intersection sets R(Di) ∩ A(Di)	Level
3	3,4	3	3	
4	4	3,4	4	VII

Table 4.11: Level-VIII iteration

Drivers (Di)	Reachability sets R(Di)	Antecedent sets A(Di)	Intersection sets R(Di) ∩ A(Di)	Level
3	3,4	3	3	VIII

Table 4.12: Summary of drivers at various iteration levels

LEVELS	DRIVERS
I	2,10
II	6
III	7
IV	1,9
V	8
VI	5
VII	4
VIII	3

4.3.6 ISM-based Model (Digraph)

Based on the conical matrix, an initial digraph including transitivity links is obtained. This is generated by nodes and lines of edges. After removing the indirect links, a final digraph is developed and is than finally converted into the ISM model by replacing nodes of the drivers with statements as shown in Figure 4.1. In this development, the level I drivers of sustainability are positioned at the top of the digraph and level II drivers are placed at second position and so on, until the level VIII drivers are placed at the bottom-most position in the ISM-based model.

Table 4.13: Conical matrix

Drivers	**2**	**3**	**10**	**6**	**7**	**1**	**5**	**9**	**8**	**4**	**Driving power**	**Rank**
D2	1	0	0	0	0	0	0	0	0	0	1	**6**
D3	1	1	1	1	0	0	0	0	0	1	5	**3**
D10	0	1	0	0	0	0	0	0	0	0	1	**6**
D6	1	0	0	1	0	0	0	0	0	0	2	**5**
D7	1	0	0	1	1	0	0	0	0	0	3	**4**
D1	0	0	1	1	1	1	1	0	0	0	5	**3**
D5	1	0	1	1	1	1	1	1	1	0	8	**2**
D9	1	0	1	1	1	0	0	1	0	0	5	**3**
D8	0	0	1	0	0	0	0	1	1	0	3	**4**
D4	1	0	1	1	1	1	1	1	1	1	9	**1**
Depending power	7	2	6	7	5	3	3	4	3	2		
Rank	**1**	**6**	**2**	**1**	**3**	**5**	**5**	**4**	**5**	**6**		

The ISM model has been developed for evaluating the interrelationship among identified drivers.

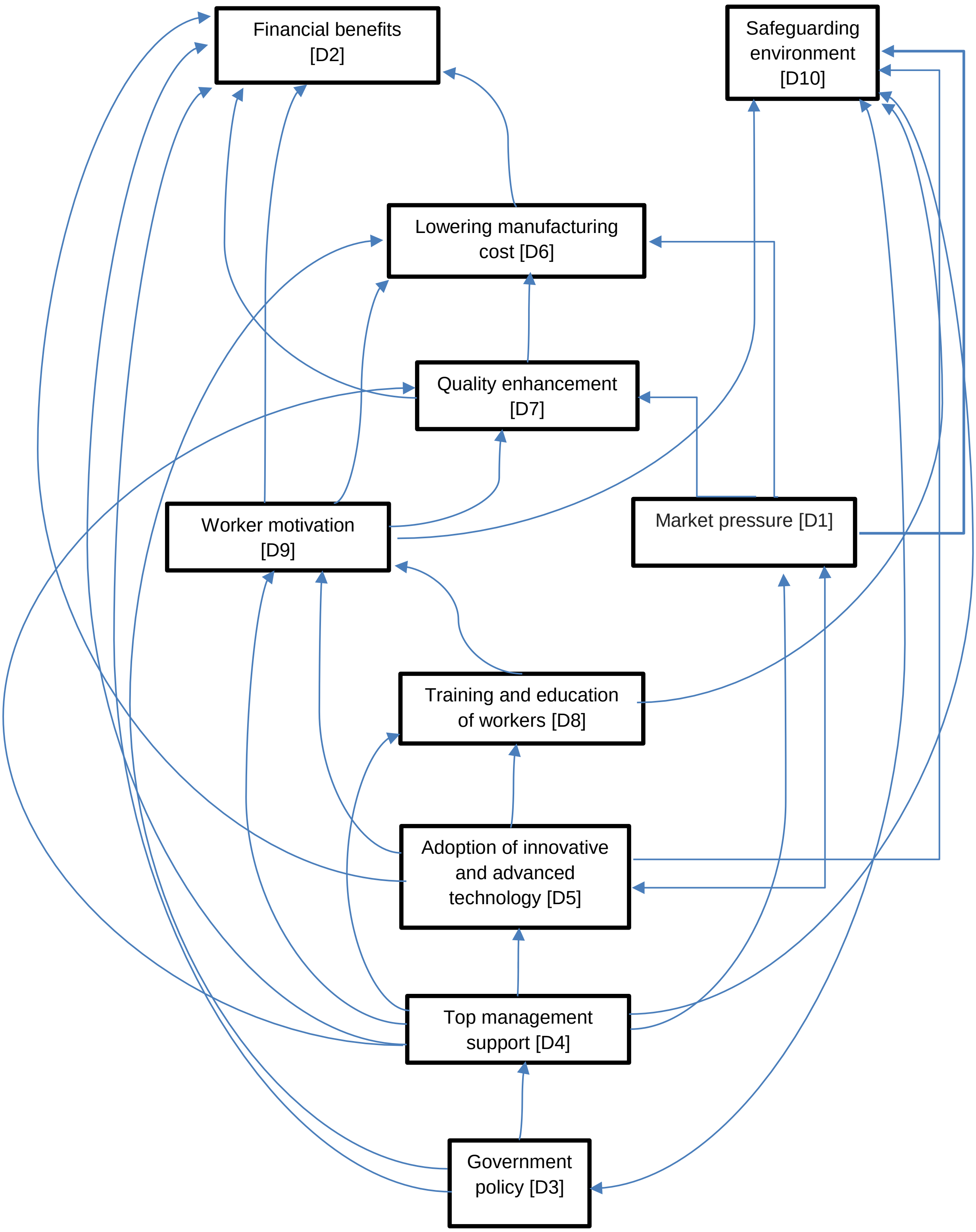


Figure 4.1: ISM based model for sustainability drivers

Proper government regulations and a strong environment policy are the most important drivers for the implementation of SM in marble sector. This ISM model depicts that these two important drivers drive most of other drivers of sustainability.

The involvement of top management (D4) and their support towards the adoption of innovative and advanced technology (D5) is driven by government policies as government rules and regulations (driver 3) are very strict for marble industries where waste reduction is achievable with strict government policies. Also top management gives its approval to a new technological framework whose aim is to provide training and education (driver 8) to the workers to improve their efficiency and also waste reduction amount can be controlled. Further training and education motivates workers (driver 9) towards working for environment sustainability and enhanced quality (driver 7). Ultimately low manufacturing cost (driver 6) leads to financial benefits (driver 2) to a firm and market pressure (driver 1) and quality improvement leads to environment safety (driver 10).

4.3.7 MICMAC analysis for sustainability drivers

The purpose of MICMAC analysis is to analyze the driving power and dependence power of variables. This is done to identify the key drivers that driving the system. The driving and dependence powers of the drivers are derived from the reachability matrix (Table 4.3) by performing summation of rows to find out driving power and summation of columns to find out the dependence power of each driver. The driving and dependence power of various drivers is given in conical matrix (Table 4.13)

The factors are categorized into four clusters based on their driving power and dependence power as follows:

I. *Autonomous factors*: These drivers have weak driving power and weak dependence. They are relatively disconnected from the system, with which they have few links, which may be very strong. These SM drivers are represented in quadrant I.

II. *Dependent factors:* This category includes those drivers which have weak driving power but strong dependence power and placed in Quadrant II. These drivers affected by any action on SM drivers driving these factors.

III. *Linkage factors*: These drivers have strong driving and strong dependence and are placed in quadrant III. They are also unstable and so any action on them will have an effect on others and also a feedback effect on themselves.

IV. *Independent factors:* These drivers have strong driving power but weak dependence power. These are represented in quadrant IV. These drivers are independent in nature which are not much affected by others, but cause effects on the factors dependent on them.

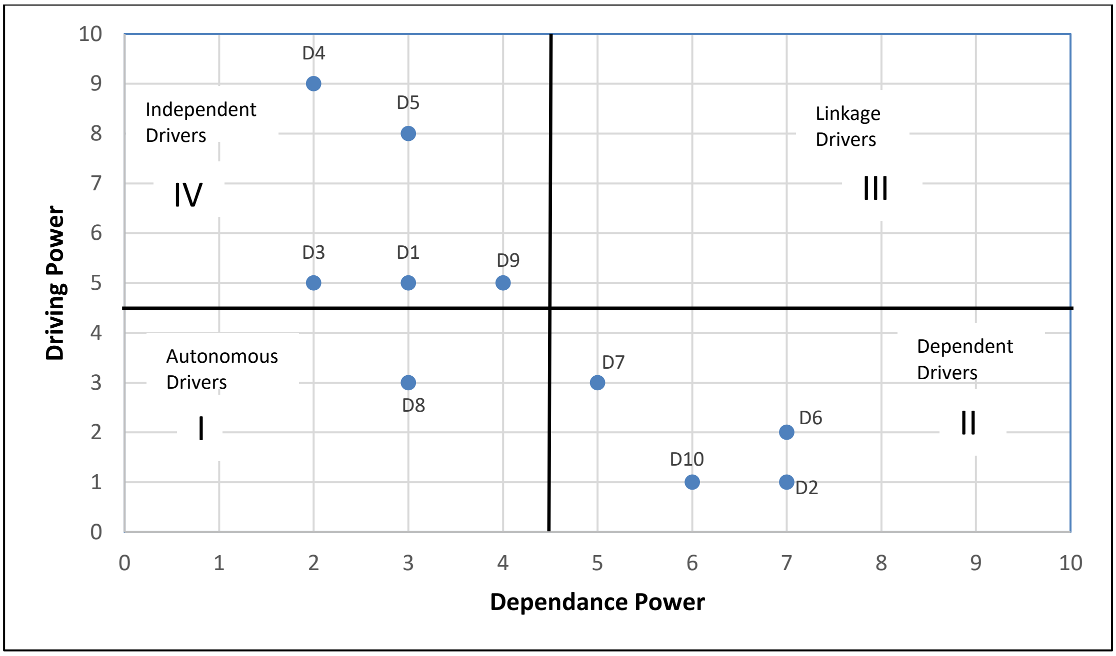


Figure 4.2: MICMAC analysis diagram for driving and dependence power for sustainability drivers

The driving power vs. dependence power diagram is shown in figure 4.2 depicting the four cluster quadrants, with driving power of the drivers represented on *y*-axis and dependence power represented on *x*-axis. As an illustration, it is observed from Table 4.13 that driver **D7** is having a driving power of "3" and a dependence of "5". Therefore, in the MICMAC analysis diagram, it is positioned in quadrant II at a place corresponding to a (5, 3) in the graph. Similarly, the remaining drivers are positioned corresponding to their driving and dependence powers.

Chapter 5
ANALYSIS OF BARRIERS FOR SUSTAINABILITY

5.1 Overview

Nature of industry is the main focus while finding the motivational and de-motivating factors towards implementing sustainability practices in the local industry. In marble industry it is very important to know that only pertinent barriers should be considered while reviewing the literature and finding the barriers. In order to implement any new concept in an industry there should be enough reasons which drives, supports, validate, motivates or demotivates its implementation and justifies the importance of the particular new concept.

5.2 Sustainability barrier

A very detailed and extensive study carried out to find out the barrier in implementing sustainability through literature survey. In this chapter a list of total nine potential barriers (available in table 5.1) which are the major that hinders sustainability implementation analyzed.

5.3 Application of ISM

The ISM technique for development of relationship model follows a systematic approach. The various steps involved in ISM approach when applied to the 9 identified sustainability barriers are explained in following sections:

5.3.1 Data Collection

The ISM methodology suggests the use of the expert opinions based on management techniques like brain storming, in developing the contextual relationship among the variables. It is done in a similar way as done for drivers.

5.3.2 Structural Self-Interaction Matrix

After identifying and enlisting 9 sustainability barriers through literature review and experts' opinion, their analysis is carried out.

Table 5.1: List of sustainability barriers

Sr. no.	Barriers
B1	Lack of awareness of sustainability concepts and if someone is conducting locally
B2	Negative attitudes towards sustainability concepts
B3	Lack of funds for green Projects
B4	Lack of standardized metrics or performance benchmarks
B5	Cost too high
B6	Lack of cooperation from senior leaders
B7	Fear of not taking risk
B8	Uncertain benefits
B9	Lack of skilled staff

First of all, a contextual relationship of "leads to" type is chosen. This means that one barriers leads to another barriers. Based on this principle, a contextual relationship is developed.

Table 5.2: Structural self-interaction matrix

Barriers	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
B1	V	V	V	V	O	V	O	X	X
B2	V	O	V	V	O	O	V	X	
B3	V	O	O	O	A	O	X		
B4	O	O	O	V	O	X			
B5	V	O	V	V	X				
B6	V	O	A	X					
B7	X	V	X						
B8	O	X							
B9	X								

Four symbols are used here to denote the direction of relationship between the barriers *i* and *j*.

V: Barrier *i* will lead to barrier factor *j*;

A: Barrier *j* will lead to barrier *i*;

X: Barrier *i* and *j* will influence each other; and

O: Barrier *i* and *j* are unrelated.

The meaning of symbols V, A, X and O are discussed in chapter 4. Using these symbols SSIM is formed as table 5.2.

5.3.3 Reachability Matrix

In this step, the reachability matrix is developed from SSIM. The SSIM table is converted into the reachability matrix by transforming the information of each cell of SSIM into binary digits (i.e. 1 or 0) in the initial reachability matrix. Rules for transformation described already in previous chapters.

Table 5.3: Reachability matrix

Barriers	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
B1	1	1	0	1	0	1	1	1	1
B2	1	1	1	0	0	1	1	0	1
B3	0	0	1	0	0	0	0	0	1
B4	0	0	0	1	0	1	0	0	0
B5	0	0	1	0	1	1	1	0	1
B6	0	0	0	0	0	1	0	0	1
B7	0	0	0	0	0	1	1	1	1
B8	0	0	0	0	0	0	0	1	0
B9	0	0	0	0	0	0	1	0	1

5.3.4 Level Partitions

In level partition the reachability set and antecedent set for each factor is found out from reachability matrix. After finding the reachability set and antecedent set for each barrier, the intersection for these sets is derived for all the barrier.

Table 5.4: Level-I iteration

Barriers (Bi)	**Reachability sets R(Bi)**	**Antecedent sets A(Bi)**	**Intersection sets R(Bi) ∩ A(Bi)**	**Level**
1	1,2,4,6,7,8,9	1,2	1,2	
2	1,2,3,6,7,9	1,2	1,2	
3	3,9	2,3,5	3	
4	4,6	1,4	4	
5	3,5,6,7,9	5	5	
6	6,9	1,2,4,5,6,7	6	
7	6,7,8,9	1,2,5,7,9	7,9	
8	8	1,7,8	8	I
9	7,9	1,2,3,5,6,7,9	7,9	I

Table 5.5: Level-II iteration

Barriers (Bi)	**Reachability sets R(Bi)**	**Antecedent sets A(Bi)**	**Intersection sets R(Bi) ∩ A(Bi)**	**Level**
1	1,2,4,6,7	1,2	1,2	
2	1,2,3,6,7	1,2	1,2	
3	3	2,3,5	3	II
4	4,6	1,4	4	
5	3,5,6,7	5	5	
6	6	1,2,4,5,6,7	6	II
7	6,7	1,2,5,7	7	

Table 5.6: Level-III iteration

Barriers (Bi)	**Reachability sets R(Bi)**	**Antecedent sets A(Bi)**	**Intersection sets R(Bi) ∩ A(Bi)**	**Level**
1	1,2,4,7	1,2	1,2	
2	1,2,7	1,2	1,2	
4	4	1,4	4	III
5	5,7	5	5	
7	7	1,2,5,7	7	III

Table 5.7: Level-IV iteration

Barriers (Bi)	**Reachability sets R(Bi)**	**Antecedent sets A(Bi)**	**Intersection sets R(Bi) ∩ A(Bi)**	**Level**
1	1,2	1,2	1,2	IV
2	1,2	1,2	1,2	IV
5	5	5	5	IV

Table 5.8: Summary of barriers at various iteration levels

LEVELS	BARRIERS
I	8,9
II	3,6
III	4,7
IV	1,2,5

5.3.5 ISM-based Model (Digraph)

Based on the conical matrix, an initial digraph including transitivity links is obtained. This is generated by nodes and lines of edges. After removing the indirect links, a final digraph is developed and is than finally converted into the ISM model by replacing nodes of the barriers with statements as shown in Figure 5.1. In this development, the level I barriers of SM are positioned at the top of the digraph and level II barriers are placed at second position and so on, until the level IV barriers are placed at the bottom-most position in the ISM-based model.

The ISM model has been developed for evaluating the interrelationship among identified barriers. It can be seen from figure 5.1 that lack of awareness about sustainability (B1), negative attitude towards sustainability (B2) and high cost of implementation (B5) are the main barriers towards sustainability implementation. Ignorance about sustainability does not allow a company to set performance benchmark and working standards (B4).

Table 5.9: Conical matrix

Barriers	8	9	3	6	4	7	1	2	5	Driving power	Rank
B8	1	0	0	0	0	0	0	0	0	1	**6**
B9	0	1	0	0	0	1	0	0	0	2	**5**
B3	0	1	1	0	0	0	0	0	0	2	**5**
B6	0	1	0	1	0	0	0	0	0	2	**5**
B4	0	0	0	1	1	0	0	0	0	2	**5**
B7	1	1	0	1	0	1	0	0	0	4	**4**
B1	1	1	0	1	1	1	1	1	0	7	**1**
B2	0	1	1	1	0	1	1	1	0	6	**2**
B5	0	1	1	1	0	1	0	0	1	5	**3**
Depending power	3	7	3	6	2	5	2	2	1		
Rank	**4**	**1**	**4**	**2**	**5**	**3**	**5**	**5**	**6**		

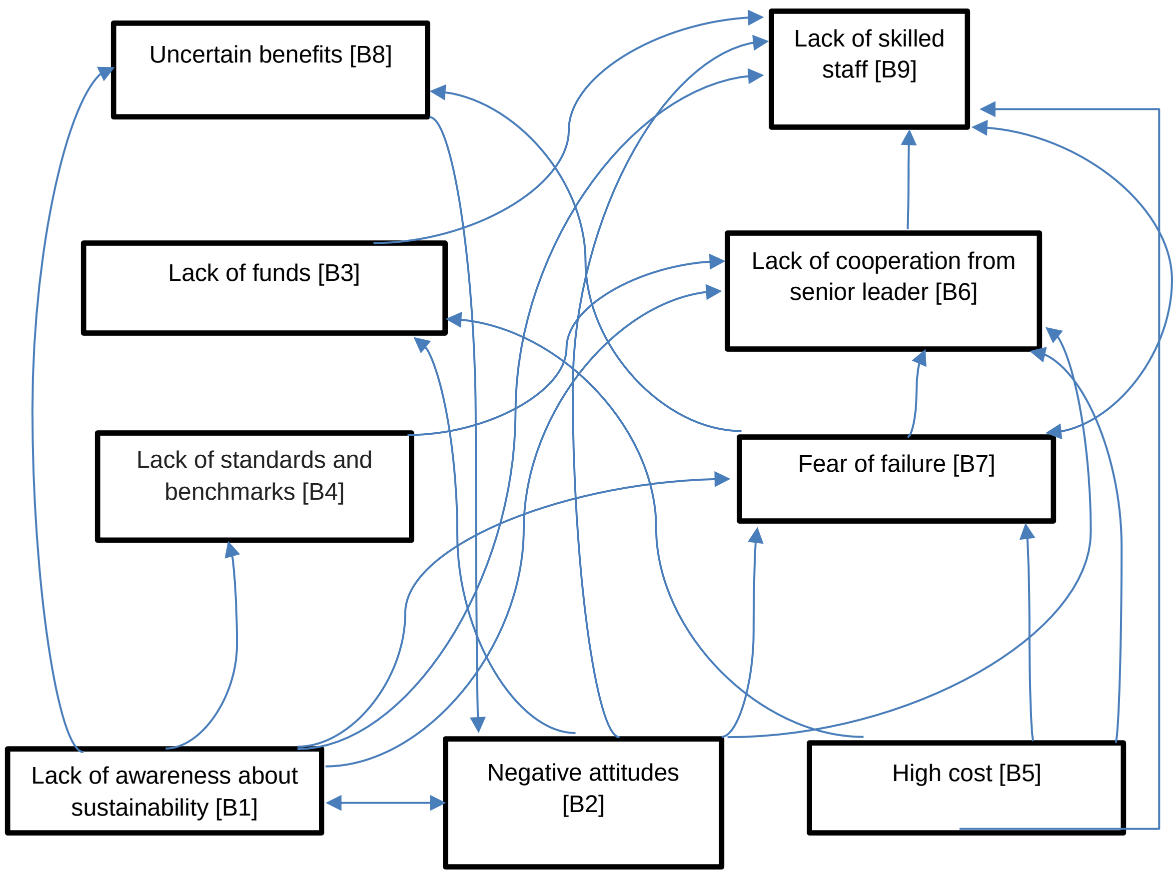


Figure 5.1: ISM based model for sustainability barriers

Fear of failure (B7) aggravates due to negative attitudes towards these concepts. Lack of funds (B3) and lack of cooperation from senior leaders (B6) form the second level and these are dependent type of barriers as fear of failure and lack of sustainability awareness increases the uncertainty about financial benefits (B8). Lack of awareness, benchmarks and funds prohibits the incorporation of skilled staff (B9) in organisation. So B1, B2 and B5 are the most important barriers on which a company should focus upon for the implementation of SM in marble sector.

5.3.6 MICMAC analysis for sustainability barriers

The purpose of MICMAC analysis is to analyze the driving power and dependence power of variables. This is done to identify the key barriers that driving the system. The driving and dependence powers of the barriers are derived from the reachability matrix (Table 5.3) by performing summation of rows to find out driving power and summation of columns to find out the dependence power of each barriers.

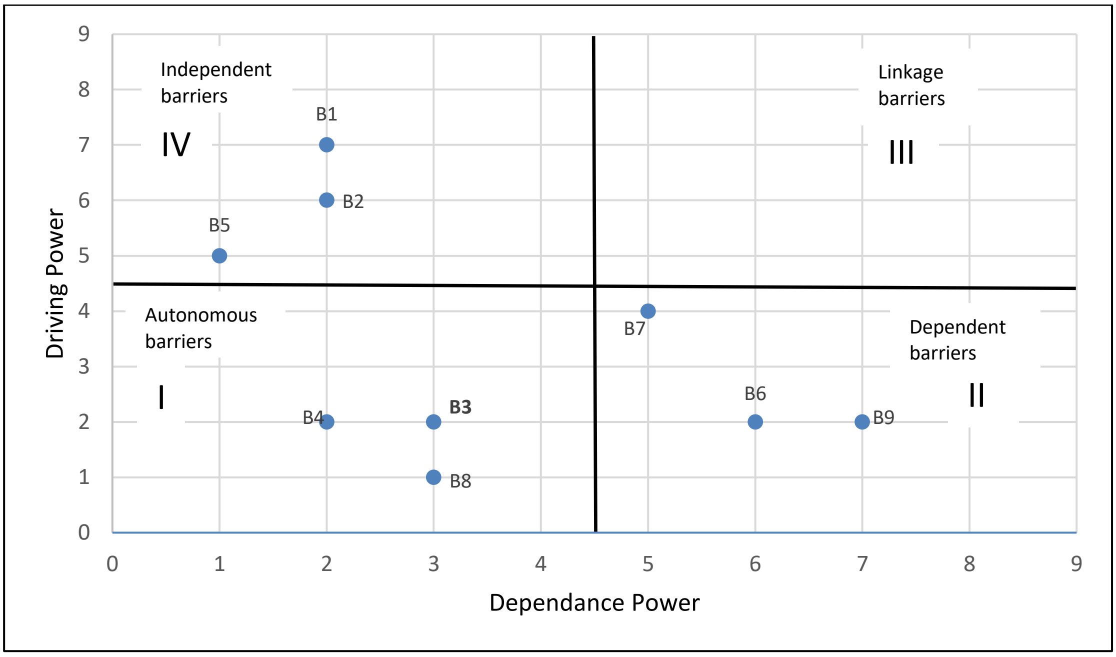


Figure 5.2: MICMAC analysis diagram for driving and dependence power for sustainability barriers

The driving and dependence power of various barriers is given in conical matrix (Table 5.9). The four cluster named as Autonomous barriers, Dependent barriers, Linkage barriers, Independent barriers. The driving power vs. dependence power diagram is shown in Figure 5.2 depicting the four cluster quadrants, with driving power of the drivers represented on *y*-axis and dependence power represented on *x*-axis.

As an illustration, it is observed from Table 5.9 that barrier B9 is having a driving power of “2” and a dependence of “7”. Therefore, in the MICMAC analysis diagram, it is positioned in quadrant II at a place corresponding to a (7, 2) in the graph. Similarly, the remaining barriers are positioned corresponding to their driving and dependence powers.

Chapter 6
CASE STUDY

6.1 Case study description

The case study is about the implementation of sustainability in three marble processing industries. The survey has been done on the plants at north western India. The present work focuses on the environmental, economic, and social impact of stone and marble industry in the north western region of India and presents a case study of three marble processing plants by evaluating the extent of sustainability of these plants. All three plants are compared on the basis of eleven evaluation criterion of sustainability. As the demand of finished marble is increasing day by day due to its high esteem and aesthetics value so it's very natural that the number of such marble processing firms are also increasing. Consequently the harm these firms doing to the environment is also increasing at an accelerated rate. Quarrying and marble processing industry is one of the major waste generating industries of which almost 70% of this valuable mineral resource is wasted in the procedures like mining, processing, and polishing. Around 40% of marble waste is generated all over the world during quarrying operations in the form of rock fragments and being dumped either in nearby empty pits, roads, riverbeds, pasturelands, agricultural fields, or landfills leading to wide spreading environmental pollution. Around 400 years ago the mining activities started in the western part of India and in this region these activities give employment to around 2.5 lakh people annually. The quarrying activities are a blessing for workers as it provides jobs to these workers but at the same time it is very dangerous on the behalf of an anthropocentric. Along with the monetary benefits there are some risks associated with it and it is the susceptibility of the environment in doing so. These marble processing plants should be monitored and regulated in such a way that they remain accountable to the environment and society.

The goal of this case study is to rate and compare three marble manufacturing firms on the basis of various criterion of sustainability by using Grey based MCDM approach to know which firm is implementing sustainability in best way. A detailed questionnaire was sent to the employees of three marble processing firms and based on the received responses the analysis is done. In this research grey decision theory is used to rate and choose the best plant among three case plants on various sustainability criterions.

6.2 Grey system theory

Grey approach was first proposed and described by deng (1989) as a technique of studying and analyzing the situations where uncertainty in available information is more. It is a technique which is used to solve the complex MADM problems which is having a lower degree of information availability and it uses grey sets (Deng et al., 2000). According to Mishra et al. (2013) grey decision theory is a simple mathematical technique with very less calculation and very helpful in benchmarking and criteria evaluation and comparison of alternatives. A research in high risk processing industries of India presented by Beriha et al. (2011) highlights the importance of proper working condition in three sectors such as construction, refractory and steel industries using grey approach. This study emphasizes on occupational health and safety (OHS) norms of processing industries. This study compares manufacturing firms on the basis of six items of safety culture. As discussed in the literature review that Grey theory is one of the methods to evaluate and study a system with uncertain and non-concurring information. The detailed qualitative analysis of all the criterions of sustainability regarding marble processing is presented in chapter 2.

Grey approach (Deng, 1989) is one of the methods used for studying uncertainty and this approach is based on degree of information known. This approach is appropriate for solving the MCDM problem in an uncertain environment (Li et al., 2007). Assuming $A = \{A1, A2, \ldots, A_m\}$ is a set of m possible alternatives while $F = \{F1, F2, \ldots, Fn\}$ is a set of n criterions, which are additively independent. $W = \{w_1, w_2, \ldots, w_n\}$ is the vector of criterion weights. This work considers the criterion weights and ratings of processing plants as linguistic variables (Li et al., 2007). Table 6.2 represents linguistic criteria weights in grey numbers and Table 6.3 represents criterion ratings in grey numbers.

A panel of three decision makers (DMs) gave responses for the criterion, criterion weights and rating of each criterion in regard to the selection of marble processing firm in terms of grey numbers. How this grey approach is applied to find out the better processing plant is described below.

Table 6.1: List of sustainability criterion for selecting a better marble processing plant

Evaluation Criteria	**Code**
Sustainability awareness	C1
Nagetive attitude	C2
Skilled staff	C3
Market pressure	C4
Government policy	C5
Top management suppport	C6
Innovative and advanced technology	C7
Safeguarding enviromnment	C8
Training and education of workers	C9
Processing cost	C10
Fear of failure	C11

Table 6.2: Scale of criterion weights (w)

Scale	**Weight**
Very low (VL)	[0.0,0.1]
Low (L)	[0.1,0.3]
Fare (F)	[0.3,0.5]
Medium High (MH)	[0.5,0.7]
High (H)	[0.7,0.9]
Very High (VH)	[0.9,1.0]

Source: Li et al. (2007), Shukla et al. (2014)

Table 6.3: Scale of criterion ratings (G)

Scale	**Ratings**
Very poor (VP)	[0,1]
Poor (P)	[1,3]
Fare (F)	[3,5]
Medium Good (MG)	[5,7]
Good (MH)	[7,9]
Very Good (H)	[9,10]

Source: Li et al. (2007), Shukla et al. (2014)

Step 1: In this step, criterion weights are identified by a group of DMs. If the group has k persons then the criterion weight is calculated as following

$$\otimes W = \frac{1}{k}[\otimes W_j^1 + \otimes W_j^2 + \dots\dots\dots + \otimes W_j^k] \qquad \text{-----------------------------} \qquad (1)$$

Where $\otimes W_j^k$ $(j = 1,2,3 \dots . n)$ is the criterion weight of k^th decision maker and can be described by grey number $\otimes W_j^k = [\underline{W}_j^k, \overline{W}_j^k]$. The operator '⊗'denotes grey number and $\underline{W}_j^k$ and $\overline{W}_j^k$ and describe lower and upper value of the j^th criterion weight, respectively.

The grey values for criterion weights can be obtained from the group of three DMs DM_1, DM_2 and DM_3 according to Equation (1). So according to equation (1) the weight for the criterion C_1 is calculated as

⊗Wj = [(0.7+0.9+0.7)/3, (0.9+1.0+0.9)/3] = [0.766, 0.933] in a very similar way all the other values of criterion weight are calculated for other criterions and denoted by C_1-C_{11} in table 6.4

Step 2: Use some linguistic variables for the ratings to make a criterion rating value. Then, the calculation of rating value will be done as following

$$\otimes G_{ij} = \frac{1}{k} [\otimes G_{ij}^1 + \otimes G_{ij}^2 + \dots \dots + \otimes G_{ij}^k] \quad \text{--------------------------------} \quad (2)$$

Where $\otimes G_{ij}^k$ (i=1, 2, ..., m; j=1, 2, ..., n) is the criteria rating of i^th alternative under j^th criterion by k^th decision maker and can be described by grey number $\otimes G_{ij}^k = [\underline{G}_{ij}^k, \overline{G}_{ij}^k]$.

Now obtain the values of criteria rating for each of the three processing plants from the DMs. Let's take an example to calculate the value of first criteria C_1 for first processing plant $P_1$and is calculated as ⊗Gij = [(9+9+7)/3, (10+10+9)/3] = [8.33, 9.66]. Similarly the criteria rating values for all three marble processing plant with respect to criteria C_1-C_{11} can be calculated and are shown in Table 6.5

Step 3: Establishing the grey decision matrix

Equation (3) shows the grey decision matrix in order to decide the best alternative plant and evaluate the level of sustainability.

$$D = \begin{bmatrix} \otimes G_{11} & \otimes G_{12} & \cdots & \otimes G_{1n} \\ \otimes G_{21} & \otimes G_{22} & \dots & \otimes G_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \otimes G_{m1} & \otimes G_{m2} & \dots & \otimes G_{mn} \end{bmatrix} \quad \text{----------------------------} \quad (3)$$

Table 6.4: Criterion weights

Criterion	**DM1**	**DM2**	**DM3**	**⊗Wj**
C1	[0.7,0.9]	[0.9,1.0]	[0.7,0.9]	[0.766,0.933]
C2	[0.9,1.0]	[0.9,1.0]	[0.7,0.9]	[0.833,0.966]
C3	[0.5,0.7]	[0.7,0.9]	[0.7,0.9]	[0.633,0.833]
C4	[0.9,1.0]	[0.9,1.0]	[0.9,1.0]	[0.90,1.00]
C5	[0.5,0.7]	[0.7,0.9]	[0.9,1.0]	[0.70,0.866]
C6	[0.1,0.3]	[0.3,0.5]	[0.5,0.7]	[0.60,0.50]
C7	[0.3,0.5]	[0.5,0.7]	[0.1,0.3]	[0.60,0.50]
C8	[0.9,1.0]	[0.9,1.0]	[0.9,1.0]	[0.90,1.00]
C9	[0.9,1.0]	[0.7,0.9]	[0.7,0.9]	[0.766,0.933]
C10	[0.5,0.7]	[0.5,0.7]	[0.7,0.9]	[0.566,0.766]
C11	[0.9,1.0]	[0.7,0.9]	[0.7,0.9]	[0.766,0.933]

Table 6.5: Criterion ratings for three marble processing plants

Criterion	**Processing plant**	**DM1**	**DM2**	**DM3**	**⊗Gij**
C1	P1	[9,10]	[9,10]	[7,9]	[8.33,9.66]
	P2	[7,9]	[5,7]	[3,5]	[5,7]
	P3	[7,9]	[7,9]	[5,7]	[6.33,8.33]
C2	P1	[3,5]	[1,3]	[1,3]	[1.66,3.66]
	P2	[1,3]	[0,1]	[1,3]	[0.66,2.33]
	P3	[3,5]	[5,7]	[3,5]	[3.66,5.66]
C3	P1	[5,7]	[7,9]	[9,10]	[7,8.66]
	P2	[3,5]	[5,7]	[5,7]	[4.33,6.33]
	P3	[5,7]	[7,9]	[7,9]	[6.33,8.33]
C4	P1	[5,7]	[5,7]	[7,9]	[5.66,7.66]
	P2	[3,5]	[3,5]	[5,7]	[3.66,5.66]
	P3	[7,9]	[7,9]	[9,10]	[7.66,9.33]

Criterion	Processing plant	DM1	DM2	DM3	⊗Gij
C5	P1	[0,1]	[1,3]	[1,3]	[0.66,2.33]
	P2	[1,3]	[0,1]	[1,3]	[0.66,2.33]
	P3	[9,10]	[9,10]	[9,10]	[9,10]
C6	P1	[0,1]	[1,3]	[1,3]	[0.66,2.33]
	P2	[0,1]	[0,1]	[0,1]	[0,1]
	P3	[3,5]	[5,7]	[5,7]	[4.33,6.33]
C7	P1	[5,7]	[5,7]	[3,5]	[4.33,6.33]
	P2	[3,5]	[3,5]	[5,7]	[3.66,5.66]
	P3	[5,7]	[5,7]	[7,9]	[5.66,7.66]
C8	P1	[3,5]	[5,7]	[5,7]	[4.33,6.33]
	P2	[1,3]	[5,7]	[5,7]	[3.66,5.66]
	P3	[3,5]	[5,7]	[7,9]	[5,7]
C9	P1	[5,7]	[7,9]	[9,10]	[7.0,8.66]
	P2	[3,5]	[5,7]	[7,9]	[5,7]
	P3	[9,10]	[9,10]	[7,9]	[8.33,9.66]
C10	P1	[7,9]	[5,7]	[7,9]	[6.33,8.33]
	P2	[3,5]	[5,7]	[7,9]	[5,7]
	P3	[9,10]	[9,10]	[9,10]	[9,10]
C11	P1	[1,3]	[1,3]	[5,7]	[2.33,4.33]
	P2	[0,1]	[0,1]	[1,3]	[0.33,1.66]
	P3	[7,9]	[7,9]	[9,10]	[7.66,9.33]

Grey decision matrix is established as stated in equation (3) using criterion rating grey values ⊗Gij for all three manufacturing system alternatives with respect to C_1-C_{11} form Table 6.6

Step 4: Normalize the grey decision matrix:

$$D^* = \begin{bmatrix} \otimes G_{11}^\star & \otimes G_{12}^\star & \cdots & \otimes G_{1n}^\star \\ \otimes G_{21}^\star & \otimes G_{22}^\star & \dots & \otimes G_{2n}^\star \\ \vdots & \vdots & \ddots & \vdots \\ \otimes G_{m1}^\star & \otimes G_{m2}^\star & \dots & \otimes G_{mn}^\star \end{bmatrix} \qquad \text{-----------------------------------} \quad (4)$$

For a benefit criteria, $\otimes G_{ij}^\star$ can be represented as

$$\otimes G_{ij}^\star = \left[\frac{\underline{G}_{ij}}{G_j^{max}}, \frac{\overline{G}_{ij}}{G_j^{max}}\right] \qquad \text{---} \quad (5)$$

Where $G_j^{max} = max_1 \leq i \leq m \, \overline{G}_{ij}$

For a cost criterion is expressed as, $\otimes G_{ij}^\star$ is expressed as,

$$\otimes G_{ij}^\star = \left[\frac{G_j^{min}}{\overline{G}_{ij}}, \frac{G_j^{min}}{\underline{G}_{ij}}\right] \qquad \text{---} \quad (6)$$

Where $G_j^{min} = min_1 \leq i \leq m \, \underline{G}_{ij}$

Table 6.6: Grey decision matrix (D)

Alternatives	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
P1	[8.33, 9.66]	[1.66, 3.66]	[7,8.6 6]	[5.66, 7.66]	[0.66, 2.33]	[0.66, 2.33]	[4.33, 6.33]	[4.33, 6.33]	[7.0, 8.66]	[6.33, 8.33]	[2.33, 4.33]
P2	[5,7]	[0.66, 2.33]	[4.33, 6.33]	[3.66, 5.66]	[0.66, 2.33]	[0,1]	[3.66, 5.66]	[3.66, 5.66]	[5,7]	[5,7]	[0.33, 1.66]
P3	[6.33, 8.33]	[3.66, 5.66]	[6.33, 8.33]	[7.66, 9.33]	[9,10]	[4.33, 6.33]	[5.66, 7.66]	[5,7]	[8.33, 9.66]	[9,10]	[7.66, 9.33]

The method of normalization used above is done in order to safeguard the property that the ranges of normalized grey numbers must lie between 0 and 1.

Here the benefit criterion are used for normalizing the grey decision matrix for first marble processing plant P_1 as D* = [8.33/9.66, 9.66/9.66] = [0.86, 1.0] similarly the normalized grey values of for all three marble processing plant with respect to criterion C_1-C_{11} can be calculated and are shown in Table 6.7

Step 5: Weighted normalized matrix is formed to give consideration and importance to each criterion.

$$D^{**} = \begin{bmatrix} \otimes V_{11} & \otimes V_{12} & \cdots & \otimes V_{1n} \\ \otimes V_{21} & \otimes V_{22} & \dots & \otimes V_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \otimes V_{m1} & \otimes V_{m2} & \dots & \otimes V_{mn} \end{bmatrix} \quad \text{---} \quad (7)$$

Where $\otimes V_{ij} = \otimes G_{ij}^{\star} \times \otimes W_j$

After normalizing the grey decision matrix now it is weighted to obtain the weighted normalized grey decision matrix and it's the product of normalized grey decision values (⊗Gij) and criterion weight values (⊗Wj) using Equation (7).

D**= [0.86x0.766, 1.0x0.933] = [0.66, 0.93]. Other grey weighted normalized values are obtained in same way and are shown in Table 6.8

Step 6: Here for referential alternatives use the ideal alternative. For r possible alternatives set A= {$A_1, A_2, A_3 \ldots\ldots, A_m$ }, now the ideal referential alternatives $A^{max} = \{\otimes G_1^{max}, \otimes G_2^{max}, \ldots\ldots, \otimes G_n^{max}\}$ can be obtained by.

$A^{max} = \{[\max_{1\le i\le m} \underline{V}_{i1}, \max_{1\le i\le m} \overline{V}_{i1}], [\max_{1\le i\le m} \underline{V}_{i2}, \max_{1\le i\le m} \overline{V}_{i2}], \ldots\ldots, [\max_{1\le i\le m} \underline{V}_{in}, \max_{1\le i\le m} \overline{V}_{in}]\}$

----- (8)

Table 6.7: Grey normalized decision matrix (D)*

Alternatives	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
P1	[0.86, 1.0]	[0.29, 0.65]	[0.81, 1.0]	[0.61, 0.82]	[0.066 , .233]	[0.10, 0.37]	[0.57, 0.83]	[0.62, 0.90]	[0.72, 0.89]	[0.63, 0.83]	[0.25, 0.46]
P2	[0.52, 0.72]	[0.17, 0.41]	[0.50, 0.73]	[0.39, 0.61]	[0.066 ,0.233	[0.0, 0.16]	[0.48, 0.74]	[0.52, 0.81]	[0.51, 0.72]	[0.5, 0.7]	[0.035 ,0.18]
P3	[0.65, 0.86]	[0.65, 1.0]	[0.73, 0.96]	[0.82, 1.0]	[0.9, 1.0]	[0.68, 1.0]	[0.74, 1.0]	[0.71, 1.0]	[0.86, 1.0]	[0.9, 1.0]	[0.82, 1.0]

Now according to equation (8) set ideal alternative marble processing plant as referential processing plant that is given as below:

A^{max} = {[0.66, 0.93], [0.54, 0.96], [0.48, 0.83], [0.74, 1.0], [0.63, 0.86], [0.44, 0.5], [0.64, 1.0], [0.66, 0.93], [0.51, 0.76], [0.63, 0.93]}.

These values of grey which are denoted by A^{max} are the maximum values of each criterion In Grey weighted normalized decision matrix (D) **.

Table 6.8: Grey weighted normalized decision matrix (D) **

Alternatives	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
P1	[0.66, 0.93]	[0.24, 0.63]	[0.51, 0.83]	[0.55, 0.82]	[0.05, 0.20]	[0.06, 0.18]	[0.34, 0.41]	[0.56, 0.90]	[0.55, 0.83]	[0.36, 0.64]	[0.19, 0.43]
P2	[0.40, 0.67]	[0.14, 0.40]	[0.32, 0.61]	[0.35, 0.61]	[0.05, 0.20]	[0.0, 0.08]	[0.29, 0.37]	[0.47, 0.81]	[0.39, 0.67]	[0.28, 0.54]	[0.03, 0.17]
P3	[0.49, 0.80]	[0.54, 0.96]	[0.46, 0.79]	[0.74, 1.0]	[0.63, 0.86]	[0.41, 0.5]	[0.44, 0.5]	[0.64, 1.0]	[0.66, 0.93]	[0.51, 0.76]	[0.63, 0.93]

Step 7: Now the next step is to calculate the grey possibility degree from ideal referential alternative A^{max} and the compared alternatives A= {A_1, A_2, ...,A_m. The grey possibility degree can be calculated by the following formula for the test alternative plants as described in equation

$P\{A_i \leq A^{max}\} = \frac{1}{n} \sum_{j=1}^{n} P\,\{\otimes V_{ij} \ \leq \otimes G_j^{max}\}$. --(9)

Grey possibility degrees for three manufacturing systems, according to equation no. (9), are given below: (Shi et.al.2005)

P ($A_1 \leq A^{max}$) = $\frac{1}{8}[P(\otimes V_{11} \leq \otimes G_1^{max}) + P(\otimes V_{12} \leq \otimes G_2^{max}) + P(\otimes V_{13} \leq \otimes G_3^{max}) + P(\otimes V_{14} \leq \otimes G_4^{max}) + P(\otimes V_{15} \leq \otimes G_5^{max}) + P(\otimes V_{16} \leq \otimes G_6^{max}) + P(\otimes V_{17} \leq \otimes G_7^{max}) + P(\otimes V_{18} \leq \otimes G_8^{max})]$

For first processing plant (calculation for criterion 2)

$P(\otimes V_{12} \leq \otimes G_2^{max})$ = [max (0, L* - max (0, $\otimes \bar{V}_{12}$-$\underline{G}_2^{max}$))/ L*]

Where $\otimes V_{12}$ = [0.24, 0.63], $\otimes G_2^{max}$ = [0.54, 0.96]

L* = L ($\otimes V_{12}$) + L ($\otimes G_2^{max}$) = ($\bar{V}_{12} - \underline{V}_{12}$) + ($\bar{G}_2^{max} - \underline{G}_2^{max}$) = (0.63 – 0.24) + (0.96 – 0.54) = 0.81

$P(\otimes V_{12} \leq \otimes G_2^{max})$ = [max (0, 0.81-0.09)/0.81] = 0.8888

Similarly $P(\otimes V_{11} \leq \otimes G_1^{max})$=0.50, $P(\otimes V_{13} \leq \otimes G_3^{max})$= 0.50, $P(\otimes V_{14} \leq \otimes G_4^{max})$= 0.9012, $P(\otimes V_{15} \leq \otimes G_5^{max})$= 1.0, $P(\otimes V_{16} \leq \otimes G_6^{max})$= 1.0, $P(\otimes V_{17} \leq \otimes G_7^{max})$= 1.0, $P(\otimes V_{18} \leq \otimes G_8^{max})$=0.6285, $P(\otimes V_{19} \leq \otimes G_9^{max})$=0.6909, $P(\otimes V_{110} \leq \otimes G_{10}^{max})$=0.7547, $P(\otimes V_{111} \leq \otimes G_{11}^{max})$=1.0

P ($A_1 \leq A^{max}$) = $\frac{1}{11}(0.50 + 0.8888 + 0.50 + 0.9012 + 1.0 + 1.0 + 1.0 + 0.6285 + 0.6909 + 0.7547 + 1.0)$= 0.8058

For plant three it is given as following

$P(\otimes V_{31} \leq \otimes G_1^{max})$ = 0.7586, similarly for criterion 2 and 3 values are $(\otimes V_{32} \leq \otimes G_2^{max})$=0.5 and $P(\otimes V_{33} \leq \otimes G_3^{max})$= 0.5692 and so on.

P ($A_3 \leq A^{max}$) = $\frac{1}{11}(0.7586 + 0.5 + 0.5692 + 0.5 + 0.5 + 0.5 + 0.5 + 0.5 + 0.5 + 0.5 + 0.5)$= 0.5298

In the identical manner the values of grey possibility degree for alternative second processing plant can be calculated which are being shown in the table 6.9

Table 6.9: Grey possibility degree of three alternative marble processing plants

Alternatives	**Grey possibility degree**
P1, P($A_1 \leq A^{max}$)	**0.8058**
P2, P($A_2 \leq A^{max}$)	**0.9482**
P3, P($A_3 \leq A^{max}$)	**0.5298**

Step 8: On the basis of the values of grey possibility degree as calculated earlier, compare all the three marble processing plants and rank them based on P {$A_i \leq A^{max}$} comparison. Higher the value of A_i, ranking order is poor and vice versa. So grey possibility degree is used to rank and to priorities the three marble processing plants. The plant for which the value is minimum is the best alternative and the one with higher value is a plant with worst level of sustainability implementation.

The practical significance of grey possibility degrees is that a lower and higher value shows very small and large deviation from ideal grey possibility values respectively. So a plant with lower value of grey possibility degree is preferable. The order of ranking of the marble processing plants is as follow: **P3> P1> P2**.

The criterion C_4 and C_8 "market pressure" and "safeguarding environment" have highest criterion weight (from Table 6.4) which signify the importance of market pressure. C_4 drives the sustainability implementation and also creates a positive environment for the implantation of such concepts. Environment safeguarding and focus upon the working standard is also very highly rated. Weights are also very high for these criterion. It suggest that experts from industries also believe that market drives the implementation of important sustainability and environment safeguarding is the sole aim of sustainability.

From table 6.8 it is clear that for plant P_1 and P_2, criterion C_8 "safeguarding environment" is most important criterion. It suggests that both the plants stress more on the environment safety and emission control. These are the basic need of a marble processing industry and minimum legal requirement should be maintained in order to safeguard the environment. The waste generation is a major problem for marble industry and by adopting the policy environment safeguarding, the environment can be saved. For plant P_3 criterion C_4 is most important as this plant focuses more on market trends. The calculated grey possibility degrees for three marble processing plants P_1, P_2 and P_3 are calculated as 0.8058, 0.9482 and 0.5298 respectively. These values represent the deviation from ideal alternative values and help in selecting the best alternative. The smaller grey possibility value of an alternative represents lower deviation from ideal alternative value and hence considered to be the most suitable alternative among others. On the other hand, higher grey possibility value represents higher deviation and hence it is considered to be the least suitable alternative. The plant for which the value of grey possibility degree is minimum is the best plant and the one with higher value is a plant with worst level of sustainability implementation. In this problem the grey possibility degree for plant P_3 is minimum and for plant P_2 is highest. So it can be concluded that plant P_3 is the best alternative plant with highest level of sustainability implementation. Thus the comparative order of all three plants is given as: $\mathbf{P_3>P_1>P_2}$.

Chapter 7
CONCLUSION

7.1 Results of ISM based model and case study

Sustainable development is becoming increasingly important for the marble industry. To respond to many sustainability challenges that it is facing, the industry must be able to measure its progress towards (or away from) sustainable development. The generic framework for indicators of sustainable development proposed in this work could be used as a tool for assessing the level of sustainability of the sector as well as of the individual marble processing companies. In this present work evaluation of sustainability is done by identifying the critical drivers and barriers for SM implementation and a case study is discussed to measure the level of sustainability and to see the effect of various drivers and barriers of sustainability in sustainability implementation. In chapter four of the thesis drivers for sustainability implementation in marble sector are identified through literature survey and expert opinion.

Quadrant I: Autonomous drivers are considered as unconnected drivers as only D8 falls in this region. Training and education of workers is drive by others drivers.

Quadrant II: Four drivers (D2, D6, D7 and D10) are labeled as *dependent drivers*. These drivers are weak driver but strongly dependent on others. So, these drivers do not need much attention from the decision makers as these drivers can be achieved by working upon the drivers on which these drivers are dependent.

Quadrant III: No drivers are seen as a *linkage* drivers that has a strong driving power as well as strong dependence. Thus, it can be deduced that all the identified drivers of SM are stable. These enablers are unstable in the fact that any action on these enablers will have an effect on others and also a feedback on themselves.

Quadrant IV: The *independent drivers* are those drivers which have a strong driving power and weak dependence power, and these may be treated as 'key drivers' as these will guide the whole system. Market pressure (D1), Government policy (D3), Top management support (D4), Adoption of innovative and advanced technology (D5) and

Worker motivation (9). All these drivers are having strong driving power and control the whole system.

Sustainability barriers are identified in chapter five of the thesis and it can be felt by marble industries that there are some barrier in sustainability implementation in marble sector. From figure 5.2 the MICMAC analysis following points can be understood.

Quadrant I: Autonomous barriers are considered as unconnected barriers. Lack of funds for green projects (B3), performance benchmark and standards (B4) and uncertain benefits (B8) fall in this region and cannot be considered as very strong barriers. Processing plants can still implement the sustainability because it does not required so much funding and standards.

Quadrant II: Three barriers (B6, B7and B9) are labeled as *dependent barriers*. These barriers are weak barrier but strongly dependent on others. So, these barrier do not need much attention from the decision makers as these barriers can be achieved by working upon the barriers on which these barrier are dependent.

Quadrant III: No barriers are seen as a *linkage* barriers that has a strong driving power as well as strong dependence. Thus, it can be deduced that all the identified barriers of SM are stable.

Quadrant IV: The *independent barriers* are those barriers which have a strong driving power and weak dependence power, and these may be treated as 'key barriers' as these will guide the whole system. Lack of awareness of sustainability concepts (B1), Negative attitudes towards sustainability concepts (B2) and Cost too high (B5). All these barriers are having strong driving power and control the whole system.

After identifying drivers and barriers a case study was conducted in three marble processing industries in north western region of India for realization of sustainability implementation in these industries. The key criterions were identified of SM and their evaluation in these three plants is done using Grey approach. After taking experts opinion from decision makers it has been found out that C4 (market pressure) and C8 (safeguarding environment) are the most important criterion. Out of the three marble plants P3 is found out to be the best industry in implementing sustainability. So plant

P1 and P3 should strictly follow to government policies and support should be provided in sustainability implantation by top management. The marble sector should work in a direction to increase the popularity of Social and environmental awareness by conducting workshops and seminars on regular basis. Importance of waste water treatment and ergonomics should become a priority in this sector.

7.2 Limitations of research

- This work is domain specific and cannot be directly used for other sectors as drivers, barriers and criterions may be different.
- ISM and Grey both approaches are subjective in nature and results depend on the knowledge of experts.

7.3 Future scope

Marble industry has few human impacts with some major environmental risks, however, each factory needs an intensive evaluation to determine the certain norms to regulate their action and to control the possible impact produced. However, new factories must be established within industrial zones to prevent environmental-community inflects and to allow better safe competition. On the other hand, existing factories have to introduce mitigation actions to minimize gradually the environmental impacts through providing proper managements relevant to environmental performance test. Further studies may consider facilities in other industries to generate solutions for sustainable manufacturing related problems. Based on the industry, detailed analysis may be required to assess waste and energy consumption of the machines in use. Further ffuzzy - ISM model could be used with MICMAC analysis in future research work to increase the sensitivity of the results.

REFERENCES

[1] Ahuja, I. P. S., & Khamba, J. S. (2008). An assessment of maintenance management initiatives in the Indian manufacturing industry. International Journal of Technology, Policy and Management, 8(3), 250-278.

[2] Aliabdo, A. A., Elmoaty, A. E. M. A., & Auda, E. M. (2014). Re-use of waste marble dust in the production of cement and concrete. Construction and building materials, 50, 28-41.

[3] Aluclu, I., Dalgic, A., & Toprak, Z. F. (2008). A fuzzy logic-based model for noise control at industrial workplaces. Applied Ergonomics, 39(3), 368-378.

[4] Amrina, E., & Yusof, S. M. (2011, December). Key performance indicators for sustainable manufacturing evaluation in automotive companies. In Industrial Engineering and Engineering Management (IEEM), 2011 IEEE International Conference on (pp. 1093-1097). IEEE.

[5] Amrina, E., & Yusof, S. M. (2012). Drivers and barriers to sustainable manufacturing initiatives in Malaysian automotive companies. In Proceedings of the Asia Pacific Industrial Engineering & Management Systems Conference (pp. 629-634).

[6] Aukour, F. J. (2009). Incorporation of marble sludge in industrial building eco-blocks or cement bricks formulation. Jordan Journal of Civil Engineering, 3(1), 58-65.

[7] Aukour, F. J., & Al-Qinna, M. I. (2008). Marble production and environmental constrains: case study from Zarqa Governorate, Jordan. Jordan J Earth Environ Sci, 1(3), 11-21.

[8] Ayber, S., & Ulutas, B. H. (2017). Assessing Sustainable Manufacturing Related Problems for Marble Facilities: An Application. Procedia Manufacturing, 8, 129-135.

[9] Azapagic, A. (2004). Developing a framework for sustainable development indicators for the mining and minerals industry. Journal of cleaner production, 12(6), 639-662.

[10] Bhadra, B. K., Gupta, A. K., Sharma, J. R., & Choudhary, B. R. (2007). Mining activity and its impact on the environment: Study from Makrana marble and

Jodhpur sandstone mining areas of Rajasthan. JOURNAL-GEOLOGICAL SOCIETY OF INDIA, 70(4), 557.

[11] Bhanot, N., Rao, P. V., & Deshmukh, S. G. (2015). Enablers and barriers of sustainable manufacturing: results from a survey of researchers and industry professionals. Procedia CIRP, 29, 562-567.

[12] Bhanot, N., Rao, P. V., & Deshmukh, S. G. (2017). An integrated approach for analyzing the enablers and barriers of sustainable manufacturing. *Journal of Cleaner Production*, *142*, 4412-4439.

[13] Brundtland, G. H. (1985). World commission on environment and development. Environmental policy and law, 14(1), 26-30.

[14] Brundtland, G. H., & Mansour, K. The World Commission on Environment and Development (WCED). 1987. Our common future, 2010.

[15] Careddu, N., & Siotto, G. (2011). Promoting ecological sustainable planning for natural stone quarrying. The case of the Orosei Marble Producing Area in Eastern Sardinia. Resources Policy, 36(4), 304-314.

[16] Cooper, D.R. and Schindler, P.S., (2008), "Business Research Methods", McGraw- Hill, New York.

[17] De Melo Neto, R. P., Kohlman Rabbani, E. R., Barkokébas Junior, B., Lago, E. M., de A, F., & Jonathas, B. (2012). Quantitative noise analysis at two marble finishing plants in Olinda, Pernambuco, Brazil. Work, 41(Supplement 1), 5850-5852.

[18] Devpura, M., Garza-Reyes, J. A., Kumar, V., Rocha-Lona, L., & Soriano-Meier, H. (2014). Exploring the application of quality improvement programmes and ISO standards in the Indian marble mining sector. International Journal of Productivity and Quality Management, 13(3), 310-328.

[19] Elkington, J. (1998). Partnerships from cannibals with forks: The triple bottom line of 21st-century business. *Environmental Quality Management*, *8*(1), 37-51.

[20] Ersoy, M. (2015). A Proposal on Occupational Accident Risk Analysis: A Case Study of a Marble Factory. Human and Ecological Risk Assessment: An International Journal, 21(8), 2099-2125.

[21] Finkbeiner, M., Schau, E. M., Lehmann, A., & Traverso, M. (2010). Towards life cycle sustainability assessment. Sustainability, 2(10), 3309-3322.

[22] Garas, G. L., Allam, M. E., & Bakhoum, E. S. (2014). Studies undertaken to incorporate marble and granite wastes in green concrete production. ARPN Journal of Engineering and Applied Sciences, 9(9), 1559-1564.

[23] Garg, D., Luthra, S., & Haleem, A. (2014). An Evaluation of Drivers in Implementing Sustainable Manufacturing in India: Using DEMATEL Approach. World Academy of Science, Engineering and Technology, International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering, 8(12), 3843-3848.

[24] Georgiadis, P., & Besiou, M. (2010). Environmental and economical sustainability of WEEE closed-loop supply chains with recycling: a system dynamics analysis. The International Journal of Advanced Manufacturing Technology, 47(5-8), 475-493.

[25] Glavič, P., & Lukman, R. (2007). Review of sustainability terms and their definitions. *Journal of cleaner production*, *15*(18), 1875-1885.

[26] Govindan, K., Khodaverdi, R., & Jafarian, A. (2013). A fuzzy multi criteria approach for measuring sustainability performance of a supplier based on triple bottom line approach. Journal of Cleaner Production, 47, 345-354.

[27] Gupta, S., Dangayach, G. S., & Singh, A. K. (2015). Key determinants of sustainable product design and manufacturing. Procedia CIRP, 26, 99-102.

[28] Gupta, S., Dangayach, G. S., Singh, A. K., & Rao, P. N. (2015). Analytic hierarchy process (AHP) model for evaluating sustainable manufacturing practices in Indian electrical panel industries. Procedia-Social and Behavioral Sciences, 189, 208-216.

[29] Haapala, K. R., Zhao, F., Camelio, J., Sutherland, J. W., Skerlos, S. J., Dornfeld, D. A., ... & Rickli, J. L. (2013). A review of engineering research in sustainable manufacturing. *Journal of Manufacturing Science and Engineering*, *135*(4), 041013.

[30] Habidin, N. F., Zubir, A. F. M., Conding, J., Jaya, N. A. S. L., & Hashim, S. (2013). Sustainable manufacturing practices, sustaining lean improvements and sustainable performance in Malaysian automotive industry. World Review of Entrepreneurship, Management and Sustainable Development, 9(4), 444-459.

[31] Hameed, M. S., & Sekar, A. S. S. (2009). Properties of green concrete containing quarry rock dust and marble sludge powder as fine aggregate. ARPN J. Eng. Appl. Sci, 4(4), 83-89.

[32] Hasan, M. A., Shankar, R., Sarkis, J., Suhail, A., & Asif, S. (2009). A study of enablers of agile manufacturing. International Journal of Industrial and Systems Engineering, 4(4), 407-430.

[33] Haslam, R., & Waterson, P. (2013). Ergonomics and sustainability.

[34] Jayal, A. D., Badurdeen, F., Dillon, O. W., & Jawahir, I. S. (2010). Sustainable manufacturing: Modeling and optimization challenges at the product, process and system levels. CIRP Journal of Manufacturing Science and Technology, 2(3), 144-152.

[35] Ji Shukla, O., Soni, G., & Anand, G. (2014). An application of grey based decision making approach for the selection of manufacturing system. Grey Systems: Theory and Application, 4(3), 447-462.

[36] Kishore, I. S., & Chowdary, C. M. (2015). A Study on Waste Utilization of Marble Dust in High Strength Concrete Mix. International Journal of Civil Engineering and Technology, 6, 12.

[37] Koplin, J., Seuring, S., & Mesterharm, M. (2007). Incorporating sustainability into supply management in the automotive industry–the case of the Volkswagen AG. Journal of Cleaner Production, 15(11), 1053-1062.

[38] Kulatunga, A. K., Jayatilaka, P. R., & Jayawickrama, M. (2013). Drivers and barriers to implement sustainable manufacturing concepts in Sri Lankan manufacturing sector. 10.14279/depositonce-3753.

[39] Mandal, A., & Deshmukh, S. G. (1994). Vendor selection using interpretive structural modelling (ISM). International Journal of Operations & Production Management, 14(6), 52-59.

[40] Mathiyazhagan K., Govindan K., NoorulHaq A. and Y. Geng (2013), "An ISM approach for the barrier analysis in implementing green supply chain management", Journal of Cleaner Production, Vol. 47, pp. 283-297.

[41] Maxwell, D., & Van der Vorst, R. (2003). Developing sustainable products and services. Journal of Cleaner Production, 11(8), 883-895.

[42] Meena, M. L., Dangayach, G. S., & Bhardwaj, A. (2014). Investigating ergonomic issues among workers in hand block textile printing industries. International Journal of Business and Systems Research, 8(4), 392-401.

[43] Mishra, S., Datta, S., & Mahapatra, S. S. (2013). Grey-based and fuzzy TOPSIS decision-making approach for agility evaluation of mass customization systems. Benchmarking: an international journal, 20(4), 440-462.

[44] Mittal, V. K., & Sangwan, K. S. (2014). Prioritizing drivers for green manufacturing: environmental, social and economic perspectives. Procedia CIRP, 15, 135-140.

[45] Mittal, V. K., Egede, P., Herrmann, C., & Sangwan, K. S. (2013). Comparison of drivers and barriers to green manufacturing: a case of India and Germany. In Re-engineering Manufacturing for Sustainability (pp. 723-728). Springer Singapore.

[46] Nambiar, A. N. (2010, January). Challenges in sustainable manufacturing. In Proceedings of the International Conference on Industrial Engineering and Operations Management.

[47] Nasr, N., & Thurston, M. (2006). Remanufacturing: A key enabler to sustainable product systems. Rochester Institute of Technology

[48] NMCC, 2006. The National Strategy for Manufacturing. Technical Report. URL: http://nmcc.nic.in/pdf/strategy_paper_0306.pdf.

[49] Ravi, V., & Shankar, R. (2005). Analysis of interactions among the barriers of reverse logistics. Technological Forecasting and Social Change, 72(8), 1011-1029.

[50] Rebitzer, G., Ekvall, T., Frischknecht, R., Hunkeler, D., Norris, G., Rydberg, T., ... & Pennington, D. W. (2004). Life cycle assessment: Part 1: Framework, goal and scope definition, inventory analysis, and applications. Environment international, 30(5), 701-720.

[51] Rosen, M. A., & Kishawy, H. A. (2012). Sustainable manufacturing and design: Concepts, practices and needs. *Sustainability*, *4*(2), 154-174.

[52] Sage, A.P. (1977), “Interpretive Structural Modeling: Methodology for Large-Scale Systems”, McGraw-Hill, New York.

[53] Topcu, I. B., Bilir, T., & Uygunoğlu, T. (2009). Effect of waste marble dust content as filler on properties of self-compacting concrete. Construction and Building Materials, 23(5), 1947-1953.

[54] Traverso, M., Rizzo, G., & Finkbeiner, M. (2010). Environmental performance of building materials: life cycle assessment of a typical Sicilian marble. The International Journal of Life Cycle Assessment, 15(1), 104.

[55] Tseng, M. L., & Chiu, A. S. (2012). Grey-entropy analytical network process for green innovation practices. Procedia-Social and Behavioral Sciences, 57, 10-21.

[56] Vaidevi, C. (2013). Indian Journal of. Indian journal of engineering, 4(9), 14-16.

[57] Vinodh, S., Prasanna, M., & Selvan, K. E. (2013). Evaluation of sustainability using an integrated approach at process and product level: a case study. International Journal of Sustainable Engineering, 6(2), 131-141.

[58] Zhu, Q., & Geng, Y. (2013). Drivers and barriers of extended supply chain practices for energy saving and emission reduction among Chinese manufacturers. Journal of Cleaner Production, 40, 6-12.

[59] Zhu, Q., & Sarkis, J. (2006). An inter-sectoral comparison of green supply chain management in China: drivers and practices. Journal of cleaner production, 14(5), 472-486.

APPENDICES

Appendix A- *Survey Questionnaire*

This *Questionnaire* is intended to investigate and evaluate the relative importance of Critical criterions for sustainability implementation in Indian marble processing industries. Please spare 5-7 minutes of your valuable time to provide responses to the questions asked below, based on your experience & knowledge.

All the personal details will be held strictly CONFIDENTIAL.

<u>*Section I*</u>

Name (optional) ___________________

Organization ___________________

Designation ___________________

Functional Area/ Department ___________________

Work Experience (years) ___________________

Have you ever worked on sustainability concept Yes/No.

<u>*Section II*</u>

Please answer the following questions and rate your firm on the following criterion on their importance in the implementation of sustainability. Give your valuable thoughts on sustainability and its importance.

❖ *How will you rate a criterion "**sustainability awareness**" for the successful implementation of sustainability in your plant?*

- Very low (VL) [0.0, 0.1]
- Low (L) [0.1, 0.3]
- Fare (F) [0.3, 0.5]
- Medium High (MH) [0.5, 0.7]
- High (H) [0.7, 0.9]
- Very High (VH) [0.9, 1.0]

(Note: In the similar fashion all the criterions are rated)

Appendix B- ***Images from plant survey***

Image 1: Marble slurry/sludge collection plant (waste water also collected here)

Image 2: Waste marble dust is being collected in tanks at plant site.


Image 3: Waste marble pieces are crushed to use with virgin concrete


Image 4: A view of a marble processing plant