CHAPTER 1

INTRODUCTION

The objective of this research is to formulate an efficient green supplier selection model by addressing the several economic and environmental issues in the green supply chain management of the process industries.

1.1 INTRODUCTION

The process industry is defined as an industry in which raw materials are treated or prepared to final or intermediate products through various stages of physical and chemical transformation such as extraction, purification, fraternization, formation, etc., under continuous or batch processing (Hübner 2007; Brennan 1998; Cox & Blackstone 2005). Various types of process industries such as chemical industry, pharmaceutical industry, food and beverage industry, pulp and paper industry, mining industry, cement industry, plastic & compound industry, rubber industry, wood processing industry, petroleum industry, base metals industry, water treatment industry and associated industry are providing basic and necessary products to support our day to day life (Hübner 2007). The process industries are at variance from the production industries by the manufacturing characteristics involved. In process industries, the products are manufactured through several synthesis processes whereas in production industries, series of alterations are involved to manufacture the objects or parts (Hübner 2007).
Generally, the manufacturing process in the process industries depends on the defined process conditions, timely movement of materials and flow of information at various stages to avoid the product failures. The proper design of the supply chain will aid the effective movement of materials, fund, information, services from the suppliers to process industry and then to customer and it is defined as “a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer” (Mentzer et al 2001). Hence, supply chain and supply chain management (SCM) has more focus in the process industries to achieve the efficient flow of material/product from source to customer and it involves suppliers, manufacturers, warehouses, distribution centers, retailers and customers (Shah 2005).

1.2 PROCESS INDUSTRY AND SCM

The supply chain management concept was familiarized in 1980’s (Oliver & Webber 1982) and companies responded with growing interest when they received observable advantages and profits through the supply chain activities (Lummus & Vokurka 1999). Various definitions are prevalent for SCM in the literature such as, coordination of organizational activities within a particular firm and through the trades within the supply chain to improve the performance of the firm and supply chain (Mentzer et al 2001); combining the major business activities from customer through the source suppliers that involves materials, services, information, final product that provides benefit to the end-users and stockholders (Lambert & Cooper 2000); integration of productivity, inventory, facility, warehouse, distribution, and transportation in the supply chain to achieve the best efficiency and responsiveness for the final product being supplied (Hugos 2003). From the definitions, the supply chain management can be understood as the integration and coordination of supply chain activities such as, sourcing of raw materials,
processing of raw materials into final or intermediate products, inventory maintenance and warehouse tracking, order management, distribution and delivery of products to the customer or end-user, and associates the partners such as suppliers, logistic providers, information providers to make the complete supply chain competitive (Lummus & Vokurka 1999).

In recent years, SCM has attained a greater value in the process industries due to the significant benefits like time, cost, quality, and efficiency and SCM functions have focused on making substantial value through innovative processes and product development and services to end-users (Stocchetti & Scattola 2011). SCM plays a significant role in process industries due to several reasons such as process improvement, supplier development for effective purchasing, cost reduction in operation, demand fulfilment, high quality product supply, tackling environmental pressures, addressing global market competitiveness, improvement in information flow, and rising complications of supply chains (Stevenson 2002). Moreover, without an efficient supply chain network, a firm cannot survive/competitive in the present global market competition (Papageorgiou 2009) and delay movement of product or material flow, the nonfulfillment of customer demand and improper sourcing may raise the operational cost and losses. Figure 1.1 presents the supply chain network in process industries. Many researchers have done the research work on SCM in various process industries, such as petrochemical industries (Yusuf et al 2014; Schulz et al 2004; Kuo & Chang 2008), chemical industries (Lainez Aguirre & Puigjaner Corbella 2013; Liu et al 2011; Zhang et al 2014), pharmaceutical industries (Laínez et al 2012; Narayana et al 2014; Wei Teng et al 2013); mining industries (Stacey et al 1999; Pan et al 2012), paper industries (Hameri & Lehtonen 2001; Jones & Ohlmann 2008), cement industries (Gupta et al 2012; Noche & Elhasia 2013), food industries (Marsden et al 1999; Reiner & Trcka 2004; Aung & Chang 2014).
1.3 ISSUES IN PROCESS INDUSTRY & SCM

1.3.1 Process Industry Issues

Recently, the process industries are restructuring and altering their business activities through the supply chain to face the challenges in the future, such as (Zhou et al 2000; Papageorgiou 2009; Shah 2005),

(i) Fluctuation in market conditions and raised competition with shorter product life cycles;

(ii) Increased environmental pressure from government and related organisations;

(iii) Implementation of policies and agreements connected with recycle, reuse, remanufacture of end-used products.
1.3.2 SCM Issues

SCM is an innovative way to manage the firm activities and relationships in a competitive environment. The main elements of SCM identified for the successful business operations are end-user satisfaction, end-user service management, demand management, order completion, process management, procurement, process/product improvement and returns (Lambert & Cooper 2000). Combining the management activities through supply chain processes instead of individual management may lead the successful SCM in an organisation. But, SCM faces some challenges due to the major risks/issues emanating from the firm, supplier and buyer side as follows (Chopra & Sodhi 2012):

a) Capacity – capacity fluctuation at core plant, supplier plant and demand fluctuation at buyer side.
b) Delays – raw material supply delay, product distribution delay and customer order delay.
c) Procurement – supplier delays in order processing, rise of material cost & transport cost, single and multiple source purchasing, long-term and short-term supplier contracts.
d) Disruption – natural disaster, labour disputes, dependency on single source supply.
e) Inventory – product ageing, variation in product value, demand and supply uncertainty.
f) Information flow – information infrastructure failures.
g) Intellectual property – supplier redesign & creates own products
h) Receivables – buyer holds the payment.

In the above discussed issues, supplier related activities predominate in SCM issues. As the suppliers are connected to the process
industries through procurement activity and environmental effects are more concerned in the process industries, this will lead to the development of the environmental based procurement, (i.e.) environmental based supplier selection by application of multi criteria decision making (MCDM) techniques in green supply chain management (GSCM) to compromise the issues in process industry SCM.

1.4 MULTI CRITERIA DECISION MAKING

The multi-criteria decision making is defined as solving multiple criteria environment to arrive at a finite decision for a complex problem. MCDM is applied in various fields for various decision making process and in SCM it is mostly applied for supplier selection issues in purchasing activity. The general process followed in MCDM is (Dodgson et al 2009),

- Identifying objectives
- Identifying the option for achieving the objectives
- Identifying the criteria to be used to compare the options
- Evaluate the options
- Decide on choices

1.4.1 History of MCDM

Decision making is a human behaviour where used in every instances. The traces of MCDM in historical origin are limitedly available in the literature. According to Köksalan et al (2013), a story in the life of King Solomon (1011-931 BC) about the mediation problem was considered as MCDM problem, and it is probably the first recorded instance of MCDM approach. Daniel Bernoulli (1700-1782) has published a research on utility theory in 1978 (Tseng & Huang 2011). In 1772, Benjamin Franklin’s
arguments methodology which he called as ‘Moral Algebra’ was clearly an early MCDM approach (Köksalan et al 2013). From the search it can be found that MCDM has relative developments only in last 40 years of period. Several MCDM approaches were developed by the researchers and it is classified in the following section.

1.4.2 MCDM Classification

MCDM problems are classified as follows (Kahraman 2008; Rao 2007) and it is shown in Figure 1.2. The list of MCDM approaches are provided in Table A1.1.

i) Multi Attribute Decision Making (MADM) – discrete type

ii) Multi Objective Decision Making (MODM) – continuous type

1.4.2.1 Multi Attribute Decision Making (MADM)

MADM is defined as making decisions among predetermined actions based on multiple attributes. It means, determine the best alternative by considering the trade-off between the set of attributes interacting in the decision making problem. Generally pre-set and limited numbers of decision alternatives are involved in MADM problems and solving MADM problem is basically a sorting and ranking technique. MADM approaches are classified as follows (Hwang & Yoon 1981; Tzeng & Huang 2011; Kahraman 2008).

Non-compensatory Methods: It is defined as making decision on alternatives by considering the decision attributes individually. It means the decision comparisons made on criteria by criteria basis and good values of the one criterion cannot be offset by the adverse values of other criteria.
**Compensatory Methods**

It is defined as making decision on alternatives by considering the trade-offs between decision criteria. It means a slight decline in one criterion is acceptable if it is compensated by some enhancement in one or more other criteria in decision making process. Compensatory methods can be classified into the following 4 subgroups.

*Weighting Methods*: The weighting method selects or evaluates an alternative based on its priority weights of criteria (e.g., SAW, AHP, ANP, etc.)

*Compromising Method*: The compromising method selects an alternative that is closest to the ideal solution. A solution relatively close to the ideal solution and far from the nadir solution is evaluated to be the best (e.g., TOPSIS, VIKOR, etc.)

*Outranking Methods*: The outranking method generates a preference ranking which best satisfies a given concordance measure (e.g., ELECTRE, PROMETHEE, etc.)

*Disaggregation Methods*: The disaggregation method refers to the analysis of global preference of the decision maker to deduce the relative importance of the evaluation criteria and develop corresponding preference model (e.g., UTA, MACBETH, etc.)

**Other Methods**

*Verbal decision analysis*: Verbal decision analysis methods select the alternatives by comparative verbal assessment of criteria and alternatives in verbal scale (e.g. ZAPROS, ZAPROS-LM, etc.)
Structural Model: The structural model refers to the identification of direct and indirect relationship between factors which describe the issue and build the overall structure to determine the solution (e.g., DEMATEL, ISM, etc.)

Probabilistic approach: In probabilistic approach, each criterion of alternatives is described by the distributed assessment using the belief structure and determines the better outcomes by comparison (e.g., PROTRADE, ERA, ORCLASS, etc.)

Integral Method: The integral method refers to the computation of preferences or expectation with respect to non-additive measures using additive utility function (e.g., Choquet Integral, Fuzzy integral evaluation, etc.)

Incomplete information system: The incomplete information system refers to the consideration of criteria in the incomplete information nature along with the complete information attributes (e.g., SMART, Rough set theory, etc.)

1.4.2.2 Multi Objective Decision Making (MODM)

MODM is aimed at optimal solution for the decision problem in which several conflicting objectives are to be considered and achieved simultaneously. Generally MODM involves a set of conflicting objectives and a set of defined constraints. Therefore, it is associated with mathematical programming for optimization problems (Tzeng & Huang 2011). MODM approaches are classified as follows based on the decision maker's information need for the MODM model (Lu & Ruan 2007).

No articulation of preference information method: The approaches under this method do not required preference information from decision maker once the objective and constraints are defined for the MODM model. It means no
information is required from decision maker to solve the MODM model (e.g., Global criterion method).

**A priori articulation of preference information:** The approaches under this method need cardinal information like achievement goals or trade-offs information from decision maker to solve the defined objectives and constraints of the MODM model. It means cardinal information has to be defined before construct the MODM model (e.g., Weighing method, Goal programming, Data envelopment analysis, etc.).

**Progressive articulation of preference information:** This method is generally referred to as Interactive method. In this method, the decision maker has to provide the preference information like trade-off information at each iteration level of the solution based on current solution to attain the optimal solution (e.g., STEM, MODI, etc.).

**A posterior articulation of preference information (non-dominated solutions generation method):** The approaches under this method determine the optimal solution of the MODM model by explicit trade-offs between the defined objectives through the trade-off information received from the decision maker (e.g., MOLP, Adaptive search method, etc.).
# MCDM classification and approaches

## Non-compensatory Methods
- Maximin method
- Closeness Centric Evaluation Method
- Lexicographic method
- Categorical constraint method
- Disjunctive constraint method
- Maxmin Method
- Socratic Method
- Socratic method
- Qualitative method
- SCOT
- Automatic design

## Non-Additive approach
- Choquet integral
- Fuzzy integral evaluation

## Comprehensive Information system
- SMART
- Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis
- GIBS (Group Integrated Behavioral System)
- Decision Support Systems

## Information collection System
- Value-Neutral Domain
- Scenario planning
- AGV

## Probability approach
- Probabilistic incremental
- Probability
- Fuzzy logic
- Possibility theory
- Fuzzy sets
- Certainty factors
- Fuzzy concept maps
- Decision trees

## Structural Model
- DEMATEL
- AHP
- VIKOR
- PROMETHEE
- ELECTRE
- ELECTRE III
- ELECTRE III
- PROMETHEE I
- PROMETHEE II
- PRISES
- SUGRA
- GRAVITY
- AHP
- SIMO
- MACBETH
- SMART
- ANP
- QVNS
- QVNS
- QVNS
- QVNS

## Verbal Decision Analysis
- ZAPROS
- ZAPROS II
- ZAPROS III
- ZAPROS IV
- ZAPROS V

## Earlier Developments (MIDRE)
- Subjective probability
- Bayesian probability
- Fuzzy sets
- Interval analysis
- Game theory
- Multi-attribute utility theory
- Multi-attribute value theory

## Earlier History
- Panel comparison
- Pairwise comparison
- Conjoint analysis
- Edgeworth box
- Condorcet's paradox
- 2-dimensional space

## Fuzzy Introduction
- Fuzzy set theory
- Fuzzy logic
- Fuzzy decision theory
- Fuzzy decision methods
- Fuzzy decision making
- Fuzzy environment

## Goal Programming (MIDRE)
- Goal Programming
- Linear Goal Programming
- Quadratic Goal Programming
- Non-linear Goal Programming
- Multiple Goal Programming
- Stochastic Goal Programming
- Geometric Programming
- Optimal Programming

## A priori articulation of preference information
- Global criterion method
- Goal Programming
- Data envelopment analysis
- Linear Goal Programming
- Goal Achievement Method
- Linear integer Goal Programming
- Nonlinear Goal Programming
- Integer Goal Programming
- Dynamic Programming
- Geometric Programming
- Optimal Programming
- Goal Programming
- Stochastic Goal Programming
- Multi-objective dynamic programming
- Genetic programming

## Progressive articulation of preference information
- Goal Programming
- STEP Method
- SIMORS
- SIMORS
- Bollier and Karp method
- Aggregate Worth Trade-off Method
- MCDA
- AHP
- GRA
- AHP
- MACBETH
- SMART
- ANP

## A posteriori articulation of preference information
- MCDA Methods
- Multiple criteria decision analysis
- Adaptive Search Method

## Further Developments (MIDRE)
- Linear programming
- Fuzzy linear programming
- Linear Programming
- Goal Programming
- Linear Programming
- Quadratic Programming
- Non-linear Programming
- Integer Programming
- Stochastic Programming

## Figure 1.2 MCDM classification and approaches
1.5 GREEN SUPPLY CHAIN MANAGEMENT

The supply chain network is the combined business activity to deliver products, services, and information to the end-user (Croxton et al 2001). In earlier work practices at companies, environmental qualities in the business processes were separately monitored and in 1990’s supply chain revolution it was integrated in supply chain as the best practice with on-going operations (Srivastava 2007) and researchers, SCM developers, and SCM users show increasing interest on GSCM. Generally, environmental effects have significant influences on the supply chain activities such as, raw material procurement, manufacturing process, supplier selection, transportation, marketing, product distribution, services to end-user and logistics (Lamming & Hampson 1996; Handfield et al 2005). Several definitions are provided for GSCM by researchers in literature and few definitions are

Hervani et al (2005) as “Green Supply Chain Management (GSCM) = Green Purchasing + Green Manufacturing / Materials Management + Green Distribution/ Marketing + Reverse Logistics”.

Srivastava (2007) as “integrating environmental thinking into supply-chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as end-of-life management of the product after its useful life”.

Sarkis et al (2011) as “integrating environmental concerns into the inter-organizational practices of SCM including reverse logistics”.

The key elements involved in GSCM are factors: environmental performance for process or product improvement; implementation of green regulations for business operations; green purchase function; green supplier management and green logistics management (Azevedo et al 2011; Sarkis 2003). Many research works on GSCM are specifically focused on green
purchasing (Green et al 1998; Min & Galle 1997; Russel 1998; Zhu et al 2007), because the purchase activity involves major contribution on final product price and green purchasing not only involves the internal environmental management initiative but also on supplier side. Bowen et al (2001) recognised the green supply chain as two types. One is ‘greening the supply process’ which integrates the environmental concerns on suppliers management like evaluating and sorting the suppliers based on their environmental performance for green purchasing, and the other is ‘product-based green supply’ which involves green based product supply. This research work examines the green supplier evaluation and selection based on environmental and economic criteria for base material procurement under green purchasing in various process industries. In recent years, researches on topic GSCM in process industries are increasing. Some of the GSCM researches in process industries are:

Chang et al (2013) have studied the GSCM implementation in five food industries and they conclude that the case companies did well in the green purchasing and marketing while encountered the objective difficulties in the implementation of green practices in manufacturing, logistics. Lorentz (2008) has described the utilization of environmental information at different stages of food supply chain and analysed the barriers to GSCM practice. Frederick & Elting (2010) have examined the important factors in implementation of GSCM practices in food industries. Hong-mei (2009) established a profit model for manufacturer and retailer in green food supply chain. Liu & Zhou (2011) examined the macro and micro factors, which influenced the implementation of GSCM in edible oil industry. Handfiled et al (2002) have developed the decision support model to identify the supplier for paper industry based on trade-offs in environmental dimensions. Hildén et al (2002) assessed the environmental policy instruments in paper and pulp

From the earlier research and analysis on the industrial practices, it has been found that still lack of research exists in the process industries such as GSCM practices and implementation specifically ‘green purchasing’ and this issue is covered in this thesis.
1.6 GREEN SUPPLIER EVALUATION AND SELECTION IN PROCESS INDUSTRY

The green purchasing function is a main activity in a green supply chain of a firm, which used to derive the right material from the right source at right price, time, delivery, service and quantity (Fawcett & Fawcett 1995) and it aided purchasing professionals to construct the environmental based purchasing strategies to improve the environmental performance and sustainability of a firm and supplier (Green et al 1998; Min & Galle 2001). The concept of green purchasing is setting the environmental criteria along with economic criteria towards the supplier selection for procurement of environmental based material/service (Green et al 1996). Moreover, the green purchasing strategies will guide the suppliers to develop their environmental performance to compete in the selection process. This thesis covers the suitable green supplier evaluation and selection in various types of process industries and the approaches applied for green supplier selection in this research work are presented in the following section.

1.6.1 Need and Significance of Green Supplier Selection in Process Industry

Green supplier evaluation and selection is the key issue in many industries supply chain nowadays because industries are spending half of the revenue for purchasing activity (Beil 2010) and increasing awareness of environmental impacts in the business operations (Akili 2009). To maximize the value of purchasing and to improve the environmental competencies in purchasing functions, the firm should evaluate and select the best green supplier for their raw material procurement (Lu et al 2007). Moreover, the process industry supplies are mainly focused on the environmental compliance, quality and time based delivery to avoid the ageing and quality
loss on the supplied material. To overcome this issue and evade the possibility of defective goods purchase from worst supplier, the green supplier selection process plays a key role in the supply chain activities. Generally, green supplier selection process is a MCDM process, which includes several economic and environmental benefit and risk criteria pertinent to the industry specified green supplier selection model (Sahu et al 2012). The green suppliers are evaluated and ranked based on the selected criterions and purchase order is placed either on the best green supplier or order quantities allocated to the suitable alternatives in case suppliers have limited supply capacity.

The significance of green supplier selection is,

- It moderately reduces the material procurement cost and improves the product development and overall profit (Zhu & Sarkis 2004; Rao & Holt 2005).
- It improves the product development, corporate performance, customer satisfaction, and firm competitiveness to compete in the global market (Mudgal et al 2009; Wu et al 2012; Chan et al 2012).
- It successively improves the environmental performance of the buyer and supplier (Humphreys et al 2003a)
- It forces the supplier towards pollution prevention and reduction (Vachon & Klassen 2007).
- It is regarded as a contribution to sustainability, social and economic development (Elkington 1999; Reuter et al 2010)
- It involves the reuse, recycle, material substitution activities in green supply (Hu & Hsu 2006).

1.6.2 Green Supplier Evaluation and Selection Techniques

The green supplier evaluation and selection in a process industry is a challenging task as the selection requires the consideration of the multiple
objectives and, economic and environmental criteria in quantitative and qualitative method (Bhutta & Huq 2002). Due to the uncertainties that accompany both qualitative and quantitative factors, the evaluation and selection of green suppliers is therefore a MCDM issue and numerous multi-criteria decision support tools have been developed for structuring and supporting the evaluation and selection decisions (Wu et al. 2010). The green supplier evaluation and selection is a four level hierarchical structure as shown in Figure 1.3.

**Figure 1.3 Green supplier selection hierarchy**

In the first level, pertinent environmental and economic criteria are selected through discussion with expert team member of the industry, wide search of literature, advice from academic experts and relevant industrial experts to support the objective of the problem. The selected criteria are evaluated by decision making team and priority weights of the criteria are calculated by applying suitable MCDM technique in the second level. In the third level, the nominated green suppliers for the objective problem are evaluated with respect to the selected criteria by decision making team and the ranking of the green suppliers are determined through the application of appropriate MCDM technique in the fourth level.
The detailed study of MCDM techniques applied for green supplier evaluation and selection is presented in literature review chapter and the approaches applied in this research are presented as follows:

**Fuzzy set theory:** The fuzzy set theory was introduced by Zadeh (1965) to resolve the uncertainty and imprecision associated with information. Fuzzy data may consist of linguistic terms such as fuzzy sets or fuzzy numbers. If the fuzzy data are linguistic terms, they are transformed into fuzzy numbers first. Then, all the fuzzy numbers (or fuzzy sets) are assigned crisp scores.

**Fuzzy Axiomatic Design (FAD):** AD principles were initiated by Suh (1990) and are widely used in engineering. The most important concept in Axiomatic Design is the "design axioms." The first axiom, Independence Axiom, states that the independence of functional requirements (FRs) should always be maintained to characterize the design goals. The FRs are defined as the minimum set of independent requirements. The second axiom, Information Axiom, states that among those designs that satisfy the Independence axiom, the design which has the smallest information content is the best design. Then, the information is defined in terms of the information content $I_k$ that is related in its simplest form to the probability of satisfying the given FRs. $I_k$ determines the design with the highest probability of success is the best design. AD principles allow for the selection of not only the best alternative within a set of criteria, but also the most appropriate alternative. It is the main difference between the classical MCDM method and AD.

**Fuzzy Analytic Hierarchy Process (FAHP):** AHP is a classical technique developed by Satty (1980). AHP approach is expressed in terms of pairwise comparison of items on a given level of the hierarchy with respect to their impact on the next high level and majorly applied in MCDM problem in many
literatures. The pairwise comparison is used to determine the priority weights of alternative and selection is carried by ranking of alternatives. Chang (1996) modified the Satty’s AHP techniques as FAHP to overcome the unconfident feeling in the pairwise comparison and priority weights are calculated by fuzzy synthetic extent and degree of possibility.

**Preference Ranking Organization METHod for Enrichment Evaluations (PROMETHEE):** PROMETHEE was developed by Brans (1982) as outranking method and later modified by Brans & Vincke (1985) to PROMETHEE I and II. PROMETHEE methods are simplest in technique to solve the MCDM problem where ranking of the alternatives are done by compromising the poor dominance and excessive relationships generated through performance functions.

**Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (FTOPSIS):** The FTOPSIS methodology extends the multi-attribute individual decision making of classical TOPSIS (Hwang & Yoon 1981) into group decision making and it is classified under compromising models, with the notion that no ideal solution exists, but a solution with optimal values on all attributes is simultaneously selected. FTOPSIS ranks the alternatives by calculate closeness coefficient of each alternative through positive ideal solution and negative ideal solution values.

**Multi Objective Linear Programming (MOLP):** MOLP is a linear programming method to determine the optimum values in the supplier issues through solving the mathematical equations for set of objectives and constraints.
Taguchi loss function: Taguchi loss function (Quality loss function) is a method of measuring loss as a result of the product or service not meeting standard specifications (Taguchi 1989). The purpose of calculating loss is to quantitatively evaluate the quality loss caused by the performance of the alternatives and, ranking is determined through this loss.

1.7 RESEARCH GAPS

This research work seeks to address the following research gaps which are identified from the previous supply chain management studies in process industries based on environmental issues.

- Develop the systematic solution procedure for supply chain optimisation under uncertainty in process industries. (Papageorgiou 2009; Puigjaner & Guillén-Gosálbez 2008; Seok et al 2012)
- Incorporate the environmental impact indicators relevant to the process industry supply chain and develop the multi objective solution framework for supplier selection issues (Papageorgiou 2009; Barbosa-Povoa 2012; Laínez et al 2012)
- Develop the green supply chain solution to improve the sustainability and resource efficiency through multi-level collaboration with suitable partners (Papageorgiou 2009; Shah 2005; Seok et al 2012)
- Identify the risk like economic and environmental issues and establish the efficient decision support system for proper trade-offs between profit and risk to satisfy the objectives (Barbosa-Povoa 2012; Laínez et al 2012)
- Formulate an explicit strategic environmental framework in the process industry to improve the process development and customer satisfaction (Schot 1992).
1.8 OBJECTIVE OF THE RESEARCH WORK

The purpose of this research work is to deal with the identified research gaps on the key issues on GSCM in the process industries. This research work develops the decision framework model for green supplier evaluation and selection based on economic and environmental criteria to address the green issues in various types of process industries.

1.8.1 Selection of Process Industries

In this research, an effective decision model was developed in the following case process industries: plastic industry (chemical), food industry, paper industry and mining and mineral industry, to help the decision team to evaluate and select the best alternate green supplier for raw material procurement. The above said process industries are selected for this research based on following green supply chain strategies established by Simpson & Samson (2008).

Risk-based strategies: Risk based green supply chain is defined as minimizing the risk through retaining the minimal internal environmental management resources and maximizes the reputation through involvement of third party environmental management system. Based on this strategy, green vendor selection for outsourcing production activity in mining industry is selected for this research.

Efficiency-based strategies: Efficiency based green supply chain involves higher level of environmental performance in the operational process in the supply chain to meet the operations-based efficiency target. As the food processing industries involve high environmental concerns in operational process like food safety, solid waste generation, etc., food process industry is selected for this research.
Innovation-based strategies: Innovation based green supply chain is defined as implementation of greater level of innovation or integration of environmental performance to the supply chain to meet the standards in specialized process, technologies or complex performance. Based on this strategy, green product supply to meet the government regulations in plastic industry is selected for this research.

Closed-loop strategies: Closed loop green supply chain is defined as restore the used or obsolete products and waste to remanufacture or recycle rather than dispose or landfill. Based on this strategy, paper industry is chosen for this research to recycle the waste to reduce the carbon emission.

Moreover, on high energy consumption and environmental impacts like CO2 emission, the above mentioned industries are selected for this research. According to Tool, A.E.P. (2010) global energy consumption report, chemical industries, paper and pulp industries, food and beverages industries, and mining and mineral industries consume 19, 3.4, 16, 6.8 per cent of energy respectively in total 51 per cent global energy consumption by industrial sector.

1.8.2 Objectives and Research Framework

The structure of this research work is given in Figure 1.4 and the main objectives of this research work are as follows:

- Establish a decision structure to support green purchasing activity, environmental management system, and green supplier development in the process industries.
Develop the appropriate economic and environmental criteria framework to address the key economic and environmental issues in the GSCM of the specified process industry.

- Analyse the operational framework of the GSCM and develop the effective green supplier selection model to support purchase personnel and decision making team at material procurement stage.
- Utilise the various decision making techniques either in individual way or in combined way to select the best green supplier for purchasing process and order allocation among the potential suppliers.

Figure 1.4 Research framework
1.9 OVERVIEW OF THE THESIS

The organisation of the thesis is as follows:

Chapter 2 presents the detailed literature review on multi criteria decision making approaches utilized for green supplier evaluation and selection in different areas. Published research from 1997 to 2014 is structurally reviewed based on green supplier selection approaches and following questions are addressed for green supplier development, (i) which selection approaches are commonly applied? (ii) what environmental and other selection criteria for green supplier management are popular? and (iii) what limitations exist?

In Chapter 3, the case study of green supplier evaluation and selection in a Singapore base polymer compounding industry was studied. In this research, FAD approach was applied to choose the best green supplier by mainly considering the country based environmental regulations along with other environmental and economic criteria for material procurement in new product development.

Chapter 4 proposes a hybrid methodology of FAHP and PROMETHEE technique for selection of appropriate green supplier in a food processing industry under uncertainty MCDM environment. In this research food safety and quality is mainly considered as environmental impact and economic criteria respectively for supplier selection in green food supply chain.

In Chapter 5, FTOPSIS and MOLP are proposed in the integrated way to evaluate and select the best green supplier in paper industry. Low carbon economy is considered in this chapter as one of the main criteria.
because paper industries moderately contributed for carbon foot prints which lead to the global warming. In this study, best green supplier was selected by FTOPSIS approach and MOLP method is used for order allocation among the potential suppliers. Moreover, various methodologies are used to compare the optimum result of the study.

Chapter 6 addresses the environmental impacts and outsourcing of core activity in the mining industry. In this study, AHP and Taguchi loss function is used to identify the suitable green vendor for the outsourcing activity based on the quality loss to the organisation due the vendor performance on the selected green criteria.

Lastly, Chapter 7 presents the conclusion, limitations, and recommendations for the future work.