# Assessing Sustainability in Supply Chain Using Dempster-Shafer Theory

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## CERTIFICATE OF APPROVAL

The thesis titled **"Assessing Sustainability in Supply Chain Using Dempster-Shafer Theory"** submitted by Student No: 1015082004, Session- October 2015, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Master of Science in Industrial & Production Engineering on May 08, 2019.

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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Mahathir Mohammad Bappy

***To the Almighty***

***To my family***

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## ABSTRACT

Sustainability assessment in supply chain is an important task for any organization in the competitive business environment. To ensure better decisions for optimizing the sustainability attributes such assessments are desirable. Therefore, it is essential to have a model of sustainability assessment in supply chain considering the triple bottom line of economic, environmental and social attributes, as failure of these attributes may lead to catastrophic consequences. The sustainability assessment process of an organization is aligned with different sources of information which can be uncertain, incomplete, and subjective in nature. To assess or monitor the sustainability, though there are many techniques available, but the intelligent interpretation of the collected information remains a challenge. Therefore, this research proposes a methodology that uses an integrated approach of Analytical Hierarchy Process (AHP) and Hierarchical Evidential Reasoning (HER) based on Dempster-Shafer (D-S) theory to develop a supply chain sustainability assessment model. After identifying the sustainability assessment criteria, AHP is used to structure and rate the criteria based on expert's opinion. In this research, subjective judgmental belief data have been used to test the model. The information is combined using D-S theory and results are depicted as supply chain sustainability index. In the proposed model, the results of D-S theory are compared using Yager's recursive rule of combination. The model generates satisfactory results based on the utilized data.

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| | |
|---|---|
| SSCM | Sustainable Supply Chain Management |
| MCDM | Multiple Criteria Decision Making |
| HER | Hierarchical Evidential Reasoning |
| DST | Dempster-Shafer Theory |
| ER | Evidential Reasoning |
| AHP | Analytic Hierarchy Process |
| TBL | Triple Bottom Line |
| LCA | Life Cycle Assessment |
| IOA | Input-Output Analysis |
| bpa or BPA | Basic Probability Assignment |
| SPI | Sustainability Performance Indicator |

# CHAPTER 1

# INTRODUCTION

## 1.1. Background of the Study

In recent times, sustainable supply chain management (SSCM) practices have become a topic of interest among academics and practitioners (Pagell & Wu, 2009; Seuring & Müller, 2008). Considering the extensive nature of the wider adoption and development of sustainability across the globe, there is a solid requirement for developing a meaningful and more focused understanding of sustainability in supply chain management practices (Ashby, Leat, & Hudson-Smith, 2012; Linton, Klassen, & Jayaraman, 2007). On the other hand, intense global competition has continued to escalate the need to improve the performance of organizations in managing their supply chains (WCED, 1987). Keeping in view the stated problems, it is therefore essential to assess sustainability in a supply chain. Multiple Criteria Decision Making (MCDM) methodologies, for example, have been used to evaluate sustainability in a supply chain (Poh & Liang, 2017).

It is recognized that organizational performance measurement is an MCDM problem, which involves hierarchical structuring of the decision variables (Uzoka, E., Seleka, 2005). Among several MCDM methods, the Hierarchical Evidential Reasoning (HER) approach is the latest development in the MCDM area. This approach advocates a multi-level hierarchy in the evaluation process, Dempster-Shafer (D-S) evidence theory, evaluation analysis model, and decision theory (Ahmadzadeh & Bengtsson, 2017). The HER framework can combine subjective, imprecise, partial or incomplete, and even conflicting data information and can handle conflict within a formal unified framework. The HER model is based on D-S theory, which is an effective tool to address epistemic uncertainty (ignorance) (Dempster, 1967; Shafer, 1976).

Previous studies for assessing sustainability in supply chains have faced some limitations. For example, most of the methods focused on only one dimension of sustainability, like social (Popovic, Barbosa-Póvoa, Kraslawski, & Carvalho, 2018) or, environmental aspects (Acquaye et al., 2018)). The integration of economic, social and environmental dimensions helps to provide a full picture of the sustainability in a supply chain. Another limitation of previous studies is that many authors failed to include uncertainty when applying MCDM methods. Thus, this research will attempt to address these limitations and develop a model for monitoring sustainability in supply chains based on D-S theory.

## 1.2. Objectives with Specific Aims

The specific objectives of this research are:

- To develop a Dempster-Shafer (D-S) theory based hierarchical model to appropriately assess the sustainability in supply chains.
- To practically assess the sustainability in supply chains using the developed model.

The proposed research will develop a D-S theory-based framework as a realistic and easily understandable tool to assess the supply chain sustainability of enterprises. The framework is expected to support decision making in supply chains, aimed at improving economic, environmental and social sustainability for long-term business excellence in a competitive environment.

## 1.3. Contributions of the Present Study

This research proposes a supply chain sustainability assessment methodology based on D-S theory under epistemic uncertainty for the organizations. The epistemic uncertainty is associated with different attributes basically due to the limited data and lack of knowledge of the experts. In this research, for modeling the supply chain sustainability assessment index, HER techniques like D-S theory and Yager's rule yield a reasonable and distinct MCDM approach, using a structured and comprehensive decision matrix. The attributes of the triple bottom line dimensions (i.e. economic, environmental and social) of sustainability are considered for sustainability assessment in supply chains. In this approach, information is collected through questionnaires or based on interviews, are targeted to an interest group, and assess the qualitative and quantitative inputs or outputs of sustainability attributes.

Sustainability assessment of the supply chains of organizations requires drawing on different sources of information. The information sources may possess a range of limitations, such as uncertainty, inadequate information, lack of knowledge of decision-makers, and inability to yield appropriate evaluations by experts. In this study, using the D-S theory, information is accumulated to incorporate epistemic uncertainties across the model. To depict the application process, a model test is performed by using deliberately collected data from the organization. To determine the weighting of selected attributes, the AHP is used prior to the calculation of HER techniques (i.e. D-S theory and Yager's rule).

The Outcomes of our analysis demonstrate that, by using HER techniques, the supply chain sustainability index of an organization can be determined. Accordingly, based on evaluation grades, the distributed condition states of sustainability in supply chains are illustrated as an outcome of the proposed model. For a comparison of results, Yager's recursive rule of combination is applied. After that, sensitivity analysis is conducted to determine the impacts of attributes weights on the outcomes of the approaches using D-S theory and Yager's rule.

### 1.4. Outline of Methodology:

The methodology to achieve the objectives of this research would be as follows:

- Supply chain sustainability attributes are identified through a survey of recent literature review and getting feedback from expert.
- The hierarchical structure with appropriate attributes is developed for defining the sustainability of supply chain properly.
- A number of experts from companies and institutions are deliberately selected for collecting necessary data or information for the sustainability attributes to test the model.
- To structure and to determine the weights of attributes the Analytical Hierarchy Process (AHP) is used.
- Assessment grades by linguistic term and utilities of assessment grades are defined by using literature.
- Attributes of the lowest level is assessed with reference to individual or a subset of the evaluation grades with different degrees of belief.
- Aggregate performance values and weights of the sustainability attributes of supply chain using D-S combination theory.

- The result from D-S rule of combination is compared by assessing Yager's recursive rule of combination. Thus, sustainability value is estimated from both calculations.
- Finally, sensitivity analysis is performed to depict the impact of factors weights in decision-making process using the D-S theory and Yager's recursive rule.

## 1.5. Organization of the Thesis

This thesis has been organized into seven chapters, along with a list of references and appendices. Chapter 1 is entitled as "Introduction" containing the background, objectives with specific aims, methodologies and contributions of the present study on sustainability assessment of the supply chain.

Chapter 2 presents the related literature on sustainability views, triple bottom line sustainability perspective, approaches of supply chain sustainability assessment, related literature on HER approach and research gap.

In Chapter 3, termed as "Theoretical and Mathematical Foundation", the theoretical background of sustainability assessment, evaluation approach, the basic theory of AHP, D-S theory, Yager's recursive rule of combination and sensitivity analysis methods are outlined.

Chapter 4, titled as "Supply Chain Sustainability Model Development", is dealing with the development of a framework using D-S theory as a HER approach.

Chapter 5, termed as "Numerical Example," consists of information collection and aggregation of data or information using D-S theory and Yager's rule to get supply chain sustainability index based on the formulated model.

Chapter 6, termed as "Results and Discussions," discusses the results and findings based on the outcomes of supply chain sustainability assessment of the organization and sensitivity analysis. Finally, Chapter 7 incorporates the research conclusion with potential recommendations for future researchers.

# CHAPTER 2

## LITERATURE REVIEW

To evaluate the relative performance of different areas, such as risk assessment, project performance assessment, system capability assessment, condition assessment, etc. the technique of HER has been applied in various instances. This method has been used where the assessment parameters are both qualitative and quantitative as well as has a vague or incomplete source of data. In this chapter, the literature review part is discussed and presented briefly based on applications to the following broad sectors.

### 2.1. Views on Sustainability

By the major political leaders in the 1980's, sustainable development was recognized as a global priority (WCED, 1987). Since then, at all levels of society an enormous amount of research has been conducted on this subject. Accordingly, sustainable development and sustainability were two of the most popular slogans of the 1980s (Pearce, 1988). However, there has been a lack of consistency in interpretations, discussed and employed in these areas.

As stated previously, sustainability refers to the utilization of resources to satisfy current needs without hampering the ability of the upcoming generation to meet their needs (WCED, 1987). As a critical and multidimensional issue sustainability engage efficiency and both of inter and intra-generational equity on an environmental, economic and social basis. Due to the complexities, different approaches are used to define and measure the progress towards the sustainability (Dzemydienë, 2008). These complexities are expressed by Wilson et al. (2007), that there is no combined consensus about the meaning of sustainability and sustainable development. Sustainable development covers development as well as sustainability, and for this, there is a puzzle. Sustainable development concern with the development of economies as well as make perfection of economic and social benefits for the present without disrupting the capability of getting those benefits in future (Goodland, R., & Ledec, 1987).

Sustainability either refers to sustaining and supplementing natural environmental systems or is a requirement for sustainable economic improvement, stated by Pearce (1988). Logical usage and replenishment of natural resources for the need of people during the present and future time also refers to the sustainable development (Rio Declaration, 1992). On the other hand, development means realizing the potential and ability of existing assets (Holdgate, 1993). The definition of sustainability should consider the globalization aspects, a large cycle of time, external effects and environmental constraints for assessing sustainability (Radermacher, 1999).

Given the fact that sustainability issues in developed countries have mostly been centered on environmental subjects, while in developing countries the issues of poverty and equity are being equally significant (Singh, Murty, Gupta, & Dikshit, 2012), one can argue that sustainable growth would refer to economic growth, which is backed by the natural and societal surroundings. Accordingly, human capabilities are extended through economic and structural development by which sustainable development can be perceived. Therefore, it can be stated that sustainability is a state whereas sustainable development is related to processes, though in literature these are used interchangeably (Aras & Crowther, 2009).

### 2.2. Triple Bottom Line Sustainability Perspective

Given the need to handle issues like, climate change, the loss of biodiversity, decreasing material availability and energy consumption demands, sustainability is becoming increasingly central to governance and policy dialogue. As identified earlier, in business management, sustainability has different interpretations ranging from an inter-generational philosophical stand to a multi-dimensional expression. Although it was originally considered a societal issue, sustainability is receiving increased attention from businesses. Among different perceptions of sustainability, one focal idea that serves to operationalize sustainability is the triple bottom line (TBL) approach, where minimum performance levels are obtained in the environmental, economic and social dimensions (Elkington, 1997). Considering business, natural and societal cases, Dyllick & Hockerts (2002) have also categorized the sustainability dimensions.

Furthermore, incorporating the planet, people, and profit as the main features of analysis, the sustainability perspective has been presented in the literature (e.g., Asif, M., Searcy, C., Zutshi, A., Ahmad, 2011; Holliday, 2001; Salzmann, Ionescu-Somers, & Steger, 2005). Advocates argue that organizations which consider environmental and social issues along with economic issues generally create more value in the long run compared to organizations that focus only on financial and profit concerns.

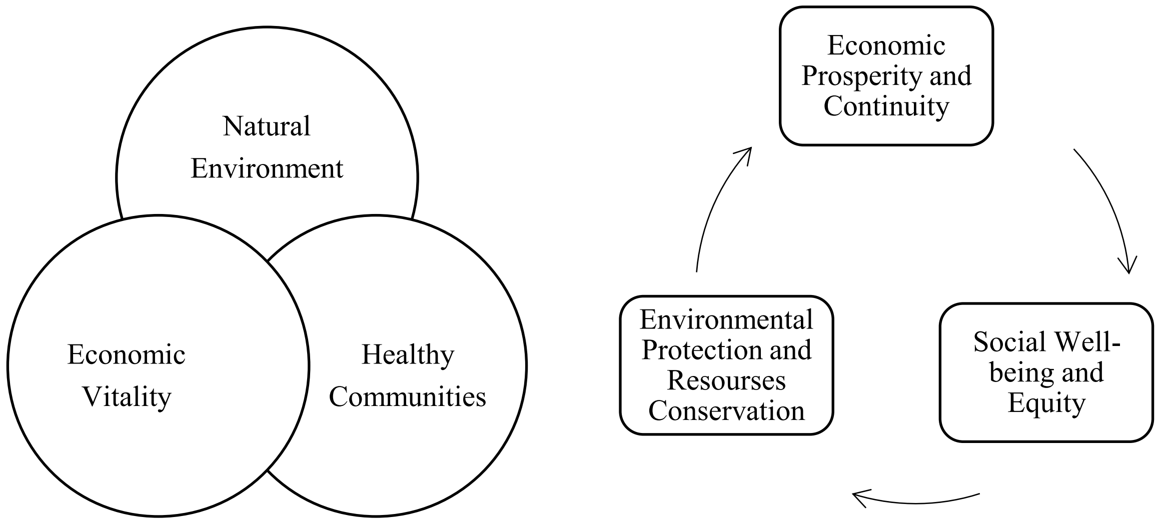


Figure 2.1: Triple bottom line of supply chain sustainability (Elkington, 1997) .

**2.3. Approaches for Sustainability Assessment in the Supply Chain**

Among researchers and practitioners, the sustainability assessment of supply chain is a growing area of interest (Brandenburg, M., Govindan, K., Sarkis, J., & Seuring, 2014; Glock, Jaber, & Searcy, 2012). However, on this subject there are limited number of literatures.

For assessing sustainability in the supply chain quantitative models may be structured into the following approaches drawing the recent research by Hassini et al. (2012), Seuring, (2013), and Brandenburg et al. (2014).

- Life Cycle Assessment (LCA) based model
- Analytical Hierarchy Process (AHP)
- Multiple Criteria Decision Making (MCDM) Structure
- Equilibrium Model
- Models based on Input-Output Analysis (IOA)
- Composite Metrics

For studying and assessing the potential environmental impacts, associated with a product, process, or action, LCA is an efficient strategy. The assessment is performed by determining and evaluating materials utilized, energy consumed, and waste released to the earth (Abdallah, Farhat, Diabat, & Kennedy, 2012; Pishvaee & Razmi, 2012). Seuring, (2013) observed LCA to be the most utilized system for surveying sustainability issues in supply chains (Seuring, 2013). This finding is supported by the previous research (i.e., Pesonen, 2001). The typical components addressed in LCA are to evaluate environmental issues and attempting to minimize their impacts in supply chain (e,g., Cholette & Venkat, 2009; Edwards, McKinnon, & Cullinane, 2010; Tan & Khoo, 2005).

In the context of supply chain, AHP is the second most commonly used approach for assessing sustainability (Seuring, 2013). For organizing and analyzing multi objective decisions AHP is a structured technique (Saaty, 1990). This approach is frequently utilized as a semi-quantitative basic decision-making procedure (e.g., Noci, 1997; Sarkis, 1998). For simplifying and structuring complex decisions this approach is broadly used (Ho, 2008). Accordingly, AHP method provided the opportunities for evaluating complex decisions situations where environmental and economic goals were assessed simultaneously (e.g., Faisal, 2010; Hsu & Hu, 2008; Sarkis, 1998).

To evaluate the performance of an overall supply chain, equilibrium modeling is a standard and well-established methodology (Meixell, M.J., Gargeya, 2005; Nagurney, Dong, & Zhang, 2002) and is another commonly used approach to assess sustainability of supply chain (Seuring, 2013). The balancing of economic and environmental issues by offering relevant optimum solution were the typical foundation of equilibrium models (e.g., Corbett & DeCroix, 2001; Kainuma & Tawara, 2006; Nagurney & Toyasaki, 2003; Saint Jean, 2008). In the published models, no probabilistic approach was emphasized.

On the other hand, the commonly utilized analytical approach is MCDM. Multiple conflicting criteria is considered in this approach. By this approach planning problem with multiple criteria is structured and solved. The main areas of emphasis of this approach is to provide optimal solution by optimizing economic and environmental criteria (e.g., Fichtner, Frank, & Rentz, 2004; Geldermann, Treitz, & Rentz, 2007; Georgiadis & Besiou, 2009; Hugo & Pistikopoulos, 2005). At initial points both the MCDM and equilibrium approach are comparable because of the intentions of finding balance between various environmental and economic performance criteria (Seuring, 2013).

For evaluating sustainability related issues in supply chain IOA is another logical modeling approach (Brandenburg, M., Govindan, K., Sarkis, J., & Seuring, 2014). In this approach, the relationships between supply chain input parameters and outputs of some performance measures can be analyzed. Throughputs of environmental capital and economic goals along with supply chain networks can also be evaluated by IOA techniques (e.g., Bonney & Jaber, 2014; Jaber, Glock, & El Saadany, 2013; Ukidwe & Bakshi, 2005).

The last logical approach of modeling that might be utilized to assess sustainability in the supply chain is creating and utilizing composite measurements (Brandenburg, M., Govindan, K., Sarkis, J., & Seuring, 2014; Hassini et al., 2012). Composite measurements connected with unpredictability (Turnhout, Hisschemöller, & Eijsackers, 2007) and considered as effective and functional tools for policy prioritization, basic decision making, and for performance-based communication of a system (Singh et al., 2012). Regarding this matter adequate research has been conducted (e.g., Booysen, 2002; Mayer, 2008; Singh et al., 2012). To summarize complex and multifaceted problems into one metric the composite metrics are used as practical tools (Singh et al., 2012). There is an argument that composite metrics are more subjective and the results of it are undesirably dependent on the specific weighting system (Böhringer & Jochem, 2007; Singh et al., 2012).

### 2.4. Related Literature on Hierarchical Evidential Reasoning Approach

The procedure of assessing schools includes numerous attributes as examined by Borhan & Jemain, (2012). They propose an Evidential Reasoning (ER) approach that could be utilized to evaluate school performance in a hierarchical structure, which includes indirect measurement of quality using standardized examination results, as opposed to straightforward measurement. The approach used is non- conventional and it employs a belief structure as a distribution to express the results of the assessments. They conclude that there is a little similarity between a normal practice currently adopted and ER approach during the ranking of Schools.

For preventing accident, using the Bayesian Network and ER approach Wang et al. (2013) proposed an accident analysis model to develop cost efficient safety measures. To maintain the originality of the multiple attributes with various types of information, ER approach provides a procedure for aggregating calculations. ER also generates solutions for subjective risk assessment with biasness. They discuss an ER based cost-benefit analysis method considering risk reduction.

Xu (2012) discussed ER approach and explained how it is utilized to analyze multiple criteria decision problems under different uncertainty using a unified structure. He explains how the ER approach is overviewed from two viewpoints: 1) theoretical development and 2) applications. He discusses how the ER approach is depicted with the connections among its different advancements.

Jiang et al. (2011) discussed weapon system capability assessment and its abilities to measure the capabilities of military capability planning. They also discussed how ER was utilized to improve different kinds of uncertainties such as subjectiveness and ignorance. To aggregate the capability measurement information from sub capability criteria to upper capability criterion the HER approach is used. They exhibit outcomes utilizing the ER approach.

To enable decision makers to effectively monitor and assess structural condition for replacing or repairing elements before major damage state is occurred; Wang et al. (2008) and Bolar et al. (2013) utilized HER framework for infrastructure risk management practices. Using this approach condition assessment of a bridge was performed by structuring the data into four categories such as primary, secondary, tertiary and life safety critical elements.

Liu et al. (2008) used HER for the appraisal of a strategic research and development projects for a car producer as it is generally a multiple-attribute decision analysis (MADA) issue. In such cases, data provided by the people is qualitative information with subjective judgment of ambiguity as well as quantitative data which may be imprecise or incomplete in nature.

To conduct the navigational risk assessment of an Inland Waterway Transportation System (IWTS), Zhang et al. (2016) utilized a fuzzy rule-based approach and an ER technique. Considering both subjective and quantitative criteria a hierarchical structure for modeling IWTS hazards (hazard identification model) is developed firstly. The quantitative criteria are changed over to subjective ones by applying a fuzzy control based quantitative information change system, which empowers the utilization of ER to incorporate the risk estimates from the bottom to the top along the hierarchy.

For evaluating confidence in safety evidence Nair et al. (2016) utilized an evidential reasoning approach by empowering assessors to give singular judgments concerning the trustworthiness and accuracy of evidence. Here, based on evidential reasoning approach the overall confidence can be aggregated quantitatively. Utilizing the Technology Acceptance Model, the proposed approach is evaluated and supported by a prototype tool

Solic et al. (2015) utilise the HER approach for information systems' security level assessment. Ji et al. (2017) proposed a hierarchal risk evaluation model utilizing the ER approach for fire or explosion risk assessment of marine vessels.

Gong et al. (2017) proposed an approach for assessing cleaner production performance in iron and steel enterprises. Based on the ER approach and the Data envelopment analysis (DEA), they initially built a nonlinear programming model to depict the relationship among iron and steel endeavors (ISEs) and acquire the ideal weight and the ideal utility value. Then, by applying the ER approach to aggregate the total assessment information, they obtained the ranking of the ISE cleaner production performance.

Sellak et al. (2017) investigated energy planning system under uncertainty, Where the ER approach has been developed for dealing with the growing complexities and uncertainties in assessments problems. Here, to assess the appropriateness regarding the use of different renewable energy technologies the ER approach is employed as a multiple criteria framework.

### 2.5. Research Gaps

The review is performed to systematically analyze the existing literature to determine the available methods and frameworks to comprehensively assess sustainability of supply chains based on available information, as shown in Table 2.1. It is observed that many studies have been performed on sustainability. In previous studies, the majority of methods do not take into consideration all three dimensions (i.e. economic, social and environmental) of sustainability. Whereas, the integration of economic, social and environmental dimensions gives true picture of the sustainability in a supply chain. Another limitation of previous studies is that many authors failed to include uncertainty when applying different methods. Many authors provided only a conceptual framework but did not conduct an aggregation procedure to obtain a sustainability index. Therefore, this research will attempt to address these limitations and develop a model for monitoring sustainability in supply chains considering economic, environmental and social attributes based on D-S theory.

Table 2.1: Summary of studies on supply chain sustainability and methodologies.

| No. | Sources | Objectives | Methodology used |
|---|---|---|---|
| 1 | (Dey & Cheffi, 2013) | To develop and deploy an analytical framework for measuring the environmental performance of manufacturing supply chains. | AHP |
| 2 | (Kumar & Garg, 2017) | To evaluate sustainable supply chain indicators, so that organizations can cultivate strategies to implement them as a priority. | Fuzzy AHP |
| 3 | (Verdecho, Rodriguez-rodriguez, Verdecho, Rodriguez-rodriguez, & Sustain-, 2017) | To monitor the progress of suppliers in relevant performance aspects and establishing action plans to improve performance. | AHP |
| 4 | (Chardine-Baumann & Botta-Genoulaz, 2014) | To improve performance, impacting the competitiveness of a company and of its supply chain organization. To evaluate and analyze the potential relationships between traditional supply chain management practices and their impact on performance. | Three level analytical assessment model for sustainable performance |
| 5 | (Qorri, Mujkić, & Kraslawski, 2018) | To develop a conceptual framework for measuring sustainability performance of supply chains. | Systematic literature review |
| 6 | (Badiezadeh, Saen, & Samavati, 2018) | To assess the sustainability of supply chain using big data. | Data envelopment analysis (DEA) |
| 7 | (Egilmez, Kucukvar, Tatari, & Bhutta, 2014) | To assess the Supply chain sustainability of the US food manufacturing sectors. | Economic Input-Output Life Cycle Assessment (EIO-LCA) and DEA approach |
| 8 | (P Ahi, 2014) | To develop a comprehensive approach for assessing sustainability performance at the company level and to develop an integrative sustainability performance framework for the broader supply chain | Systematic literature review and stochastic models |

| | | | |
|---|---|---|---|
| | | context. | |
| 9 | (Barros & Azevedo, 2016) | To propose a framework to assess and monitor sustainability in the automotive supply chain | Empirical/Case study |
| 10 | (Schöggl, Fritz, & Baumgartner, 2016) | To provide a conceptual framework for supply chain sustainability assessment. To provide an overview of available methods for assessment and propose approaches for aggregating sustainability indicators. | Systematic literature review and focus group workshops with experts. |
| 11 | (Denoël, 2015) | To find out how companies are measuring sustainability performance along the supply chain and how this process is managed. | Balanced Scorecard and case study. |

# CHAPTER 3

## THEORETICAL AND MATHEMATICAL FOUNDATION

The theoretical background in this work scopes over the topics of sustainability assessment and uncertainty analysis formulations. This chapter explains basic concepts in supply chain sustainability characterization and its assessment along with the detail of the method used in this research for sustainability assessment in supply chain.

### 3.1. Sustainability Assessment

Sustainability is a wide-ranging, complex, and debated topic (Wilkinson, A., Hill, M., & Gollan, 2001). There are complications when attempting to apply the principles of sustainability in practice, as the ambiguity and vagueness surrounds the definition of sustainability (WCED, 1987). Considering this, it is highly unlikely to produce a comprehensive metric or index of sustainability that would satisfy all the requirements exhibited by totally different philosophies (Spangenberg, 2005). Moreover, there is a major gap between the diffusion of sustainability discussions and its feasible applications (Hamdouch & Zuindeau, 2010). Sustainability is viewed as a broad and interdisciplinary approach incorporating environmental, economic and social issues at different scales (e.g., individual system, company, and supply chain).

Sustainability interpreted for business management as an inter-generational philosophical stand to a multi-dimensional expression. Assurance is made by the inter-generational philosophy position that future generations will not be negatively impacted by decisions that are made today. On the other hand, balancing the environmental, economic, and social dimensions of sustainability is the key concentration of the multi-dimensional view. In this view, sustainability builds interconnections among important subjects as well as dynamics within an organization or supply chain besides the aggregation of important subjects (Singh et al., 2012; Yakovleva, Sarkis, & Sloan, 2012). Multidimensionality characteristic of sustainability creates difficulty to monitor sustainability performance (Bodini, 2012). Though, a number of researches has been conducted on sustainability at regional and national level, and few attempts taken to design metrics at the level of individual system (e.g., supply chain), but the issue of uncertainty rarely been considered (Searcy, 2012).

Moreover, among different stakeholders, policy makers, although some of the developed metrics are accepted but most them are not generally used due to measurement, weighting and indicator selection problems (Singh, Murty, Gupta, & Dikshit, 2009). All these issues highlight the demand for additional research on the subject. It is also demonstrated that, there is a clear requirement for developing integrative frameworks that take all sustainability features into account for assessing the sustainability level of supply chains.

### 3.2. Evaluation Approach

The proposed approach for assessing the sustainability of supply chains involves three decision-making techniques, namely the AHP, D-S theory and Yager's recursive rule of combination. The AHP technique is used mainly to allocate weights or rate the selected criteria for sustainability assessment of supply chains. The D-S theory is used for data fusion or aggregating information. The D-S theory can treat incomplete, uncertain information in the form of basic probability assignments. On the other hand, Yager's recursive rule of combination is likely to that of D-S theory with some modification. Yager's rule is used to compare the outcomes of D-S theory. In detail these three techniques are described as follows:

#### 3.2.1. Analytic Hierarchy Process (AHP)

A multi-criteria decision-making technique proposed by Saaty (1990) is known as AHP. The steps of AHP are as follows;

1. Definition of the problem and determining the goals of the problem.
2. The hierarchical structuring from the top (objectives) through the intermediate levels (criteria) to the lowest level (alternatives).
3. Using the relative scale of measurement as shown in Table 3.1, construction of a set of pair-wise comparison matrices (size $n \times n$) is to perform for each of the lower levels with one matrix and thus for each element in the level immediately above. The pairwise comparisons are done in terms of preference of one element over the other.
4. To construct matrices for step 3 there are $n(n-1)/2$ judgments required per matrix. In the pair-wise comparison reciprocals are automatically assigned.

5. After performing all pair-wise comparisons, the consistency is determined by using the eigenvalue $\lambda_{max}$ to calculate the consistency index CI where CI= $(\lambda_{max-} n) / (n - 1)$, where n is the size of matrix. By seeing the value of consistency ratio CR for the accurate matrix value in Table 3.2, the consistency of judgment can be checked. The judgment matrix is acceptable if CR ≤ 0.1, otherwise it is considered inconsistent. To get a consistent matrix the judgements should be reviewed for improvement.
6. Now the hierarchical synthesis is used to weight the normalized eigenvectors by the weights of the criteria and the sum is taken over all weighted eigenvector entries corresponding to those in the next lower level of the hierarchy.

AHP allows the verification of transitivity property in criteria weights, that is if criteria 'a' has higher weight than criteria 'b' which has higher weight than criteria 'c', then criteria 'a' will always have higher weight than criteria 'c'. For this, AHP is chosen over other simple weight allocation techniques.

Table 3.1: Pairwise comparison scale for AHP preferences.

| Rating(s) | Verbal judgment of preferences |
|---|---|
| *1* | Equally preferred |
| *3* | Moderately preferred |
| *5* | Strongly preferred |
| *7* | Very strongly preferred |
| *9* | Extremely preferred |
| *2, 4, 6, 8* | Intermediate values between the two adjacent Judgments |
| Reciprocals | When activity *i* compared to j is assigned one of the above numbers, then activity *j* compared to i is assigned its reciprocal |

Table 3.2: Random consistency index (RI) value.

| Size of matrix | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* | *10* |
|---|---|---|---|---|---|---|---|---|---|---|
| RI | *0* | *0* | *0.58* | *0.9* | *1.12* | *1.24* | *1.32* | *1.41* | *1.45* | *1.49* |

### 3.2.2. Dempster–Shafer (D-S) Theory

A mathematical theory of evidence is the D-S theory. It is an expansion of Dempster (1967) through the seminal work on the subject by Shafer (1976). As a generalization of probability theory, the D-S theory can be interpreted, where probabilities are assigned to sets as opposed to mutually exclusive singletons. Evidence is associated with only one possible event in traditional probability theory. Whereas, evidence can be associated with multiple possible events, e.g., sets of events in D-S theory. For this, evidence in D-S theory becomes highly meaningful without having to resort to assumptions about the events within the evidential set. The D-S model collapses to the traditional probabilistic formulation where the evidence is enough to permit the assignment of probabilities to single events. The model of D-S theory is designed to cope with varying levels of precision regarding the information and no further assumptions are needed to represent the information, which is one of the most important features. Uncertainty, of system responses can also be represented with this approach. Here, an imprecise input can be characterized by a set or an interval and the resulting output is a set or an interval. For an example, if hypotheses include sets of: {low}, {medium} and {high}, D-S theory would enable probability to be assigned to an additional {low, medium} set. Similarly, D-S theory can additionally assign probability to interval hypotheses, if a cumulative distribution function is thought to contain a set of scalar hypotheses for a variable. As such, D-S theory enables a finer representation of uncertainty information compared to Bayesian theory, by formally allowing a more precise allocation of evidence to both disjoint and non-disjoint sets. D-S theory's frame of discernment reduces to that of a Bayesian characterization, if data consist of disjoint hypotheses. D-S theory possesses the advantage of handling conflict and incompleteness simultaneously in a formal unified framework.

This capability enables this framework for modeling uncertainties. By incorporating fuzzy membership functions within the framework of fuzzy D-S (FDS), Vagueness can be handled (Klir & Folger, 1988).

The fundamental set in D-S theory is the frame of discernment ($\Theta$) and consists of an exhaustive set of mutually exclusive hypotheses or propositions. For an example, for an attribute, 'Human rights' the set of propositions can be defined to include 'low' (L), 'medium' (M) or 'high' (H). Having the property of exhaustiveness, no other sets exist in the frame of discernment and the intersection between pairs of sets is a null set (e.g., $L \cap M = \emptyset$), i.e., they are mutually exclusive. The set of all possible subsets of $\Theta$ (including the empty set $\emptyset$) is defined as the power set, $2^{\Theta}$. As an example, if $\Theta$ (the frame of discernment) is comprised of three propositions, $\Theta = \{L, M, H\}$, its power set will consist of 8 subsets as follows:

$2^{\Theta} = \{\emptyset, \{L\}, \{M\}, \{H\}, \{L, M\}, \{M, H\}, \{L, H\}, \{L, M, H\}\}$.

The last subset ($\{L, M, H\} = \Theta$), among the subsets denotes complete ignorance as it fails to provide any specific information. In the power set of $\Theta$ each subset is called a focal element. Subsets can also be intervals, such as $\{[2.5\ 4]\}$ *or* $\{[4\ 17] \cup [22\ 35]\}$. Each focal element may be assigned a degree of belief $\in [0, 1]$, based on the evidence provided where *0* represents no belief and *1* represents a complete belief. The degree of belief for each proposition is termed a basic probability assignment (*bpa*), or mass function (*m*), e.g., $m(\{L, M\}) = 0.8$. D-S theory uses a generalized notion of probability termed a basic probability assignment *bpa*, or mass function, m. *bpa* is the proportion of all relevant and available evidence (such as empirical evidence or expert knowledge), that support a particular focal element. The *bpa* ranges between *0* and *1*.

Noted that *bpa* is not similar to the classical definition of probability. It is a mapping of the power set to the interval between *0* and *1*, where the summation of the *bpa*'s of all subsets (i.e., all possibilities) of the power set is 1, and the *bpa* of the null set is $m(\emptyset) = 0$ (Zhang et al., 2016). Followings are the properties of proposition $m(A)$:

$$\sum_{A \subseteq \Theta} m(A) = 1 \tag{3.1}$$

$$\forall A \subseteq \Theta \quad 0 \leq m(A) \leq 1 \tag{3.2}$$

Here, the probability of an event lies between 0 and 1 as per Equation (3.2). Suppose that on a frame of discernment $\Theta = \{L, M, H\}$ the evidence is $m(M) = 0.6$. According to Equation (3.1), the total *bpa* should *1*, therefore *0.4* is assigned to ignorance, i.e., $m(\Theta) = m(L, M, H) = 0.4$, and the remaining subsets have zero probability mass. In comparison to D-S theory, Bayesian theory equally distributes missing evidence to the remainder disjoint subsets (Laplace Principle of Insufficient Reason) while D-S theory requires all missing evidence to be assigned to ignorance.

Equation (3.1) corresponds to an exhaustive assumption which means that no other state than the universal set elements can possibly be achieved. If there is no relevant evidence to any focal element, then remainder *bpa* is assigned to ignorance ($\Theta$). And the summation of *bpa*'s of focal elements to equal to *1* as required by Equation (3.2). Belief is the lower bound for probability in D-S theory (as well as in other frameworks). For $A_i$ (a proposition of interest), the belief function is defined as the sum of all the *bpa*'s of the proper subsets $A_k$ of $A_i$, i.e., $A_k \subseteq A_i$ for proposition $A_i$. The basic relation between belief and *bpa* is expressed as:

$$bel\,(\mathrm{A_i}) = \sum_{\mathrm{A_k} \subseteq \mathrm{A_i}} m(A_k) \qquad (3.3)$$

The two other properties of belief function are:

$$\begin{cases} bel\,(\emptyset) = 0 \\ bel\,(\Theta) = 1 \end{cases} \qquad (3.4)$$

In Table 3.3, consider the frame of discernment is given and *bpa* are given in second row for intervals in the first row.

Table 3.3: Frame of discernments an example

| $A_i$ | Ø | [1.5 6] | [6 9] | [9 11.2] | [1.5 9] | [6 11.2] | [1.5 6] ∪ [9 11.2] | [1.5 11.2] |
|---|---|---|---|---|---|---|---|---|
| $m(A_i)$ | 0 | 0.5 | 0.3 | 0 | 0 | 0 | 0 | 0.2 |

For two focal elements the calculation of belief functions is shown below. For belief functions of the entire interval (see Table 3.2).

*bel ([1.5 6] ∪ [9 11.2]) = m ([1.5 6]) + m ([9 11.2]) = 0.5*

*bel ([1.5 11.2] = m ([1.5 6]) + m ([6 9]) + m ([9 11.2]) + m ([1.5 9]) + m ([6 11.2]) + m ([1.5 6] ∪ [9 11.2]) + m ([1.5 11.2]) = 1*

The plausibility is the upper bound of probability, which is the summation of *bpa*'s of all sets, $A_k$ that intersect with the set of interest, $A_i$, i.e., $A_k \cap A_i \neq \emptyset$. Plausibility is defined as:

$$pl(A_i) = \sum_{A_k \cap A_i \neq \emptyset} m(A_k) \qquad (3.5)$$

Through the doubt function belief and plausibility functions are linked to each other, defined as the complement of belief:

$$pl(A_i) = 1 - bel(\neg A_i) \qquad (3.6)$$

Where $\neg A_i$ is the complement of $A_i$. For belief and plausibility, it is also possible to derive the following relationships:

$pl\ (A_i) \geq bel\ (A_i);\ pl\ (\emptyset) = 0;\ pl\ (\Theta) = 1;\ pl\ (\neg A_i) = 1 - bel\ (A_i)$

Using the data from Table 3.1, the plausibility function for [1.5 6] can be derived as:

$Pl\ ([1.5\ 6]) = m\ ([1.5\ 6]) + m\ ([1.5\ 9]) + m\ ([1.5\ 6] \cup [9\ 11.2]) + m\ ([1.5\ 11.2]) = 0.7$

In similar fashion the calculated plausibility functions for all intervals is given in Table 3.4.

Table 3.4: The belief and plausibility functions for the example interval

| $A_i$ | ∅ | [1.5 6] | [6 9] | [9 11.2] | [1.5 9] | [6 11.2] | [1.5 6] ∪ [9 11.2] | [1.5 11.2] |
|---|---|---|---|---|---|---|---|---|
| $m(A_i)$ | 0 | 0.5 | 0.3 | 0 | 0 | 0 | 0 | 0.2 |
| $bel(A_i)$ | 0 | 0.5 | 0.3 | 0 | 0.8 | 0.3 | 0.5 | 1 |
| $pl(A_i)$ | 0 | 0.7 | 0.5 | 0.2 | 1 | 0.5 | 0.7 | 1 |

### 3.2.3. Dempster-Shafer (D-S) Rule of Combination

To aggregate multiple sources of information, the D-S theory can be used as a HER approach. Assume two bodies of evidence exist in $\Theta$, i.e., two basic probability assignments $m_1(A)$ and $m_2(A)$ to a subset $A \subseteq \Theta$. According to the D-S rule of combination the combined probability assignment, $m_{12}(A)$, is as follows:

$$m_{12}(A) = m_1(A) \oplus m_2(A)$$

$$= \begin{cases} 0 & \text{When, A}=\emptyset \\ \dfrac{\sum_{X\cap Y=A,\forall X,Y\subseteq\Theta} m_1(X)\, m_2(Y)}{1-K} & \text{When, A}\neq\emptyset \end{cases} \quad (3.7)$$

where, $K=\sum_{X\cap Y=\emptyset,\forall X,Y\subseteq\Theta} m_1(X)\, m_2(Y)$. Here, $m_{12}(A)$, (the combined mass probability assignment) for a subset $A$ is calculated from $m_1$ and $m_2$ by adding all products of the form '$m_1(X).m_2(Y)$' where $X$ and $Y$ are the subsets and their intersection is always $A$. Using factor $K$, the conflict between subsets $X$ and $Y$ is represented, where $X\cap Y=\emptyset$.

The commutative property of the D-S theory ensures that regardless of the order in which the two bodies of evidence are combined, the rule yields the same value (Nair et al., 2015). Therefore, for more than two bodies of evidence, the D-S rule can be generalized as,

$$m_{1,2,\ldots,M} = m_1 \oplus m_2 \oplus m_M \quad (3.8)$$

A generic sustainability HER framework is depicted in Figure 3.1, where, in the aggregation, $e^i_k$ is $i^{th}$ parameter, $S(e^i_k)$ is the evaluation for a parameter $e^i_k$, $m(e^i_k)$ is the basic probability assignment set for parameter $e^i_k$, and $\lambda^i_k$ is the normalized relative weight of parameter $e^i_k$ to attribute $E_k$.

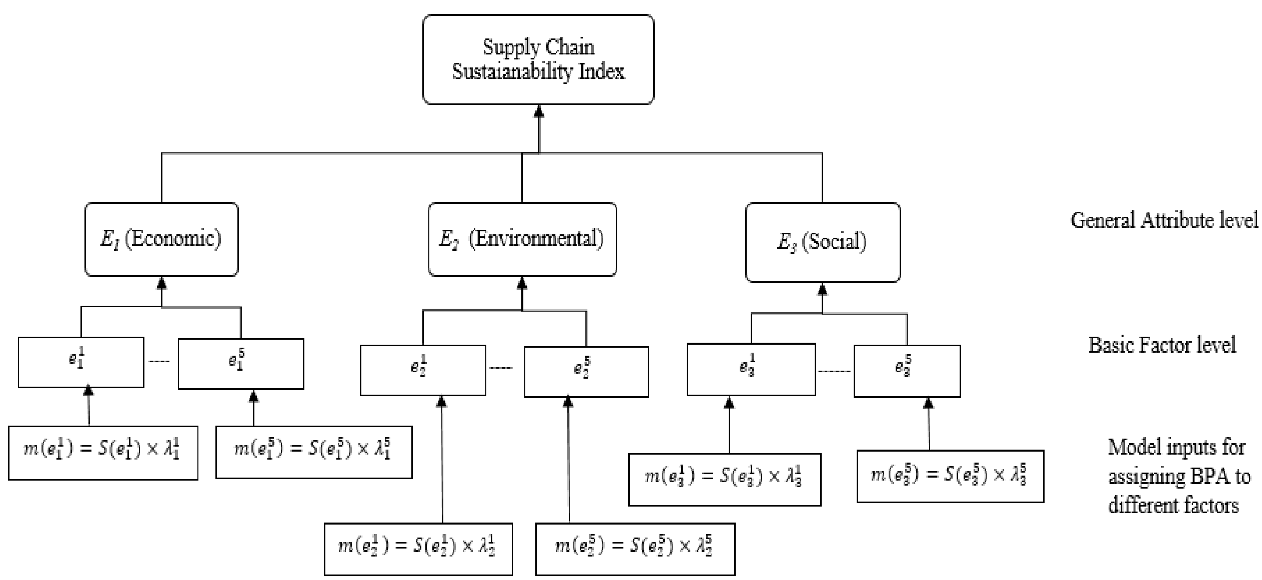


Figure 3.1: Generic supply chain sustainability framework for HER model.

The computational complexity will increase exponentially if the combination rule is directly used in Equation (3.8). Normally, to avoid this complexity the D-S rule of combination is used recursively. In this thesis, to the hierarchical framework the recursive D-S algorithm is applied, and the computations are performed according to Yang & Xu, (2002).

Let, a basic probability mass, $m_{n,i}$, representing the degree to which the $i^{th}$ basic attribute $e_i$ supports the hypothesis that attribute $e_i$ is assessed to the $n^{th}$ evaluation grade $H_n$. where, $H = \{H_1\ H_2 \ldots H_n \ldots H_N\}$. Using the following distribution or by Equation (3.9) an assessment for $e_i$ ($i = 1, 2 \ldots L$) of an alternative may be mathematically represented:

$$S(e_i) = \{(H_n, \beta_{n,i}), n = 1,2, \ldots, N\} \quad (3.9)$$

Where, $\beta_{n,i} \geq 0, \sum_{n=1}^{N} \beta_{n,i} \leq 1$ and $\beta_{n,i}$ represents a degree of belief. From the above distributed assessment, it is observed that the attribute $e_i$ is assessed to the grade $H_n$ with the degree of belief of $\beta_{n,i}$, $n= 1, 2\ldots N$. If $\sum_{n=1}^{N} \beta_{n,i} = 1$then the assessment $S(e_i)$ is complete and incomplete if $\sum_{n=1}^{N} \beta_{n,i} < 1$.

Let, $m_{H,I}$ be a remaining probability mass unassigned to any individual grade after all the $N$ grades have been considered for assessing the general attribute as far as $e_i$ is concerned. $m_{n,i}$ is calculated as follows:

$$m_{n,i}=\omega_i\beta_{n,i},\ n=1,2, \ldots N \quad (3.10)$$

Where, $\omega_i$ is weight for assessing an attribute $e_i$ or $E_i$ which should be normalized. $m_{H,i}$ is expressed by,

$$m_{H,i} = 1 - \sum_{n=1}^{N} m_{n,i} \quad (3.11)$$

As the subset of the first $i$ basic attributes $E_{I(i)}$ defined as follows:

$$E_{I(i)} = \{e_1 e_2 \ldots e_i\} \quad (3.12)$$

Let, a probability mass $m_{n,I(i)}$ is defined as the degree to which all the i. attributes in $E_{I(i)}$ support the hypothesis. Which means that y is assessed to the grade $H_n$. After all the basic attributes in

$E_{I(i)}$ have been assessed the remaining probability mass $m_{H,I(i)}$ is unassigned to individual grades. And in terms of the relative weights of attributes and the incompleteness in an assessment the remaining probability mass initially unassigned to any individual evaluation grades will be treated separately. In this way, the upper and lower bounds of the belief degrees can be generated using the concepts of the belief measure and the plausibility measure in the D-S theory of evidence. From other MCDA approaches this is one of the distinctive features of the HER approach.

According to the proposed rule by Jian Bo Yang (2001), a quantitative attribute can be assessed using numerical values (Yen, 1990). Here, to aggregate quantitative attribute with other qualitative attributes an equivalence rules need to be extracted from the decision maker to transform the value to an equivalent expectation. For a decision maker, it is fundamental to provide rules retaining each evaluation grade to a particular value to carry out transformation. Generally, suppose an attribute $e_i$ with a value $h_{n,I}$ is judged to be equivalent to a grade $H_n$. Then by the following equivalent expectation the value $h_j$ can be represented;

$$S(h_j) = \{(H_n, \beta_{n,j}), n = 1,2, \dots, N\} \tag{3.13}$$

where,

$$\beta_{n,j} = \frac{h_{n+1,i} - h_j}{h_{n+1,i} - h_{n,i}}, \beta_{n+1,j} = 1 - \beta_{n,j} \quad \text{if } h_{n,i} \le h_j \le h_{n+1,i} \tag{3.14}$$

$$\beta_{k,j} = 0 \quad \text{for, } k=1, 2 \dots N,\ k \neq n, n+1 \tag{3.15}$$

Here, the initially unassigned remaining probability mass to any individual grades is decomposed into two parts: i) $\bar{m}_{H,i}$and ii) $\tilde{m}_{H,i}$ , Where,

$$\bar{m}_{H,i} = 1 - \omega_i \tag{3.16}$$

$$\tilde{m}_{H,i} = \omega_i (1 - \sum_{n=1}^{N} \beta_{n,i}) \tag{3.17}$$

$$m_{H,i} = \bar{m}_{H,i} + \tilde{m}_{H,i} \tag{3.18}$$

In the remaining probability mass, $\bar{m}_{H,i}$is the first part, which is not yet assigned to individual grades. Because in the assessment the attribute $i$ (denoted by $e_i$) only plays one-part relative to its weight. $\bar{m}_{H,i}$ is a function of $\omega_i$ , which decrease linearly. If the weight of $e_i$ is zero or $\omega_i = 0$; $\bar{m}_{H,i}$will be '1', $\bar{m}_{H,i}$ will be '0' if $e_i$ complete the assessment or $\omega_i = 1$.$\bar{m}_{H,i}$ also represents the degree to which other attributes can make impact on the assessment. For this, $\bar{m}_{H,i}$ should be assigned eventually to individual grades in a way that is dependent upon how all attributes are weighted and assessed.

The second part of the remaining probability mass is $\tilde{m}_{H,i}$, which is unassigned to individual grades due to the incompleteness in the assessment *S(e<sub>i</sub>)*.If *S(e<sub>i</sub>)* is complete, or $\sum_{n=1}^{N} \beta_{n,i} = 1$then $\tilde{m}_{H,i}$ will be zero; otherwise, $\tilde{m}_{H,i}$ will be positive. $\omega_i$ is proportional to $\tilde{m}_{H,i}$ and will cause the subsequent assessments to be incomplete.

By aggregating (denoted by *⊕)* the assessments $S(e_i)$ and $S(e_j)$ as follows the combined probability masses are generated. Let by aggregating the first $i$ assessments the combined probability masses denoted by $m_{n,I(i)}$ ($n$=1,2, …, $N$), $\tilde{m}_{H,i}$ and $\bar{m}_{H,i}$ are generated. Then to combine the first $i^{th}$ assessments with the $(i+1)^{\text{th}}$ assessment the following HER algorithm is used in a recursive manner .

$$\{H_n\}: m_{n,I(i+1)} = K_{I(i+1)} [m_{n,I(i)} m_{n,i+1} + m_{H,I(i)} m_{n,i+1} + m_{n,I(i)} m_{H,i+1}] \quad (3.19)$$

$$m_{H,I(i)} = \bar{m}_{H,I(i)} + \tilde{m}_{H,I(i)} \quad n = 1,2, ..., N \quad (3.20)$$

$$\{H\}: \tilde{m}_{H,I(i+1)} = K_{I(i+1)} [\tilde{m}_{H,I(i)} \tilde{m}_{H,i+1} + \bar{m}_{H,I(i)} \tilde{m}_{H,i+1} + \tilde{m}_{H,I(i)} \bar{m}_{H,i+1}] \quad (3.21)$$

$$\{H_n\}: \bar{m}_{H,I(i+1)} = K_{I(i+1)} [\bar{m}_{H,I(i)} \bar{m}_{H,i+1}] \quad (3.22)$$

$$K_{I(i+1)} = \left[1 - \sum_{t=1}^{N} \sum_{\substack{j=1 \\ j \neq t}}^{N} m_{t,I(i)} m_{j,i+1}\right]^{-1} \quad i = 1, 2, ..., L-1 \quad (3.23)$$

Therefore, the incompleteness synthesis axiom can satisfy the terms $\bar{m}_{H,I(i)}\tilde{m}_{H,i+1}$ and $\tilde{m}_{H,I(i)}\bar{m}_{H,i+1}$ are assigned to $\tilde{m}_{H,I(i+1)}$, rather than to $\bar{m}_{H,I(i+1)}$. Using the following normalization process all $L$ assessments have been aggregated and the combined degrees of belief are generated by assigning $\bar{m}_{H,I(L)}$ proportionally back to all individual grades:

$$\{H_n\}: \beta_n = \frac{m_{n,I(L)}}{1 - \bar{m}_{H,I(L)}} \quad n = 1, 2, \ldots, N \quad (3.24)$$

$$\{H\}: \beta_H = \frac{\tilde{m}_{H,I(L)}}{1 - \bar{m}_{H,I(L)}} \quad (3.25)$$

In Equation (3.24), the $\beta_n$ refers to the likelihood to which $H_n$ is assessed. In Equation (3.25), the $\beta_H$ denotes the unassigned degree of belief representing the extent of incompleteness in the overall assessment.

In brief, for information acquisition and representation of the HER algorithm is composed of Equation (3.9), whereas Equations (3.10,), (3.11), (3.16) and (3.17) for basic probability assignments, (3.19) - (3.23) for aggregation of attributes, and (3.24) - (3.25) for computing combined degrees of belief.

With the following distribution in Equation (3.26), the generated assessment for $y$ similar to that of Equation (3.9) can be represented as;

$$S(y) = \{(H_n, \beta_{n,i}), n = 1,2, \dots, N\} \quad (3.26)$$

From Equation (3.26), it is observed that with the degree of belief of $\beta_n$ ($n$= 1, 2… N), y is assessed to the grade $H_n$.

### 3.2.4. Expected Utility and Utility Interval of the HER Approach

To show the difference between two assessments, there may be occasions where distributed descriptions are not sufficient. Therefore, numerical value generation equivalent to the distributed assessments in a sense is desirable. To define such values the concept of expected utility is used. The utility of the grade $H_n$ is supposed $u(H_n)$ with

$$u(H_{n+1}) > u(H_n) \quad \text{if } H_{n+1} \text{ is preferred to } H_n. \quad (3.27)$$

Using the probability assignment method or by constructing regression models, using partial rankings or pairwise comparisons $u(H_n)$ may be estimated (Yang & Xu, 2002). The value of $\beta_H$ will be zero, if all assessments are complete and precise, and for ranking alternatives the expected utility of the attribute y can be used, which is calculated as follows;

$$u(y) = \sum_{n=1}^{N} \beta_n u(H_n) \tag{3.28}$$

It is preferred an alternative 'a' to another alternative 'b' on y if and only if $u(y(a)) > u(y(b))$.

The value of $\beta_H$ become positive, if any assessment for the basic attribute is incomplete. The $\beta_n$ given in (3.24) represents the belief measure in the D-S theory, within the HER assessment framework and thus provides the lower bound of the likelihood to which y is assessed to $H_n$ (J. Yang & Xu, 2002). On the other hand, plausibility measure expresses the upper bound of the likelihood (Yen, 1990). The plausibility measure for $H_n$ within the HER evaluation framework is given by $(\beta_n + \beta_H)$. Thus, the range of the likelihood to which y may be assessed to $H_n$ is provided by the belief interval $[\beta_n, (\beta_n + \beta_H)]$. If all assessments are complete, then the interval will reduce to a point $\beta_n$.

It is obvious that if any basic assessment is incomplete, the likelihood to which y may be assessed to $H_n$ is not unique and can be anything in the interval $[\beta_n, (\beta_n + \beta_H)]$. For this, three measures named minimum, maximum and average expected utilities are defined to characterize the assessment for y.

Assuming $H_1$ is the least evaluation grade with lowest utility and $H_n$ the most preferred grade having the highest utility. Here, the maximum, minimum and average expected utilities on y are sequentially expressed by the following equations:

$$u_{max}(y) = \sum_{n=1}^{N-1} \beta_n u(H_n) + (\beta_N + \beta_H) u(H_N) \tag{3.29}$$

$$u_{min}(y) = (\beta_1 + \beta_H) u(H_1) + \sum_{n=2}^{N} \beta_n u(H_n) \tag{3.30}$$

$$u_{avg}(y) = \frac{u_{max}(y) + u_{min}(y)}{2} \tag{3.31}$$

If the assessments $S(e_i)$ are complete, then $\beta_H = 0$ and $u(y) = u_{max}(y) = u_{min}(y) = u_{avg}(y)$. It is noted that, for characterizing an assessment the above utilities are used but not for the aggregation attribute.

Based on their utility intervals the ranking of two alternatives$a_l$ and$a_k$is performed. The $a_l$ is said to be indifferent to $a_k$ if and only if $u_{min}(y(a_l)) = u_{min}(y(a_k))$ and $u_{max}(y(a_l)) = u_{max}(y(a_k))$; and $a_l$is said to be preferred to$a_k$on y if and only if $u_{min}(y(a_l)) > u_{max}(y(a_k))$. Otherwise, to generate a ranking average expected utility may be used. Here, if $u_{avg}(y(a_l)) > u_{avg}(y(a_k))$ but $u_{max}(y(a_k)) > u_{min}(y(a_l))$, then it could be concluded that $a_l$ is preferred to $a_k$ on an average basis. However, as there is a chance that $a_k$ may have higher utility than $a_l$, so, this ranking is not reliable. In such cases, the quality of the original assessments must be improved by reducing incompleteness present in the original assessments associated with $a_l$ and $a_k$ to generate a reliable ranking. It is noted that, there is no need to improve the quality of information related to other alternatives to clarify the relationship between $a_l$ and $a_k$.

### 3.2.5. Yager's Rule of Combination:

In this study, Yager's recursive combination technique similar to that of previously stated D-S rule of combination is applied in this study for assessment of attributes. The only difference between the Yager and D-S rule is the elimination of normalization by non-conflicting evidence. The conflicting evidence represented by the factor 'K' is shifted to ignorance during data combination (Tesfamariam, Sadiq & Najjaran, 2010). The only modified Equations of D-S theory in Yager rule of combination can be generalized for multiple parameters as follows:

$$\{H_n\}: m_{n,I(i+1)} = [m_{n,I(i)} m_{n,i+1} + m_{H,I(i)} m_{n,i+1} + m_{n,I(i)} m_{H,i+1}] \tag{3.32}$$

$$m_{H,I(i)} = \bar{m}_{H,I(i)} + \tilde{m}_{H,I(i)} \quad n = 1,2, \ldots N \tag{3.33}$$

$$\{H\}: \tilde{m}_{H,I(i+1)} = [\tilde{m}_{H,I(i)} \tilde{m}_{H,i+1} + \bar{m}_{H,I(i)} \tilde{m}_{H,i+1} + \tilde{m}_{H,I(i)} \bar{m}_{H,i+1}] \tag{3.34}$$

$$\{H_n\}: \bar{m}_{H,I(i+1)} = K_{I(i+1)} + [\bar{m}_{H,I(i)} \bar{m}_{H,i+1}] \tag{3.35}$$

where,

$$K_{I(i+1)} = \sum_{t=1}^{N} \sum_{\substack{j=1 \\ j \neq t}}^{N} m_{t,I(i)} m_{j,i+1} \quad i = 1, 2, \ldots, L-1 \tag{3.36}$$

### 3.3. Sensitivity Analysis

Sensitivity analysis can determine how sensitive is the overall decision to small changes in the individual weights assigned during the pair-wise comparison process (Awasthi, A., & Chauhan, S. S., 2011). By slightly changing, the values of the weights and observing the impacts on the decision this question can be answered. It is suitable in situations where uncertainties exist in the definition of the importance of different attributes. In this study, sensitivity analysis is used to analyze the importance of criteria weights on supply chain sustainability performance for both methods of D-S theory and Yager's rule of combination. To investigate the effect on final decision-making process, other parameters can also be varied in sensitivity analysis. Such as, change in the belief values or change in the utility values of information sources. In this thesis, sensitivity analysis is performed in a unified manner as change in criteria weights.

# CHAPTER 4

## SUPPLY CHAIN SUSTAINABILITY MODEL DEVELOPMENT

### 4.1. Problem Statement and Methodology

The HER approach is suitable to assess sustainability in supply chain of the organizations. Because the data required for sustainability assessment in supply chain of are in qualitative and quantitative form. Subjective judgements are also required for such assessment where remains incomplete information and vagueness. As sustainability assessment concerned with the multiple criteria for this the incorporation of HER approach as a powerful tool to deal with MCDM under uncertainties is very much congenial and contemporary decision. As a HER technique D-S evidence theory advocates a multi-level hierarchy in the evaluation process. This is an evaluation analysis model and decision theory. The D-S method so far is capable of handling MCDM problems with uncertainties, incommensurable units, mixture of qualitative and quantitative attributes, as well as mixture of deterministic and probabilistic attributes (Shan, 2015). The main advantages of the D-S theory are;

- To deal with uncertainty (aleatory and epistemic), incomplete and conflicting data as well as complete and precise data.
- To offer the users of D-S theory to provide judgments both in qualitatively and quantitively.
- To consider uncertainties and risk associated with the assessment procedure.
- As a structured approach, to provide a logical, impartial and recursive method for data aggregation of an assessment.

This thesis proposes supply chain sustainability assessment model under epistemic uncertainty based on belief structure. In this sustainability assessment framework, the algorithm of supply chain sustainability model consists of some key phases which are: preliminary phase, data collection phase, supply chain sustainability measurement phase and result comparison phase. In a brief, to assess supply chain sustainability the key phases have to follow to implement the proposed sustainability assessment model as shown in Figure 4.1.

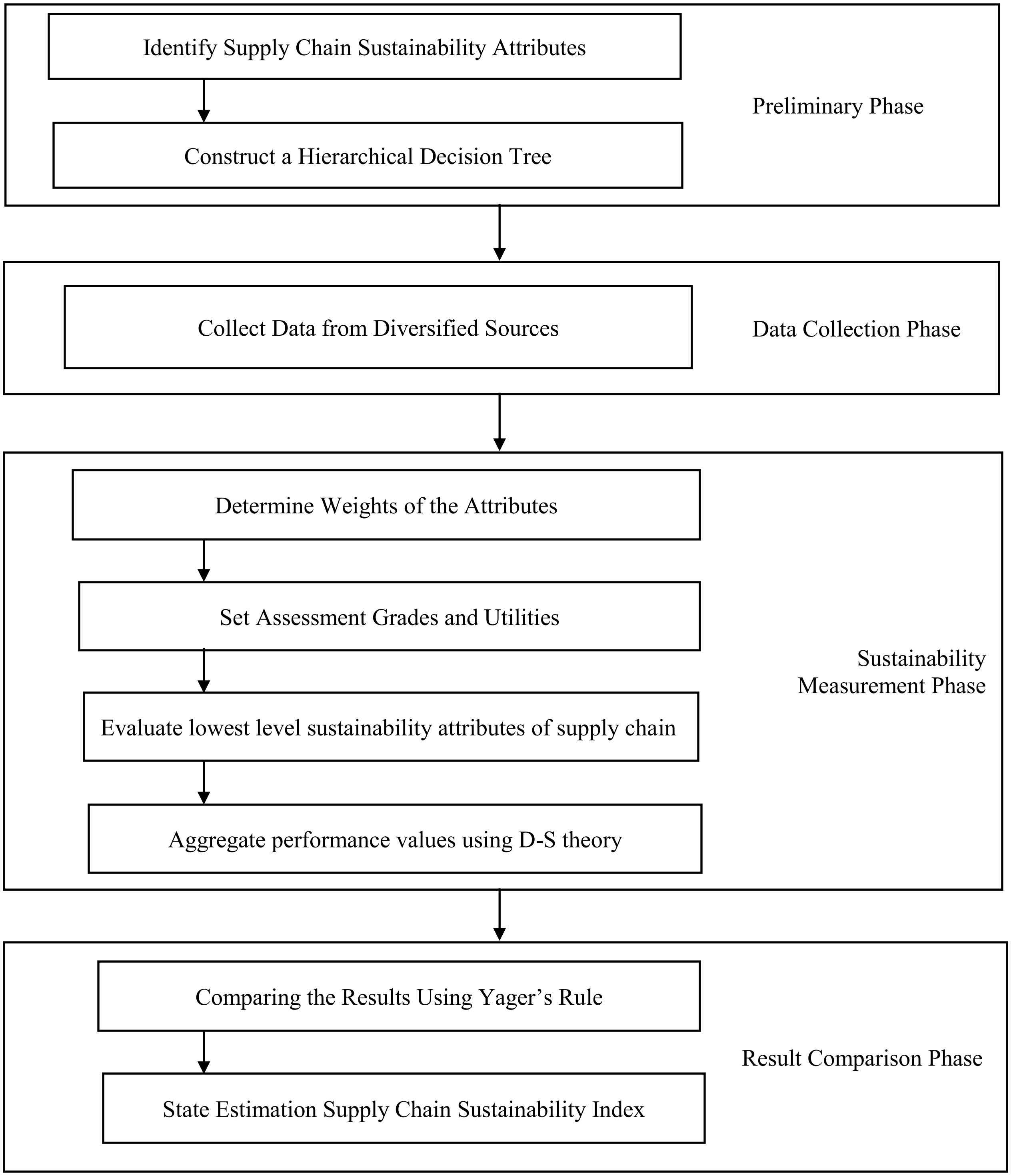


Figure 4.1: Proposed framework of sustainability assessment in supply chain.

The details of the supply chain sustainability assessment methodology are described as follows:

#### 4.1.1. Preliminary Phase

##### 4.1.1.1. Identify supply chain sustainability attributes

Supply Chain Sustainability attributes are identified through literature review and experts' opinion. The review process is conducted on scientific papers, which are extracted from the on line databases of 'SCOPUS'. Studying the abstract and skimming content of each paper the review is performed. In this study, the total number of paper reviewed is 245 based on keyword analysis in the relevant domain. Respondents with relevant experience, including sustainability managers, consultants, industry associates, academics, and stakeholder are selected to obtain opinion regarding sustainability attributes. The details of the respondents are provided in the appendix.

##### 4.1.1.2. Construct a hierarchical decision tree

The identified attributes are categorized into general and basic level. In this research, under the three general attributes of supply chain sustainability fifteen basic attributes are selected. Using the identified attributes, a three-level hierarchical decision tree is formed to fully depict supply chain sustainability.

#### 4.1.2. Data collection Phase

##### 4.1.2.1 Collect data from relevant sources

For assessing sustainability in the supply chain, it is often hard to obtain a sufficient amount of historical and statistical data. Therefore, in this research, experts' or respondent's judgements are used for assessing sustainability in a supply chain. Diverse respondents should be used to reduce the bias of the assessments. To indicate respondents from different backgrounds and sectors, the term diversified is used.

#### 4.1.3. Sustainability measurement Phase

##### 4.1.3.1. Determine weights of the attributes

As different attributes have varied impact on the sustainability, for this weight are introduced into the supply chain sustainability assessment model. Based on the respondents' knowledge, experience and expertise, using the AHP method, the weights of the general and basic attributes are determined and assigned.

#### 4.1.3.2. Set assessment grades and utilities

To assess sustainability the evaluation grades generally known as assessment standards need to be defined. Based on the requirement of the problem at hand it is identified what kind of standards should be used. In the literature, the most common and preferred evaluation grades are: Poor (P), Fairly Poor (F), Average (A), Good (G), and Excellent (E) (Kong, Xu, Yang, & Ma, 2015). For simplicity reasons, in this study the same set of evaluation grades has been used. Using utility in a unified manner the evaluation grades of supply chain sustainability assessment attributes can be quantified as $u(P) = 0$, $u(F) = 0.25$, $u(A) = 0.50$, $u(G) = 0.75$, and $u(E) = 1$.

#### 4.1.3.3. Evaluate lowest level sustainability attributes

In the sustainability decision tree or hierarchical structure, the sub factors of general attributes are termed as lowest level attributes. The key dimensions are expressed by these attributes of lowest level. To assess the sustainability of a supply chain, evaluation of these attributes is a key concern for an organization. The basic attributes are judged subjectively by expert or concerned manager based on the condition state of the attributes. Basic probability assignments (bpa) or degrees of belief are assigned to the evaluation grades by the respondent based on available knowledge or information, by judging the attributes condition.

#### 4.1.3.4. Aggregate performance values using D-S theory

For data fusion or information aggregation, D-S theory is used. The D-S rule of combination is commutative and associative in nature. Therefore, evidence or performance values comes from the expert judgement on different attributes can be combined in any order due to the inherent properties of the D-S rule. So, the combination of evidence or belief can be carried out in a pair wise approach in the case of multiple belief structures.

### 4.1.4. Result comparison Phase

#### 4.1.4.1. Comparing the results using Yager's rule

To compare the results from the D-S theory, the Yager rule is applied. Yager's recursive rule of combination is similar to that of D-S theory with some modifications. The elimination of normalization by non-conflicting evidence is the only difference in Yager rule.

**4.1.4.2. State estimation Supply Chain Sustainability index**

Using the utilities of evaluation grades and weights of the attributes, the supply chain sustainability index value is calculated for both D-S theory and Yager's rule. Form the sustainability index value overall condition state of an organization can be expressed based on the performance of sustainability attributes. In this stage, sensitivity analysis can be conducted to identify changes in the results with respect to the changes in attributes weights.

## 4.2. Supply Chain Sustainability Assessment Model Formulation

To ensure better measurement accuracy, the HER scoring method is adopted to support multiple criteria decision making under uncertainty. The assessment is performed by a belief decision matrix where attributes are aggregated using the HER algorithm. For this, to represent an assessment the HER approach applies a belief structure (Guo, Yang, Chin, & Wang, 2007; J. B. Yang, Wang, Xu, & Chin, 2006). In this study, $H_n$ is used to represent the evaluation grades and the assessment of sub-criterion $e_i$, whereby $S(e_i)$ is represented as follows:

$$S(e_1) = \{(H_1, \beta_{1,1}), (H_2, \beta_{2,1}), (H_3, \beta_{3,1}), (H_4, \beta_{4,1}), (H_5, \beta_{5,1})\} \quad (4.1)$$

where $H_n$ is an evaluation grade, $\beta_{n,1}$ denotes the degree of belief that $e_1$ is assessed to an evaluation grade $H_n$, which satisfies $1 \geq \beta_{n,1} \geq 0$ and $\sum_{n=1}^{5} \beta_{n,1} \leq 1$. An assessment is completed when $\sum_{n=1}^{5} \beta_{n,1} = 1$, and incomplete when $\sum_{n=1}^{5} \beta_{n,1} < 1$. Incomplete assessment is common as assessments are subjective and the evidence for assessments can be incomplete, vague and uncertain. Unlike the conventional scoring approaches, using the belief structure, assessors are not forced to make a complete judgment when they are not 100 percent sure about the subjective judgments or when evidence is not complete. Moreover, instead of a single average score the belief structure enables the representation of an assessment as a distribution (Lam, Chin, Yang, & Liang, 2007). In this way, more accurately assessors can make judgments.

### 4.2.1. Overview of Supply Chain Sustainability Attributes

To assess sustainability a set of attributes need to be carefully identified initially. In this research, by reviewing literature and getting feedback from the experts' supply chain sustainability attributes are identified. The attributes are categorized into two categories such as general attributes and basic attributes. General attributes are branched into basic attributes. In this research, three general attributes and fifteen basic attributes (lowest level attribute) are selected and proposed to develop the hierarchical structure. This hierarchical structure is used to assess the sustainability in supply chain. The general attributes are economic sustainability, environmental sustainability and social sustainability whereas the basic attributes are profitability, market competitiveness, research & development expenditures, local procurement, operating costs, energy efficiency, water management, waste management, supplier assessment, emissions, human rights, health and safety, training and education, consumer issues, and supplier relationship. The selected attributes are summarized in Table 4.1. The representation of the variables, information sources and optimization required to the different attributes are also shown here. On the other hand, in the Table 4.2 the simplified meanings of all the identified attributes is defined. The simplified meanings of the attributes express the concerned sustainability performance indicators (SPIs).

Table 4.1: Overview of the selected attributes

| Attribute | Representation | Source | Optimize* |
|---|---|---|---|
| Economic sustainability | Qt (General) | (E; Q) | Maximize |
| Profitability | Qt (Basic) | (E; Q) | Maximize |
| Market competitiveness | Qt (Basic) | (E; Q) | Maximize |
| Research & development expenditures | Qt (Basic) | (E; Q) | Minimize |
| Local procurement | Qt (Basic) | (E; Q) | Maximize |
| Operating costs | Qt (Basic) | (E; Q) | Minimize |
| Environmental sustainability | Qt (General) | (E; Q) | Maximize |
| Energy efficiency | Qt (Basic) | (E; Q) | Maximize |
| Waste management | Qt (Basic) | (E; Q) | Maximize |
| Water management | Qt (Basic) | (E; Q) | Maximize |
| Supplier assessment | Ql (Basic) | (E; Q) | Maximize |

| | | | |
|---|---|---|---|
| Emissions | Qt (Basic) | (E; Q) | Minimize |
| Social sustainability | Qt (General) | (E; Q) | Maximize |
| Human rights | Ql (Basic) | (E; Q) | Maximize |
| Health and safety | Qt (Basic) | (E; Q) | Maximize |
| Training and education | Qt (Basic) | (E; Q) | Maximize |
| Consumer issues | Qt (Basic) | (E; Q) | Minimize |
| Supplier relationship | Ql (Basic) | (E; Q) | Maximize |

E: experts' opinions, Q: questionnaire, Qt: quantitative, and Ql: qualitative.

*Optimization deals with whether low or a high value for a given attribute is suitable.

Table 4.2: Simplified meanings of sustainability attribute categories

| General attributes | Basic attributes | Simplified meanings | References |
|---|---|---|---|
| Economic | | | |
| | Profitability | It illustrates the financial health of an organization. This attribute category classifies information related to total sales/ revenue and operating profit. | (A. Azapagic, 2003), (Adisa Azapagic, 2004), (Moullin, 2007) |
| | Market Competitiveness | It deals with the information related to an organization's economic performances as compared to its competitors in the same market. It classifies SPIs related to an organizations market share performances, the offering of competitive wages and the earning per share performance. | (A. Azapagic, 2003), (Cho, Lee, Ahn, & Hwang, 2012) |
| | Research & Development expenditures | It describes and considers an organization's economic performance in terms of organization's expenditures on research and development for a particular period of time. | (Payman Ahi, Searcy, & Jaber, 2016), (Roca & Searcy, 2012) |
| | Local procurement | It describes the percentage of procurement budget spent on local suppliers. | (Hervani, Helms, & Sarkis, 2005) |
| | Operating costs | It deals with information related to the total annual operating cost of the organization. | (Adisa Azapagic, 2004), (Hervani et al., 2005) |
| Environmental | | | |

| | | | |
|---|---|---|---|
| | Energy Efficiency | It expresses information related to the total energy consumption from all forms of renewable as well as non-renewable energy sources and specific energy consumption within an organization. | (Payman Ahi et al., 2016), (A. Azapagic, 2003), (IChem, 2002), (Morali & Searcy, 2013) |
| | Waste Management | It deals with the information related to all forms of waste produced and recycled by an organization i.e. the total waste produced, total hazardous waste produced, and the total amount of waste recycled. | (Adisa Azapagic, 2004), (Hassini et al., 2012). |
| | Water Management | It describes all forms of water consumption and classifies SPIs related to the total water consumption as well as the total water discharge and the quality of water discharge. | (Adisa Azapagic, 2004), (Moullin, 2007), (Tanzil & Beloff, 2006). |
| | Supplier assessment | It deals with the information related to suppliers' environmental performance and their selection criteria. It classifies SPIs that measure supplier sustainability related performance and number of local or national suppliers. | (A. Azapagic & Perdan, 2000; Hassini et al., 2012; Roca & Searcy, 2012) |
| | Emissions | It deals with the information related to all forms of emissions by an organization and classifies SPIs related to the total GHHs emission (direct and indirect GHHs), ozone-depleting substances, VOCs, Nox, Sox, and particulate matters. | (A. Azapagic, 2003; GRI, 2013; Moullin, 2007). |
| Social | | | |
| | Human Rights | It deals with the information related to the violation of basic human rights. It classifies SPIs related to incidents of discrimination, forced and child labor, corruption and violation of the rights to the freedom association. | (Adisa Azapagic, 2004; Kozlowski, Searcy, & Bardecki, 2015; Moullin, 2007). |
| | Health and Safety | It describes information regarding health and safety issues related to the work in an organization. It classifies SPIs related to the number of injuries and illness, days lost due to occupational injuries, and fatalities with the work. | (Adisa Azapagic, 2004; Kozlowski et al., 2015; Roca & Searcy, 2012) |

| | | | |
|---|---|---|---|
| | Training and Education | It deals with training and education opportunities provided to employees. It classifies SPIs related to the number of employees given training and the hours of training provided to both male and female employees of the organization. | (A. Azapagic, 2003; Adisa Azapagic, 2004) |
| | Consumer Issues | It classifies information related to consumer issues such as consumer's complaints, product returns, and incidents of misleading, deceptive or fraudulent information to the consumer by an organization. | (A. Azapagic, 2003; Cho et al., 2012; Roca & Searcy, 2012) |
| | Supplier Relationship | Supplier relationship is important issue of social sustainability and it deals with the business practices related to supplier selection, supplier evaluation and supplier development. Thus, companies should play role by considering sustainable elements in combination with suppliers. | (Schiele, 2007) |

### 4.2.2. Structuring the Hierarchy for Sustainability Assessment in Supply Chains

With literature review and taking experts' opinion, the hierarchical structure for assessing sustainability in supply chain is proposed. In this structure, some general and basic attributes are used as sustainability performance indicators. The hierarchical structure is depicted in Figure 4.1. Level 1 in the structure indicates the goal, being the supply chain sustainability index. Level 2 in the hierarchy expresses three general assessment attributes, known as economic sustainability index, environmental sustainability index and social sustainability index. Level 3 illustrates the lowest level attributes in the hierarchy which are decomposed from the three general attributes.

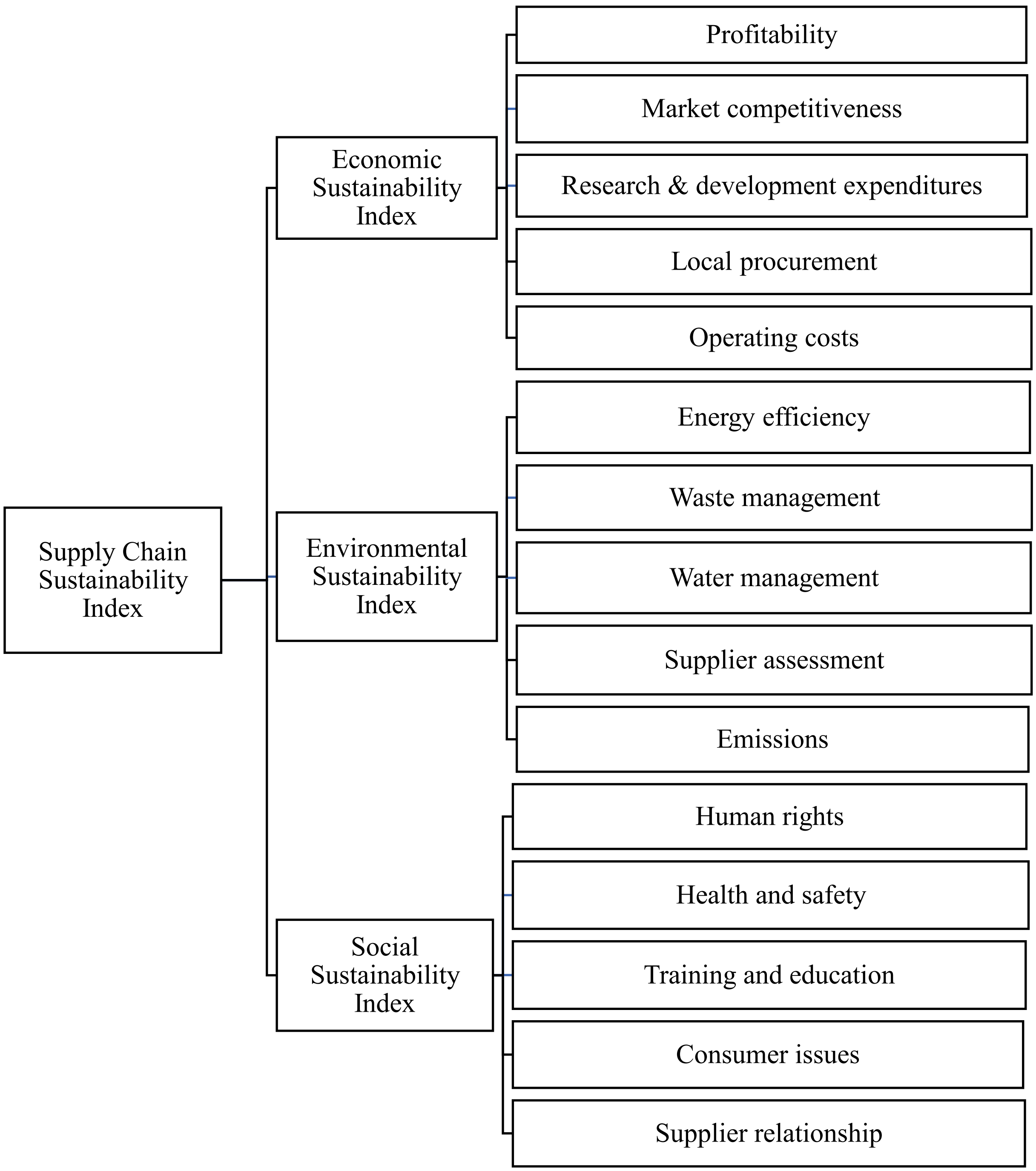


Figure 4.2: Proposed hierarchical representation of supply chain sustainability attributes.

# CHAPTER 5

## NUMERICAL EXAMPLE

In this chapter, a numerical example of the sustainability assessment of supply chains for the organization is presented to demonstrate the applicability of the proposed methodology.

### 5.1. Attributes' Weights and Assessment Grades with Utility

In the sustainability assessment process in supply chain, the identified attributes usually have different degrees of importance and play different roles in sustainability. Some of them are crucial, some of them are very important, and accordingly, some of them are less important as per their impact on supply chain sustainability. In this study, to set weights of the selected attributes, the AHP technique is utilized for processing relevant data. With the help of the expert's opinion or inputs, the weights are determined. The selected experts have practical concepts in the field of supply chain sustainability. Experts' feedback or opinion is collected through interview-based survey, e-mail communication and telephonic discussion using a questionnaire as given in the Appendix A. Focusing on several themes, the interview protocol is prepared based on questionnaires. The pairwise comparison relation matrices are formed by using the Saaty scale through experts' opinion for both of the general and basic attributes. Then by processing the pairwise comparison data using AHP, the weightage value for different attributes is computed, and thus the weights of all general and basic attributes are assigned. In Table 5.1, the weights of all attributes are illustrated.

Table 5.1: Weights of the attributes

| Attributes | | Weight |
|---|---|---|
| Economic Sustainability | | 0.63 |
| | Profitability | 0.46 |
| | Market competitiveness | 0.14 |
| | Research & development expenditures | 0.06 |
| | Local procurement | 0.08 |
| | Operating costs | 0.26 |

| | | |
|---|---|---|
| Environmental Sustainability | | 0.20 |
| | Energy efficiency | 0.44 |
| | Waste management | 0.20 |
| | Water management | 0.13 |
| | Supplier assessment | 0.08 |
| | Emissions | 0.15 |
| Social Sustainability | | 0.17 |
| | Human rights | 0.45 |
| | Health and safety | 0.22 |
| | Training and education | 0.13 |
| | Consumer issues | 0.09 |
| | Supplier relationship | 0.11 |

Moreover, for assessing supply chain sustainability the evaluation grades generally known as assessment standards need to be defined. It is found in literature that, depending on the problem several types of evaluation grades are proposed or defined. In some research, 0 or 1 (i.e., yes or no) have been used as a rating concept, some used good and worst to express the performances, whilst others used assessment grades of: good, fair, and poor. So, based on the requirement of the problem at hand it is identified what kind of standards should be used. In the literature the most used and preferred evaluation grades are: Poor (P), Fairly Poor (F), Average (A), Good (G), and Excellent (E) (Kong et al., 2015). For simplicity reasons, in this study the same set of evaluation grades has been used.

In this research, using utility in a unified manner the evaluation grades of supply chain sustainability assessment attributes can be quantified as follows:

$u(H_1) = u(Poor) = 0$

$u(H_2) = u(Fairly\ Poor) = 0.25$

$u(H_3) = u(Average) = 0.5$

$u(H_4) = u(Good) = 0.75$

$u(H_5) = u(Excellent) = 1$

The hierarchy of sustainability assessment in supply chain possesses identified attributes in different levels. The results of the overall assessments can be obtained by combining the assessments of the lowest level attributes in the hierarchical structure. In this study, the hierarchical evidential reasoning scoring method is able to integrate both complete and incomplete assessments by combining the degree of belief of lower level attributes considering the weightage value (Yang & Xu, 2002). The assessment is performed based on evaluation analysis model and combination rule of D-S theory. Then the assessment results are compared using Yager's recursive rule of combination.

### 5.2. Data Collection

This study includes an organization producing homogenous products. The D-S theory is considered to be the most suitable for sustainability assessment in supply chain as the selected organization is in the same business. Most of the organizations in the studied region are concerned with garments or textiles and contribute to the national economy. Therefore, assessment of supply chain sustainability of this sector is very crucial because the management should be aware of sustainability issues for strategic decision-making to survive in the competitive business environment.

With extensive communication with the management of some deliberately selected organizations and exploring the websites of the organizations, it is found that few organizations are producing sustainability reports or maintaining organized data structure. In this study, a garments company is selected for assessing sustainability in supply chains. Supply chain sustainability concept is at initial stage to these organizations. In this research, the selected organization recently started to maintain records on sustainability dimensions and generating a report. The selected organization belongs a sustainability department with a team. The interview-based survey is performed to obtain the required data. The expert has to provide a degree of belief or basic probability assignment data on evaluation grades or on sets of evaluation grades as required by the theory used in this thesis.

The required belief data or degrees of confidence are directly collected from the respondents. To collect belief data for different attributes eighteen experts along with the top management or decision makers and stakeholders are selected from the studied organization. The profile of the experts is provided in Appendix B and C. The experts provide relevant data about the sustainability attributes based on available knowledge or information. Based on the panel consensus of the experts the final data for the assessment are generated. In this process, educated guesses by the experts are also crucial. To list the data for selected attributes, the data sheet is developed. Based on the subjective judgments, the data are generated for different attributes as per the evaluation grades assigned in the model. For example, in Table 5.2, for the basic attribute 'Human rights' the data is set as (Good, 1.0), which states that the degree to which the evidence supports these evaluation grades or condition states is 100%, Good. These subjective judgements are assigned to the grades or condition states by considering the performance of the organization regarding 'Human rights' (i.e. no forced labor, no child labor, non-discrimination, and freedom of association). On the other hand, as a quantitative attribute, 'health and safety' is subjectively judged on evaluation grades based on performance criteria like the number of injuries and illness, days lost due to occupational injuries, and fatalities at the work-place. Thus, in judging the performance or condition of the measures of the attributes, the total or a portion of the belief exactly in the evaluation grade is collected and assigned for the selected attributes. As such, subjective judgments of the attributes of social Sustainability with degrees of belief on different evaluation grades are presented in Table 5.2.

Table 5.2: Subjective judgments for assessing social sustainability

| | Degree of belief (β) | Evaluation Grades | | | | |
|---|---|---|---|---|---|---|
| | | Poor | Fairly Poor | Average | Good | Excellent |
| Basic Attribute | Human rights (%) | 0 | 0 | 0 | 1.0 | 0 |
| | Health and safety (%) | 0 | 0.3 | 0.7 | 0 | 0 |
| | Training and education (%) | 0.2 | 0.3 | 0.4 | 0 | 0 |
| | Consumer issues (%) | 0 | 0 | 0.5 | 0.5 | 0 |
| | Supplier relationship (%) | 0 | 0 | 0 | 0.6 | 0.4 |

Using the distributions as defined in Equation (4.1) and grades defined in the previous chapter, the above five assessments can be represented as follows:

*S (Human rights) = {(good,1.0)}* 5.1

*S (Health and safety) = {(fairly poor, 0.3), (average, 0.7)}* 5.2

*S (Training and education) = {(poor, 0.2), (fairly poor, 0.3), (average, 0.4)}* 5.3

*S (Consumer issues) = {(average, 0.5), (good, 0.5)}* 5.4

*S (Supplier relationship) = {(good, 0.6), (excellent, 0.4)}* 5.5

In the distributions, only the grades with nonzero degrees of belief are listed. From the five assessments, it is observed that an assessment of 5.3 is not complete and it expresses 90% basic probability assignment (bpa) whereas the remaining 10% bpa refers to the ignorance according to the theory. In terms of the basic attributes, other assessment information is illustrated in Table 5.3. In Table 5.3, the evaluation grades namely poor, fairly poor, average, good, and excellent, are abbreviated as P, F, A, G, and E, respectively, and a number in a bracket denotes a degree of belief to which an attribute is assessed to a grade. For instance, G (0.9) refers "good to a degree of 0.9 (90%)."

Table 5.3: Generalized decision matrix for assessments

| General Attributes | | Basic Attributes | Information |
|---|---|---|---|
| Supply Chain Sustainability Index | Economic Sustainability (0.63) | Profitability (0.46) | G (1.0) |
| | | Market competitiveness (0.14) | A (0.3), G (0.7) |
| | | Research & development expenditures (0.06) | P (0.4), F (0.3), G (0.3) |
| | | Local procurement (0.08) | F (0.2), A (0.8) |
| | | Operating costs (0.26) | G (0.6), E (0.4) |
| | Environmental Sustainability (0.2) | Energy efficiency (0.44) | A (1) |
| | | Waste management (0.2) | P (0.2), F (0.8) |
| | | Water management (0.13) | G (0.7), E (0.3) |
| | | Supplier assessment (0.08) | F (0.5), A (0.5) |
| | | Emissions (0.15) | A (1.0) |
| | Social Sustainability (0.17) | Human rights (0.45) | G (1.0) |
| | | Health and safety (0.22) | F (0.3), A (0.7) |
| | | Training and education (0.13) | P (0.2), F (0.3), A (0.4) |
| | | Consumer issues (0.09) | A (0.5), G (0.5) |
| | | Supplier relationship (0.11) | G (0.6), E (0.4) |

### 5.3. Combination of Assessments Using Dempster-Shafer (D-S) Theory

The judgments as depicted in Table 5.1 or in Equations 5.1-5.5 could be combined to assess the social sustainability. It is assumed from Table 5.1 that the value of social sustainability should be good enough. To make a precise assessment, the relative importance of the five attributes must be assigned. So, the derived weights of each attribute are used from Table 5.2.

Dempster-Shafer recursive rule of combination is applied here as a hierarchical evidential reasoning algorithm. In the first step of calculation, assessment is performed to get social sustainability value (y) by combining five basic attributes: human rights, health and safety, training and education, consumer issues, and supplier relationship, as illustrated in Equations 5.1-5.5 and denoted by $e_1, e_2, e_3, e_4, e_5$, , respectively. As defined in Equation 3.12, let $y = e_1 \oplus e_2 \oplus e_3 \oplus e_4 \oplus e_5$, where, the aggregation of two attributes is denoted by $\oplus$. Then, the degree of beliefs can be acquired from Equations 5.1-5.5 and Equation 3.9. After that, to obtain the probability masses, the degrees of belief are multiplied with the corresponding weights of the attribute using Equations 3.10, 3.11, 3.16-3.18. Now to calculate the combined probability masses the recursive Equations 3.19-3.23 is used. Let $m_{n,I(1)} = m_{n,1}$ for $n = 1, 2 \dots 5$. Firstly, two attributes human rights, and health and safety have to be combined using these Equations. Then, in the second step training and education is to be combined with the results of human rights, and health and safety. After that in the third step consumer issues is to be combined with the second step output. And finally, supplier relationship is to be combined with the third step output. The combined degrees of belief are then calculated from Equations 3.24 and 3.25. The assessment of social sustainability by aggregating human rights, health and safety, training and education, consumer issues, and supplier relationship, is represented by the following distribution according to Equation (3.26);

$$S(Social\ Sustainability) = S(human\ rights \oplus health\ and\ safety \oplus training\ and\ education \oplus consumer\ issues \oplus supplier\ relationship)$$

= {(poor, 0.02), (fairly poor, 0.08), (average, 0.21), (good, 0.65), (excellent, 0.03)}

Therefore, the degree of confidence for the social sustainability condition ‘good’ is the highest. However, this sustainability condition rating assessment is only based on information from one of the three general attributes.

Now, the assessment of environmental sustainability by aggregating Energy efficiency, Waste management, Water management, Supplier assessment, and Emissions is represented by the following distribution according to Equation (3.26);

$$S(Environmental\ Sustainability) = S(Energy\ efficiency \oplus Waste\ management \oplus Supplier\ assessment \oplus Water\ management \oplus Emissions)$$

= {(poor, 0.03), (fairly poor, 0.15), (average, 0.73), (good, 0.06), (excellent, 0.03)}

Therefore, the degree of confidence for the environmental sustainability condition ‘average’ is the highest. Similarly, the assessment of economic sustainability by aggregating profitability, market competitiveness, research & development expenditures, local procurement, operating costs is represented by the following distribution according to Equation (3.26);

$$S(Economic\ Sustainability) = S(Profitability \oplus Market\ competitiveness \oplus Research\ \&\ development\ expenditures \oplus Local\ Procurement \oplus Operating\ costs)$$

= {(poor, 0.01), (fairly poor, 0.02), (average, 0.08), (good, 0.81), (excellent, 0.08)}

Here, the degree of confidence for the economic sustainability condition ‘good’ is the highest.

To determine the assessment grades of the higher level, the same calculation procedure is followed at each level of the hierarchy. Thus, the final assessment values are found for the supply chain sustainability index of an organization. To ascertain overall supply chain sustainability, all three general attributes are combined as follows to obtain the overall confidence rating.

$$S(Supply\ Chain\ Sustainability) = S(Economic\ sustainability \oplus Environmental\ Sustainability \oplus SocialSustainability)$$

= {(poor, 0.01), (fairly poor, 0.04), (average, 0.16), (good, 0.72), (excellent, 0.06)}

The final assessment grades are then calculated using Equation (3.29) and (3.30) and the utility value of the evaluation grades mentioned in Chapter 4, to get the index value in a single quantitative value. Using Equations 3.29 and 3.30 a range of final result is found, which is denoted by $U_{max}$ and $U_{min}$. If there remains uncertainty in the data, then the calculation generates a range of the final index. Usually for the simplicity of the assessment purpose an average value of these ranges is used. Here the value of $U_{max}$ and $U_{min}$ remain same if there is no uncertainty. Thus, sustainability index of supply chain is obtained for an organization using Dempster-Shafer theory. The results are shown and discussed in the following chapter. It is noted that changing the order of combining the five basic attributes does not change the result at all. The calculation of data combining procedure is depicted as follows.

### 5.3.1. Interpretative Evaluation of Social Sustainability Index Using D-S Theory

The evaluation grade wise subjective judgment or condition rating $S(e_k^i)$ for each basic attribute under general attribute of social sustainability is collected as a belief in percentage or degree of confidence $(H_n, \beta_{n,i})$, where

$S(e_3^1)$ = *{(P, 0.00), (F, 0.00), (A, 0.00), (G, 1.00), (E, 0.00)}*

$S(e_3^2)$ = *{(P, 0.00), (F, 0.30), (A, 0.70), (G, 0.00), (E, 0.00)}*

$S(e_3^3)$ = *{(P, 0.20), (F, 0.30), (A, 0.40), (G, 0.00), (E, 0.00)}*

$S(e_3^4)$ = *{(P, 0.00), (F, 0.00), (A, 0.50), (G, 0.50), (E, 0.00)}*

$S(e_3^5)$ = *{(P, 0.00), (F, 0.00), (A, 0.00), (G, 0.60), (E, 0.40)}*

Here, sequentially the symbol *P, F, G, A* and *E* refers poor, fairly poor, average, good and excellent, to represent the condition state or evaluation grade.

The relative weights of the basic attributes contributing to the general attribute $E_3$ are:

$\lambda_3$ = $\{\lambda_3^1, \lambda_3^2, \lambda_3^3, \lambda_3^4, \lambda_3^5\}$ = {0.45, 0.22, 0.13, 0.09, 0.11}

The condition ratings are multiplied by the weights to get BPA, $m(e_3^i)$. Here, the difference between one and the summation of weighted degrees of belief or condition ratings denotes the epistemic uncertainty or ignorance *(H).* The aggregation of the basic attributes representing the general attribute (i.e. social sustainability index) is as follows:

Social sustainability index = $S(e_3^1) \times \lambda_3^1 \oplus S(e_3^2) \times \lambda_3^2 \oplus S(e_3^3) \times \lambda_3^3 \oplus S(e_3^4) \times \lambda_3^4 \oplus S(e_3^5) \times \lambda_3^5$

Therefore, the basic probability assignments (BPAs) for each basic attribute are as follows:

$$m_{3,1} = \{m_{3,1}^{H_n}, m_{3,1}^{H}\} = \{0.00, 0.00, 0.00, 0.45, 0.00, 0.55\}$$

$$m_{3,2} = \{m_{3,2}^{H_n}, m_{3,2}^{H}\} = \{0.00, 0.07, 0.15, 0.00, 0.00, 0.78\}$$

$$m_{3,3} = \{m_{3,3}^{H_n}, m_{3,3}^{H}\} = \{0.026, 0.039, 0.052, 0.00, 0.00, 0.883\}$$

$$m_{3,4} = \{m_{3,4}^{H_n}, m_{3,4}^{H}\} = \{0.00, 0.00, 0.045, 0.045, 0.00, 0.91\}$$

$$m_{3,5} = \{m_{3,5}^{H_n}, m_{3,5}^{H}\} = \{0.00, 0.00, 0.00, 0.066, 0.044, 0.89\}$$

Using the D-S theory the combined probability assignments is computed as follows. As per the property of D-S theory initially let, $m_{I_3(1)} = m_{3,1}$. Now, using D-S rule of combination aggregation of first two basic attributes is performed as follows:

$$K_{I_3(2)} = \left(1 - \sum_{s=1}^{4} \sum_{l=1, l\neq s}^{4} m_{I_3(1)}^{s} m_{3,2}^{l}\right)^{-1}$$

$$= \left[1 - (0 + \cdots + 0 + m_{3,1}^{H_4} m_{3,2}^{H_2} + m_{3,1}^{H_4} m_{3,2}^{H_3} + 0 + m_{3,1}^{H_5} m_{3,2}^{H_2} + m_{3,1}^{H_5} m_{3,2}^{H_3} + 0\right]^{-1}$$

$$= [1 - (0.45 \times 0.00 + 0.45 \times 0.066 + 0.45 \times 0.154 + 0.45 \times 0.00)]^{-1} = 1.11$$

Therefore, the combined BPAs for the first two basic attributes are:

$$m_{I_3(2)}^{H_1} = K_{I_3(2)}\left(m_{3,1}^{H_1} m_{3,2}^{H_1} + m_{3,1}^{H_1} m_{3,2}^{H} + m_{3,1}^{H} m_{3,2}^{H_1}\right)$$

$$= 1.11 \times (0 + 0.00 \times 0.78 + 0.55 \times 0.00) = 0.00$$

$$m_{I_3(2)}^{H_2} = K_{I_3(2)}\left(m_{3,1}^{H_2} m_{3,2}^{H_2} + m_{3,1}^{H_2} m_{3,2}^{H} + m_{3,1}^{H} m_{3,2}^{H_2}\right)$$

$$= 1.11 \times (0.00 \times 0.066 + 0.00 \times 0.78 + 0.55 \times 0.066) = 0.04$$

$$m_{I_3(2)}^{H_3} = K_{I_3(2)}\left(m_{3,1}^{H_3} m_{3,2}^{H_3} + m_{3,1}^{H_3} m_{3,2}^{H} + m_{3,1}^{H} m_{3,2}^{H_3}\right)$$

$= 1.11 \times (0.00 \times 0.154 + 0.00 \times 0.78 + 0.55 \times 0.154) \; = 0.09$

$m^{H_4}_{I_3(2)} = K_{I_3(2)}\left(m^{H_4}_{3,1} m^{H_4}_{3,2} + m^{H_4}_{3,1} m^{H}_{3,2} + m^{H}_{3,1} m^{H_4}_{3,2}\right)$

$= 1.11 \times (0.45 \times 0.00 + 0.45 \times 0.78 + 0.55 \times 0.00) \; = 0.39$

$m^{H_5}_{I_3(2)} = K_{I_3(2)}\left(m^{H_5}_{3,1} m^{H_5}_{3,2} + m^{H_5}_{3,1} m^{H}_{3,2} + m^{H}_{3,1} m^{H_5}_{3,2}\right)$

$= 1.11 \times (0.00 \times 0.00 + 0.00 \times 0.78 + 0.55 \times 0.00) \; = 0.00$

$m^{H}_{I_3(2)} = K_{I_3(2)}\left(m^{H}_{3,1} m^{H}_{3,2}\right) = 1.11 \times (0.55 \times 0.78) = 0.48$

In the second stage, the combining of the above results is performed with the BPAs of third attributes as follows,

$K_{I_3(3)} = \left(1 - \sum_{s=1}^{4} \sum_{l=1, l \neq s}^{4} m^{s}_{I_3(2)} m^{l}_{3,3}\right)^{-1}$ = 1.06

Therefore, for three basic attributes the combined BPAs are;

$m^{H_1}_{I_3(3)} = K_{I_3(3)}\left(m^{H_1}_{I_3(2)} m^{H_1}_{3,3} + m^{H_1}_{I_3(2)} m^{H}_{3,3} + m^{H}_{I_3(2)} m^{H_1}_{3,3}\right) = 0.01$

$m^{H_2}_{I_3(3)} = K_{I_3(3)}\left(m^{H_2}_{I_3(2)} m^{H_2}_{3,3} + m^{H_2}_{I_3(2)} m^{H}_{3,3} + m^{H}_{I_3(2)} m^{H_2}_{3,3}\right) = 0.06$

$m^{H_3}_{I_3(3)} = K_{I_3(3)}\left(m^{H_3}_{I_3(2)} m^{H_3}_{3,3} + m^{H_3}_{I_3(2)} m^{H}_{3,3} + m^{H}_{I_3(2)} m^{H_3}_{3,3}\right) = 0.12$

$m^{H_4}_{I_3(3)} = K_{I_3(3)}\left(m^{H_4}_{I_3(2)} m^{H_4}_{3,3} + m^{H_4}_{I_3(2)} m^{H}_{3,3} + m^{H}_{I_3(2)} m^{H_4}_{3,3}\right) = 0.36$

$m^{H_5}_{I_3(3)} = K_{I_3(3)}\left(m^{H_5}_{I_3(2)} m^{H_5}_{3,3} + m^{H_5}_{I_3(2)} m^{H}_{3,3} + m^{H}_{I_3(2)} m^{H_5}_{3,3}\right) = 0.00$

$m^{H}_{I_3(3)} = K_{I_3(3)} m^{H}_{I_3(2)} m^{H}_{3,3} = 0.44$

In step three, the combining of fourth basic attribute's BPAs is performed with the output BPAs from the second stage and then the results are found as,

$K_{I_3(4)} = 1.03$,

Here, the combined BPAs of four basic attributes are:

$m^{H_1}_{I_3(4)}$ = 0.01, $m^{H_2}_{I_3(4)}$ = 0.06, $m^{H_3}_{I_3(4)}$ = 0.14, $m^{H_4}_{I_3(4)}$ = 0.38, and $m^{H_5}_{I_3(4)}$ = 0.00,

$m^{H}_{I_3(4)}$= 0.41

Finally, in step four following the calculation procedure as in step three the combining of the above results with the fifth attributes is performed to get the combined BPAs of the five basic attributes as follows:

$K_{I_3(5)} = 1.04,$

Here, the combined BPAs of five basic attributes of social sustainability are as follows:

$m_{I_3(5)}^{H_1} = 0.01, m_{I_3(5)}^{H_2} = 0.05, m_{I_3(5)}^{H_3} = 0.13, m_{I_3(5)}^{H_4} = 0.40$, and $m_{I_3(5)}^{H_5} = 0.02,$

$m_{I_3(5)}^{H} = 0.38$

Now, using the following normalization process all $L$ assessments are aggregated and the combined degrees of belief are generated for the social sustainability index by assigning $\bar{m}_{H,I(L)}$ proportionally back to all individual evaluation grades or condition states;

$\{H_n\}: \beta_n = \frac{m_{n,I(L)}}{1-\bar{m}_{H,I(L)}}$ $n = 1, 2, \ldots, N$

Where, $\{H_1\}: \beta_1 = \frac{m_{1,I(5)}}{1-\bar{m}_{H,I(5)}}$

$\{H_1\}: \beta_1 = \frac{0.01}{1-0.38}$ = 0.02, similarly it is found that, $\beta_2$= 0.08, $\beta_3$= 0.21, $\beta_4$= 0.65, $\beta_5$= 0.03

Therefore, the final condition rating for the social sustainability index ($E_3$) is {(poor, 0.02), (fairly poor, 0.08), (average, 0.21), (good, 0.65), (excellent, 0.03)}. In this process the conflict does not contribute much to the combined data, as the conflict between the data is normalized by $K$ which might be valuable for good decision making. It is found that the degree of confidence for the evaluation grade or condition state 'Good' is 65%, which is the highest in the social sustainability index.

Using the following equation, the degree of belief of associated uncertainty or unassigned degree of belief is calculated as follows:

$\{H\}: \beta_H = \frac{\tilde{m}_{H,I(L)}}{1-\bar{m}_{H,I(L)}} = \frac{0.01}{1-0.38} = 0.0092$

It is found from the D-S theory-based calculation that, for the social sustainability index the unassigned degree of belief is 0.92%.

### 5.3.2. Interpretative Evaluation of Environmental Sustainability Index Using D-S Theory

The evaluation grade wise subjective judgment or condition rating $S(e_k^i)$ for each basic attribute under general attribute of environmental sustainability is collected as a belief in percentage or degree of confidence $(H_n, \beta_{n,i})$, where

$S(e_2^1)$ = *{(P, 0.00), (F, 0.00), (A, 1.00), (G, 0.00), (E, 0.00)}*

$S(e_2^2)$ = *{(P, 0.20), (F, 0.80), (A, 0.00), (G, 0.00), (E, 0.00)}*

$S(e_2^3)$ = *{(P, 0.00), (F, 0.00), (A, 0.00), (G, 0.70), (E, 0.30)}*

$S(e_2^4)$ = *{(P, 0.00), (F, 0.50), (A, 0.50), (G, 0.00), (E, 0.00)}*

$S(e_2^5)$ = *{(P, 0.00), (F, 0.00), (A, 1.00), (G, 0.00), (E, 0.00)}*

Here, sequentially the symbol *P, F, G, A* and *E* refers poor, fairly poor, average, good and excellent, to represent the condition state or evaluation grade.

The relative weights of the basic attributes contributing to the general attribute $E_2$ are:

$\lambda_2 = \{\lambda_2^1, \lambda_2^2, \lambda_2^3, \lambda_2^4, \lambda_2^5\} = \{0.44, 0.20, 0.13, 0.08, 0.15\}$

The condition ratings are multiplied by the weights to get BPA, $m(e_2^i)$. The aggregation of the basic attributes representing the general attribute (i.e. environmental sustainability index) is as follows:

Environmental sustainability index $= S(e_2^1) \times \lambda_2^1 \oplus S(e_2^2) \times \lambda_2^2 \oplus S(e_2^3) \times \lambda_2^3 \oplus S(e_2^4) \times \lambda_2^4 \oplus S(e_2^5) \times \lambda_2^5$

Therefore, the basic probability assignments (BPAs) for each basic attribute are as follows:

$$m_{2,1} = \{m_{2,1}^{H_n}, m_{2,1}^{H}\} = \{0.00, 0.00, 0.44, 0.00, 0.00, 0.56\}$$

$$m_{2,2} = \{m_{2,2}^{H_n}, m_{2,2}^{H}\} = \{0.04, 0.16, 0.00, 0.00, 0.00, 0.80\}$$

$$m_{2,3} = \{m_{2,3}^{H_n}, m_{2,3}^{H}\} = \{0.00, 0.00, 0.00, 0.091, 0.039, 0.87\}$$

$$m_{2,4} = \{m_{2,4}^{H_n}, m_{2,4}^{H}\} = \{0.00, 0.04, 0.04, 0.00, 0.00, 0.92\}$$

$$m_{2,5} = \{m_{2,5}^{H_n}, m_{2,5}^{H}\} = \{0.00, 0.00, 0.15, 0.00, 0.00, 0.85\}$$

Using the D-S theory the combined probability assignments is computed as follows. As per the property of D-S theory initially let, $m_{I_2(1)} = m_{2,1}$. Now, using D-S rule of combination aggregation of first two basic attributes is performed as follows:

$$K_{I_2(2)} = \left(1 - \sum_{s=1}^{4} \sum_{l=1, l \neq s}^{4} m_{I_2(1)}^{s} m_{2,2}^{l}\right)^{-1}$$

$$= \left[1 - (0 + \cdots + 0 + m_{2,1}^{H_4} m_{2,2}^{H_2} + m_{2,1}^{H_4} m_{2,2}^{H_3} + 0 + m_{2,1}^{H_5} m_{2,2}^{H_2} + m_{2,1}^{H_5} m_{2,2}^{H_3} + 0\right]^{-1}$$

$$= [1 - (0.44 \times 0.04 + 0.44 \times 0.16)]^{-1} = 1.10$$

Therefore, the combined BPAs for the first two basic attributes are:

$$m_{I_2(2)}^{H_1} = K_{I_2(2)}\left(m_{2,1}^{H_1} m_{2,2}^{H_1} + m_{2,1}^{H_1} m_{2,2}^{H} + m_{2,1}^{H} m_{2,2}^{H_1}\right)$$

$$= 1.10 \times (0 \times 0.04 + 0.00 \times 0.8 + 0.04 \times 0.56) = 0.02$$

$$m_{I_2(2)}^{H_2} = K_{I_2(2)}\left(m_{2,1}^{H_2} m_{2,2}^{H_2} + m_{2,1}^{H_2} m_{2,2}^{H} + m_{2,1}^{H} m_{2,2}^{H_2}\right) = 0.10$$

$$m_{I_2(2)}^{H_3} = K_{I_2(2)}\left(m_{2,1}^{H_3} m_{2,2}^{H_3} + m_{2,1}^{H_3} m_{2,2}^{H} + m_{2,1}^{H} m_{2,2}^{H_3}\right) = 0.39$$

$$m_{I_2(2)}^{H_4} = K_{I_2(2)}\left(m_{2,1}^{H_4} m_{2,2}^{H_4} + m_{2,1}^{H_4} m_{2,2}^{H} + m_{2,1}^{H} m_{2,2}^{H_4}\right) = 0.00$$

$$m_{I_2(2)}^{H_5} = K_{I_2(2)}\left(m_{2,1}^{H_5} m_{2,2}^{H_5} + m_{2,1}^{H_5} m_{2,2}^{H} + m_{2,1}^{H} m_{2,2}^{H_5}\right) = 0.00$$

$$m_{I_2(2)}^{H} = K_{I_2(2)}\left(m_{2,1}^{H} m_{2,2}^{H}\right) = 1.10 \times (0.56 \times 0.80) = 0.49$$

In the second stage, the combining of the above results is performed with the BPAs of third attributes as follows,

$$K_{I_2(3)} = \left(1 - \sum_{s=1}^{4} \sum_{l=1, l \neq s}^{4} m_{I_2(2)}^{s} m_{2,3}^{l}\right)^{-1} = 1.07$$

Therefore, for three basic attributes the combined BPAs are;

$$m_{I_2(3)}^{H_1} = K_{I_2(3)}\left(m_{I_2(2)}^{H_1} m_{2,3}^{H_1} + m_{I_2(2)}^{H_1} m_{2,3}^{H} + m_{I_2(2)}^{H} m_{2,3}^{H_1}\right) = 0.02$$

$$m_{I_2(3)}^{H_2} = K_{I_2(3)}\left(m_{I_2(2)}^{H_2} m_{2,3}^{H_2} + m_{I_2(2)}^{H_2} m_{2,3}^{H} + m_{I_2(2)}^{H} m_{2,3}^{H_2}\right) = 0.09$$

$$m_{I_2(3)}^{H_3} = K_{I_2(3)}\left(m_{I_2(2)}^{H_3} m_{2,3}^{H_3} + m_{I_2(2)}^{H_3} m_{2,3}^{H} + m_{I_2(2)}^{H} m_{2,3}^{H_3}\right) = 0.36$$

$$m_{I_2(3)}^{H_4} = K_{I_2(3)}\left(m_{I_2(2)}^{H_4} m_{2,3}^{H_4} + m_{I_2(2)}^{H_4} m_{2,3}^{H} + m_{I_2(2)}^{H} m_{2,3}^{H_4}\right) = 0.05$$

$m_{I_2(3)}^{H_5} = K_{I_2(3)} \left( m_{I_2(2)}^{H_5} m_{2,3}^{H_5} + m_{I_2(2)}^{H_5} m_{2,3}^{H} + m_{I_2(2)}^{H} m_{2,3}^{H_5} \right) = 0.02$

$m_{I_2(3)}^{H} = K_{I_2(3)} m_{I_2(2)}^{H} m_{2,3}^{H} = 0.46$

In step three, the combining of fourth basic attribute's BPAs is performed with the output BPAs from the second stage and then the results are found as,

$K_{I_2(4)} = 1.03$,

Here, the combined BPAs of four basic attributes are:

$m_{I_2(4)}^{H_1} = 0.02$, $m_{I_2(4)}^{H_2} = 0.11$, $m_{I_2(4)}^{H_3} = 0.37$, $m_{I_2(4)}^{H_4} = 0.05$, and $m_{I_2(4)}^{H_5} = 0.02$,

$m_{I_2(4)}^{H}$= 0.43

Finally, in step four following the calculation procedure as in step three the combining of the above results with the fifth attributes is performed to get the combined BPAs of the five basic attributes as follows:

$K_{I_2(5)} = 1.03$,

Here, the combined BPAs of five basic attributes of social sustainability are as follows:

$m_{I_2(5)}^{H_1} = 0.02$, $m_{I_2(5)}^{H_2} = 0.10$, $m_{I_2(5)}^{H_3} = 0.45$, $m_{I_2(5)}^{H_4} = 0.04$, and $m_{I_2(5)}^{H_5} = 0.02$,

$m_{I_2(5)}^{H}$= 0.38

Now, using the following normalization process all $L$ assessments are aggregated and the combined degrees of belief are generated for the environmental sustainability index by assigning $\bar{m}_{H,I(L)}$ proportionally back to all individual evaluation grades or condition states;

$\{H_n\}$: $\beta_n = \frac{m_{n,I(L)}}{1-\bar{m}_{H,I(L)}}$ $n = 1, 2, \ldots, N$

Where, $\{H_1\}$: $\beta_1 = \frac{m_{1,I(5)}}{1-\bar{m}_{H,I(5)}}$

$\{H_1\}$: $\beta_1 = \frac{0.02}{1-0.38}$ = 0.03, similarly it is found that, $\beta_2$= 0.15, $\beta_3$= 0.73, $\beta_4$= 0.06, $\beta_5$= 0.03

Therefore, the final condition rating for the environmental sustainability index ($E_2$) is {(poor, 0.03), (fairly poor, 0.15), (average, 0.73), (good, 0.06), (excellent, 0.03)}. In this process the conflict does not contribute much to the combined data, as the conflict between the data is normalized by *K* which might be valuable for good decision making. It is found that the degree of confidence for the evaluation grade or condition state 'average' is 73%, which is the highest in the social sustainability index.

Using the following equation, the degree of belief of associated uncertainty or unassigned degree of belief is calculated as follows:

$$\{H\}: \beta_H = \frac{\tilde{m}_{H,I(L)}}{1-\tilde{m}_{H,I(L)}} = \frac{0.00}{1-0.38} = 0.00$$

It is found from the D-S theory-based calculation that, for the environmental sustainability index the unassigned degree of belief is 0.00%.

**5.3.3. Interpretative Evaluation of Economic Sustainability Index Using D-S Theory**

The evaluation grade wise subjective judgment or condition rating $S(e_k^i)$ for each basic attribute under general attribute of economic sustainability is collected as a belief in percentage or degree of confidence $(H_n, \beta_{n,i})$, where

$S(e_1^1)$ = *{(P, 0.00), (F, 0.00), (A, 0.00), (G, 1.00), (E, 0.00)}*

$S(e_1^2)$ = *{(P, 0.00), (F, 0.00), (A, 0.30), (G, 0.70), (E, 0.00)}*

$S(e_1^3)$ = *{(P, 0.40), (F, 0.30), (A, 0.30), (G, 0.00), (E, 0.00)}*

$S(e_1^4)$ = *{(P, 0.00), (F, 0.20), (A, 0.80), (G, 0.00), (E, 0.00)}*

$S(e_1^5)$ = *{(P, 0.00), (F, 0.00), (A, 0.00), (G, 0.60), (E, 0.40)}*

Here, sequentially the symbol *P, F, G, A* and *E* refers poor, fairly poor, average, good and excellent, to represent the condition state or evaluation grade.

The relative weights of the basic attributes contributing to the general attribute $E_1$ are:

$\lambda_1 = \{\lambda_1^1, \lambda_1^2, \lambda_1^3, \lambda_1^4, \lambda_1^5\}$ = {0.46, 0.14, 0.06, 0.08, 0.26}

The condition ratings are multiplied by the weights to get BPA, $m\left(e_1^i\right)$. Here, the difference between one and the summation of weighted degrees of belief or condition ratings denotes the ignorance *(H)*. The aggregation of the basic attributes representing the general attribute (i.e. economic sustainability index) is as follows:

Economic sustainability index = $S(e_1^1) \times \lambda_1^1 \oplus S(e_1^2) \times \lambda_1^2 \oplus S(e_1^3) \times \lambda_1^3 \oplus S(e_1^4) \times \lambda_1^4 \oplus S(e_1^5) \times \lambda_1^5$

Therefore, the basic probability assignments (BPAs) for each basic attribute are as follows:

$m_{1,1} = \left\{m_{1,1}^{H_n}, m_{1,1}^{H}\right\} = \{0.00, 0.00, 0.00, 0.46, 0.00, 0.54\}$

$m_{1,2} = \left\{m_{1,2}^{H_n}, m_{1,2}^{H}\right\} = \{0.00, 0.00, 0.042, 0.098, 0.00, 0.86\}$

$m_{1,3} = \left\{m_{1,3}^{H_n}, m_{1,3}^{H}\right\} = \{0.024, 0.018, 0.018, 0.00, 0.00, 0.94\}$

$m_{1,4} = \left\{m_{1,4}^{H_n}, m_{1,4}^{H}\right\} = \{0.00, 0.016, 0.064, 0.00, 0.00, 0.92\}$

$m_{3,5} = \left\{m_{1,5}^{H_n}, m_{1,5}^{H}\right\} = \{0.00, 0.00, 0.00, 0.156, 0.104, 0.74\}$

Using the D-S theory the combined probability assignments is computed as follows. As per the property of D-S theory initially let, $m_{I_1(1)} = m_{1,1}$. Now, using D-S rule of combination aggregation of first two basic attributes is performed as follows:

$$K_{I_1(2)} = \left(1 - \sum_{s=1}^{4} \sum_{l=1, l \neq s}^{4} m_{I_1(1)}^{s} m_{1,2}^{l}\right)^{-1}$$

$$= \left[1 - (0 + \cdots + 0 + m_{1,1}^{H_4} m_{1,2}^{H_2} + m_{1,1}^{H_4} m_{1,2}^{H_3} + 0 + m_{1,1}^{H_5} m_{1,2}^{H_2} + m_{1,1}^{H_5} m_{1,2}^{H_3} + 0\right]^{-1}$$

$$= [1 - (0 + 0 + 0.46 \times 0.042 + 0)]^{-1} = 1.02$$

Therefore, the combined BPAs for the first two basic attributes are:

$$m_{I_1(2)}^{H_1} = K_{I_1(2)}\left(m_{1,1}^{H_1} m_{1,2}^{H_1} + m_{1,1}^{H_1} m_{1,2}^{H} + m_{1,1}^{H} m_{1,2}^{H_1}\right)$$

$$= 1.11 \times (0 + 0.0 \times 0.86 + 0.0 \times 0.54) = 0.00$$

$$m_{1(2)}^{H_2} = K_{I_1(2)}\left(m_{1,1}^{H_2} m_{1,2}^{H_2} + m_{1,1}^{H_2} m_{1,2}^{H} + m_{1,1}^{H} m_{1,2}^{H_2}\right) = 0.00$$

$$m_{I_1(2)}^{H_3} = K_{I_1(2)}\left(m_{1,1}^{H_3} m_{1,2}^{H_3} + m_{1,1}^{H_3} m_{1,2}^{H} + m_{1,1}^{H} m_{1,2}^{H_3}\right) = 0.02$$

$$m_{I_1(2)}^{H_4} = K_{I_1(2)}\left(m_{1,1}^{H_4} m_{1,2}^{H_4} + m_{1,1}^{H_4} m_{1,2}^{H} + m_{1,1}^{H} m_{1,2}^{H_4}\right) = 0.50$$

$m_{I_1(2)}^{H_5} = K_{I_1(2)}\left(m_{1,1}^{H_5} m_{1,2}^{H_5} + m_{1,1}^{H_5} m_{1,2}^{H} + m_{1,1}^{H} m_{1,2}^{H_5}\right) = 0.00$

$m_{I_1(2)}^{H} = K_{I_1(2)}\left(m_{1,1}^{H} m_{1,2}^{H}\right) = 1.02 \times (0.54 \times 0.86) = 0.47$

In the second stage, the combining of the above results is performed with the BPAs of third attributes as follows,

$K_{I_1(3)} = \left(1 - \sum_{s=1}^{4} \sum_{l=1, l \neq s}^{4} m_{I_1(2)}^{s} m_{1,3}^{l}\right)^{-1} = 1.03$

Therefore, for three basic attributes the combined BPAs are;

$m_{I_1(3)}^{H_1} = K_{I_1(3)}\left(m_{I_1(2)}^{H_1} m_{1,3}^{H_1} + m_{I_1(2)}^{H_1} m_{1,3}^{H} + m_{I_1(2)}^{H} m_{1,3}^{H_1}\right) = 0.01$

$m_{I_1(3)}^{H_2} = K_{I_1(3)}\left(m_{I_1(2)}^{H_2} m_{1,3}^{H_2} + m_{I_1(2)}^{H_2} m_{1,3}^{H} + m_{I_1(2)}^{H} m_{1,3}^{H_2}\right) = 0.01$

$m_{I_1(3)}^{H_3} = K_{I_1(3)}\left(m_{I_1(2)}^{H_3} m_{1,3}^{H_3} + m_{I_1(2)}^{H_3} m_{1,3}^{H} + m_{I_1(2)}^{H} m_{1,3}^{H_3}\right) = 0.03$

$m_{I_1(3)}^{H_4} = K_{I_1(3)}\left(m_{I_1(2)}^{H_4} m_{1,3}^{H_4} + m_{I_1(2)}^{H_4} m_{1,3}^{H} + m_{I_1(2)}^{H} m_{1,3}^{H_4}\right) = 0.49$

$m_{I_1(3)}^{H_5} = K_{I_1(3)}\left(m_{I_1(2)}^{H_5} m_{1,3}^{H_5} + m_{I_1(2)}^{H_5} m_{1,3}^{H} + m_{I_1(2)}^{H} m_{1,3}^{H_5}\right) = 0.00$

$m_{I_1(3)}^{H} = K_{I_1(3)} m_{I_1(2)}^{H} m_{1,3}^{H} = 0.46$

In step three, the combining of fourth basic attribute's BPAs is performed with the output BPAs from the second stage and then the results are found as,

$K_{I_1(4)} = 1.04$,

Here, the combined BPAs of four basic attributes are:

$m_{I_1(4)}^{H_1} = 0.01$, $m_{I_1(4)}^{H_2} = 0.02$, $m_{I_1(4)}^{H_3} = 0.06$, $m_{I_1(4)}^{H_4} = 0.47$, and $m_{I_1(4)}^{H_5} = 0.00$,

$m_{I_1(4)}^{H} = 0.44$

Finally, in step four following the calculation procedure as in step three the combining of the above results with the fifth attributes is performed to get the combined BPAs of the five basic attributes as follows:

$K_{I_1(5)} = 1.08$,

Here, the combined BPAs of five basic attributes of economic sustainability are as follows:

$m^{H_1}_{I_1(5)} = 0.01, m^{H_2}_{I_1(5)} = 0.01, m^{H_3}_{I_1(5)} = 0.05, m^{H_4}_{I_1(5)} = 0.53$, and $m^{H_5}_{I_1(5)} = 0.05$,

$m^{H}_{I_1(5)} = 0.35$

Now, using the following normalization process all $L$ assessments are aggregated and the combined degrees of belief are generated for the social sustainability index by assigning $\bar{m}_{H,I(L)}$ proportionally back to all individual evaluation grades or condition states;

$$\{H_n\}: \beta_n = \frac{m_{n,I(L)}}{1-\bar{m}_{H,I(L)}} \quad n = 1, 2, \ldots, N$$

Where, $\{H_1\}: \beta_1 = \frac{m_{1,I(5)}}{1-\bar{m}_{H,I(5)}}$

$\{H_1\}: \beta_1 = \frac{0.01}{1-0.35}$ = 0.01, similarly it is found that, $\beta_2$= 0.02, $\beta_3$= 0.08, $\beta_4$= 0.81, $\beta_5$= 0.08

Therefore, the final condition rating for the economic sustainability index ($E_1$) is {(poor, 0.01), (fairly poor, 0.02), (average, 0.08), (good, 0.81), (excellent, 0.08)}. In this process the conflict does not contribute much to the combined data, as the conflict between the data is normalized by $K$ which might be valuable for good decision making. It is found that the degree of confidence for the evaluation grade or condition state 'good' is 81%, which is the highest in the economic sustainability index.

Using the following equation, the degree of belief of associated uncertainty or unassigned degree of belief is calculated as follows:

$$\{H\}: \beta_H = \frac{\tilde{m}_{H,I(L)}}{1-\bar{m}_{H,I(L)}} = \frac{0.00}{1-0.35} = 0.00$$

It is found from the D-S theory-based calculation that, for the economic sustainability index the unassigned degree of belief is 0.00%.

### 5.3.4. Interpretative Evaluation of Supply Chain Sustainability Index Using D-S Theory

Thus, calculating the condition ratings of the economic, environmental and social sustainability index, and combining these dimensions the overall condition rating for the supply chain sustainability is obtained.

The evaluation grade wise subjective judgment or condition rating $S(E_k)$ for each general attribute is obtained from the previous calculations as belief percentage or degree of confidence $(H_n, \beta_{n,i})$, where

$S(E_1)$ = *{(P, 0.01), (F, 0.02), (A, 0.08), (G, 0.81), (E, 0.08)}*

$S(E_2)$ = *{(P, 0.03), (F, 0.15), (A, 0.73), (G, 0.06), (E, 0.03)}*

$S(E_3)$ = *{(P, 0.02), (F, 0.08), (A, 0.21), (G, 0.65), (E, 0.03)}*

The relative weights to the general attributes are:

$\lambda_E = \{\lambda_E^1, \lambda_E^2, \lambda_E^3\} = \{0.63, 0.20, 0.17\}$

The condition ratings are multiplied by the weights to get BPA, $m(E_1)$. Here, the difference between one and the summation of weighted degrees of belief or condition ratings denotes the ignorance *(H)*. The aggregation of the general attributes representing the supply chain sustainability index as follows:

Supply chain sustainability index = $S(E_1) \times \lambda_E^1 \oplus S(E_2) \times \lambda_E^2 \oplus S(E_3) \times \lambda_E^3$

Therefore, the basic probability assignments (BPAs) for each basic attribute are as follows:

$$m_{E,1} = \{m_{E,1}^{H_n}, m_{E,1}^{H}\} = \{0.01, 0.01, 0.05, 0.51, 0.05, 0.37\}$$

$$m_{E,2} = \{m_{E,2}^{H_n}, m_{E,2}^{H}\} = \{0.01, 0.03, 0.15, 0.01, 0.01, 0.80\}$$

$$m_{E,3} = \{m_{E,3}^{H_n}, m_{E,3}^{H}\} = \{0.00, 0.01, 0.03, 0.11, 0.01, 0.83\}$$

Using the D-S theory the combined probability assignments is computed as follows. As per the property of D-S theory initially let, $m_{I_E(1)} = m_{E,1}$. Now, using D-S rule of combination aggregation of first two basic attributes is performed as follows:

$$K_{I_E(2)} = \left(1 - \sum_{s=1}^{4} \sum_{l=1, l\neq s}^{4} m_{I_E(1)}^{s} m_{E,2}^{l}\right)^{-1}$$

$$= \left[1 - (0 + \cdots + 0 + m_{E,1}^{H_4} m_{E,2}^{H_2} + m_{E,1}^{H_4} m_{E,2}^{H_3} + 0 + m_{E,1}^{H_5} m_{E,2}^{H_2} + m_{E,1}^{H_5} m_{E,2}^{H_3} + 0\right]^{-1}$$

$$= 1.13$$

Therefore, the combined BPAs for the first two basic attributes are:

$m_{I_E(2)}^{H_1} = K_{I_E(2)}\left(m_{E,1}^{H_1}m_{E,2}^{H_1} + m_{E,1}^{H_1}m_{E,2}^{H} + m_{E,1}^{H}m_{E,2}^{H_1}\right)$

$= 1.13 \times (0.01 \times 0.01 + 0.01 \times 0.80 + 0.01 \times 0.37) = 0.01$

$m_{E(2)}^{H_2} = K_{I_E(2)}\left(m_{E,1}^{H_2}m_{E,2}^{H_2} + m_{E,1}^{H_2}m_{E,2}^{H} + m_{E,1}^{H}m_{E,2}^{H_2}\right) = 0.02$

$m_{I_E(2)}^{H_3} = K_{I_E(2)}\left(m_{E,1}^{H_3}m_{E,2}^{H_3} + m_{E,1}^{H_3}m_{E,2}^{H} + m_{E,1}^{H}m_{E,2}^{H_3}\right) = 0.11$

$m_{I_E(2)}^{H_4} = K_{I_E(2)}\left(m_{E,1}^{H_4}m_{E,2}^{H_4} + m_{E,1}^{H_4}m_{E,2}^{H} + m_{E,1}^{H}m_{E,2}^{H_4}\right) = 0.47$

$m_{I_E(2)}^{H_5} = K_{I_E(2)}\left(m_{E,1}^{H_5}m_{E,2}^{H_5} + m_{E,1}^{H_5}m_{E,2}^{H} + m_{E,1}^{H}m_{E,2}^{H_5}\right) = 0.05$

$m_{I_E(2)}^{H} = K_{I_E(2)}\left(m_{E,1}^{H}m_{E,2}^{H}\right) = 1.13 \times (0.37 \times 0.80) = 0.33$

In the second stage, the combining of the above results is performed with the BPAs of third attributes as follows,

$K_{I_E(3)} = \left(1 - \sum_{s=1}^{4}\sum_{l=1,l\neq s}^{4} m_{I_E(2)}^{s}m_{E,3}^{l}\right)^{-1} = 1.06$

Therefore, for the three attributes the combined BPAs are;

$m_{I_E(3)}^{H_1} = K_{I_E(3)}\left(m_{I_E(2)}^{H_1}m_{E,3}^{H_1} + m_{I_E(2)}^{H_1}m_{1,3}^{H} + m_{I_E(2)}^{H}m_{E,3}^{H_1}\right) = 0.01$

$m_{I_E(3)}^{H_2} = K_{I_E(3)}\left(m_{I_E(2)}^{H_2}m_{E,3}^{H_2} + m_{I_E(2)}^{H_2}m_{E,3}^{H} + m_{I_E(2)}^{H}m_{E,3}^{H_2}\right) = 0.03$

$m_{I_E(3)}^{H_3} = K_{I_E(3)}\left(m_{I_E(2)}^{H_3}m_{E,3}^{H_3} + m_{I_E(2)}^{H_3}m_{E,3}^{H} + m_{I_E(2)}^{H}m_{E,3}^{H_3}\right) = 0.12$

$m_{I_E(3)}^{H_4} = K_{I_E(3)}\left(m_{I_E(2)}^{H_4}m_{E,3}^{H_4} + m_{I_E(2)}^{H_4}m_{E,3}^{H} + m_{E(2)}^{H}m_{E,3}^{H_4}\right) = 0.51$

$m_{I_E(3)}^{H_5} = K_{I_E(3)}\left(m_{I_E(2)}^{H_5}m_{E,3}^{H_5} + m_{I_E(2)}^{H_5}m_{E,3}^{H} + m_{I_E(2)}^{H}m_{E,3}^{H_5}\right) = 0.04$

$m_{I_E(3)}^{H} = K_{I_E(3)}m_{I_E(2)}^{H}m_{E,3}^{H} = 0.29$

Now, using the following normalization process all $L$ assessments are aggregated and the combined degrees of belief are generated for the supply chain sustainability by assigning $\bar{m}_{H,I(L)}$ proportionally back to all individual evaluation grades or condition states;

$\{H_n\}: \beta_n = \frac{m_{n,I(L)}}{1-\bar{m}_{H,I(L)}}$ $n = 1, 2, \ldots, N$

Where, $\{H_1\}: \beta_1 = \frac{m_{1,I(5)}}{1-\bar{m}_{H,I(5)}}$

$\{H_1\}: \beta_1 = \frac{0.01}{1-0.29}$ = 0.01, similarly it is found that, $\beta_2$= 0.04, $\beta_3$= 0.16, $\beta_4$= 0.72, $\beta_5$= 0.06

Therefore, the final condition rating for the supply chain sustainability index is {(poor, 0.01), (fairly poor, 0.04), (average, 0.16), (good, 0.72), (excellent, 0.06)}. In this process the conflict does not contribute much to the combined data, as the conflict between the data is normalized by $K$ which might be valuable for good decision making. It is found that the degree of confidence for the evaluation grade or condition state 'good' is 72%, which is the highest in the supply chain sustainability index.

Using the following equation, the degree of belief of associated uncertainty or unassigned degree of belief is calculated as follows:

$$\{H\}: \beta_H = \frac{\tilde{m}_{H,I(L)}}{1-\bar{m}_{H,I(L)}} = \frac{0.0006}{1-0.29} = 0.00078$$

It is found from the D-S theory-based calculation that, for the supply chain sustainability index the unassigned degree of belief is 0.08%.

**5.4. Utility Perspective Calculation of Supply Chain Sustainability Based on D-S theory**

Basically, D-S theory depicts the distributed descriptions of the sustainability in supply chain. To show the difference between two assessments, there may be occasions where distributed descriptions are not sufficient. Therefore, numerical value generation equivalent to the distributed assessments in a sense is desirable. Here, considering the stated issue, to get a single numerical value for supply chain sustainability ($y$), the maximum, minimum and average expected utilities on '$y$' are sequentially calculated by the following equations:

$$u_{max}(y) = \sum_{n=1}^{N-1} \beta_n u(H_n) + (\beta_N + \beta_H) u(H_N)$$

$$u_{max}(y) = \sum_{n=1}^{4} \beta_n u(H_n) + (\beta_N + \beta_H) u(H_N)$$

$$u_{max}(y) = \beta_1 u(H_1) + \beta_2 u(H_2) + \beta_3 u(H_3) + \beta_4 u(H_4) + (\beta_5 + \beta_H) u(H_5)$$

$= (0.01 \times 0 + 0.04 \times 0.25 + 0.16 \times 0.50 + 0.72 \times 0.75) + (0.06 + 0.00078) \times 1$

$= 0.694366263$

$$u_{min}(y) = (\beta_1 + \beta_H)u(H_1) + \sum_{n=2}^{N} \beta_n u(H_n)$$

$$u_{min}(y) = (\beta_1 + \beta_H)u(H_1) + \sum_{n=2}^{5} \beta_n u(H_n)$$

$$u_{min}(y) = (\beta_1 + \beta_H)u(H_1) + \beta_2 u(H_2) + \beta_3 u(H_3) + \beta_4 u(H_4) + \beta_5 u(H_5)$$

$= (0.01 + 0.00078) \times 0 + (0.04 \times 0.25 + 0.16 \times 0.50 + 0.72 \times 0.75 + 0.06 \times 1)$

$= 0.693589365$

$$u_{avg}(y) = \frac{u_{max}(y) + u_{min}(y)}{2} = \frac{0.694366263 + 0.693589365}{2} = 0.693977814$$

Here, $N$ is the number of evaluation grade (i.e. $N=5$). It is observed that the average utility value for the supply chain sustainability index is *0.693977814*, which lies between the unified utility value of the average and good condition.

**5.5. Combination of Assessments Using Yager's Rule**

The Yager's rule as discussed in chapter 3, differs from the D-S combination rule in handling conflict, that is represented by '$k$' in D-S rule. Instead of a normalization process, the conflict attributed to '$k$' is shifted to ignorance. To assess the sustainability of supply chains using this approach, similar steps are followed as in the D-S rule of combination. Only difference in calculation is that, to calculate the combined probability masses the recursive Equations 3.32-3.36 are used in the Yager's rule of combination instead of Equations 3.19–3.23, which are used in D-S rule of combination. All other calculation's Equations are similar to that of combination of assessments using D-S theory. Finally, the assessment of social sustainability by aggregating human rights, health and safety, training and education, consumer issues, and supplier relationship, is therefore represented by the following distribution according to the Equation (3.26):

$$S(Social\ Sustainability) = S(human\ rights \oplus health\ and\ safety \oplus training\ and\ education \oplus consumer\ issues \oplus supplier\ relationship)$$

= {(poor, 0.02), (fairly poor, 0.08), (average, 0.21), (good, 0.64), (excellent, 0.04)}

To determine the assessment grades of the higher level, the same calculation procedure is followed at each level of the hierarchy. Thus, to compare the result of D-S theory the final assessment values are generated as supply chain sustainability index using Yager recursive rule of combination.

To ascertain overall supply chain sustainability, all three general attributes are combined as follows to obtain the overall confidence rating.

$$S(Supply\ Chain\ Sustainability) = S(Economic\ sustainability \oplus Environmental\ Sustainability \oplus SocialSustainability)$$

= {(poor, 0.01), (fairly poor, 0.04), (average, 0.17), (good, 0.71), (excellent, 0.07)}

The final assessment grades are then calculated using Equation (3.29) and (3.30) and the utility value of the evaluation grades mentioned in Chapter 4, to get the index value in a single quantitative value. Using Equations 3.29 and 3.30 a range of final result is found, which is denoted by $U_{max}$ and $U_{min}$. The results are illustrated and discussed in Chapter 6.

### 5.5.1. Interpretative Evaluation of Social Sustainability Index Using Yager's Rule

Yager's rule is similar to that of D-S theory; the only difference is that, the conflict represented by the factor '*K*' is shifted to ignorance during data combination.

$$K_{I_3(2)} = \left( \sum_{s=1}^{4} \sum_{l=1, l \neq s}^{4} m_{I_3(1)}^{s} m_{3,2}^{l} \right)$$

$$= (0 + \cdots + 0 + m_{3,1}^{H_4} m_{3,2}^{H_2} + m_{3,1}^{H_4} m_{3,2}^{H_3} + 0 + m_{3,1}^{H_5} m_{3,2}^{H_2} + m_{3,1}^{H_5} m_{3,2}^{H_3} + 0)$$

$$= (0.45 \times 0.00 + 0.45 \times 0.066 + 0.45 \times 0.154 + 0.45 \times 0.00) = 0.10$$

For the first two parameters, the combined BPAs are as follows:

$$m_{I_3(2)}^{H_1} = \left( m_{3,1}^{H_1} m_{3,2}^{H_1} + m_{3,1}^{H_1} m_{3,2}^{H} + m_{3,1}^{H} m_{3,2}^{H_1} \right)$$

$$= (0 + 0.00 \times 0.78 + 0.55 \times 0.00) = 0.00$$

$$m_{I_3(2)}^{H_2} = \left( m_{3,1}^{H_2} m_{3,2}^{H_2} + m_{3,1}^{H_2} m_{3,2}^{H} + m_{3,1}^{H} m_{3,2}^{H_2} \right)$$

$$= (0.00 \times 0.066 + 0.00 \times 0.78 + 0.55 \times 0.066) = 0.04$$

$$m_{I_3(2)}^{H_3} = \left(m_{3,1}^{H_3} m_{3,2}^{H_3} + m_{3,1}^{H_3} m_{3,2}^{H} + m_{3,1}^{H} m_{3,2}^{H_3}\right)$$

$$= (0.00 \times 0.154 + 0.00 \times 0.78 + 0.55 \times 0.154) = 0.08$$

$$m_{I_3(2)}^{H_4} = \left(m_{3,1}^{H_4} m_{3,2}^{H_4} + m_{3,1}^{H_4} m_{3,2}^{H} + m_{3,1}^{H} m_{3,2}^{H_4}\right)$$

$$= (0.36 \times 0.00 + 0.36 \times 0.78 + 0.55 \times 0.00) = 0.35$$

$$m_{I_3(2)}^{H_5} = \left(m_{3,1}^{H_5} m_{3,2}^{H_5} + m_{3,1}^{H_5} m_{3,2}^{H} + m_{3,1}^{H} m_{3,2}^{H_5}\right)$$

$$= (0.09 \times 0.00 + 0.09 \times 0.78 + 0.55 \times 0.00) = 0.00$$

$$m_{I_3(2)}^{H} = K_{I_3(2)} + \left(m_{3,1}^{H} m_{3,2}^{H}\right) = 0.10 + (0.55 \times 0.78) = 0.53$$

Similarly, the BPAs of the third attribute are combined with the combined BPAs of the above two attributes to get the combined BPAs for the three attributes. Combining the fourth with the combined BPAs of the three attributes generates the combined BPAs of four attributes. Finally, by combining the fifth basic attribute with the four combined BPAs the combined BPAs for the five basic attributes can be obtained as follows:

$m_{I_3(5)}^{H_1} = 0.01$, $m_{I_3(5)}^{H_2} = 0.04$, $m_{I_3(5)}^{H_3} = 0.11$, $m_{I_3(5)}^{H_4} = 0.34$, and $m_{I_3(5)}^{H_5} = 0.02$,

$m_{I_3(5)}^{H} = 0.47$

Then, following a similar approach to D-S theory, in Yager's rule, the final condition rating for the social sustainability index is ($E_3$) is {(poor, 0.02), (fairly poor, 0.08), (average, 0.21), (good, 0.64), (excellent, 0.04)}. It is found that, the degree of confidence for the evaluation grade or condition state 'Good' is 64%, which is the highest in the social sustainability index. From this calculation, it is found that, for the social sustainability index, the unassigned degree of belief is 1.05%.

**5.5.2. Interpretative Evaluation of Environmental Sustainability Index Using Yager's Rule**

Here, the conflict represented by the factor '*K*' is shifted to ignorance during data combination.

$$K_{I_2(2)} = \left(\sum_{s=1}^{4} \sum_{l=1, l \neq s}^{4} m_{I_2(1)}^{s} m_{2,2}^{l}\right)$$

$$= (0 + \cdots + 0 + m_{2,1}^{H_4} m_{2,2}^{H_2} + m_{2,1}^{H_4} m_{2,2}^{H_3} + 0 + m_{2,1}^{H_5} m_{2,2}^{H_2} + m_{2,1}^{H_5} m_{2,2}^{H_3} + 0)$$

$$= (0.44 \times 0.04 + 0.44 \times 0.16 + 0 + 0) = 0.09$$

For the first two parameters, the combined BPAs are as follows:

$$m_{I_2(2)}^{H_1} = \left(m_{2,1}^{H_1} m_{2,2}^{H_1} + m_{2,1}^{H_1} m_{2,2}^{H} + m_{2,1}^{H} m_{2,2}^{H_1}\right)$$

$$= (0 + 0.0 \times 0.8 + 0.04 \times 0.56) \ = 0.02$$

$$m_{I_2(2)}^{H_2} = \left(m_{2,1}^{H_2} m_{2,2}^{H_2} + m_{2,1}^{H_2} m_{2,2}^{H} + m_{2,1}^{H} m_{2,2}^{H_2}\right) = 0.09$$

$$m_{I_2(2)}^{H_3} = \left(m_{2,1}^{H_3} m_{2,2}^{H_3} + m_{2,1}^{H_3} m_{2,2}^{H} + m_{2,1}^{H} m_{2,2}^{H_3}\right) \ = 0.35$$

$$m_{I_2(2)}^{H_4} = \left(m_{2,1}^{H_4} m_{2,2}^{H_4} + m_{2,1}^{H_4} m_{2,2}^{H} + m_{2,1}^{H} m_{2,2}^{H_4}\right) \ = 0.00$$

$$m_{I_2(2)}^{H_5} = \left(m_{2,1}^{H_5} m_{2,2}^{H_5} + m_{2,1}^{H_5} m_{2,2}^{H} + m_{2,1}^{H} m_{2,2}^{H_5}\right) \ = 0.00$$

$$m_{I_2(2)}^{H} = K_{I_2(2)} + \left(m_{2,1}^{H} m_{2,2}^{H}\right) = 0.09 + (0.56 \times 0.80) = 0.54$$

Similarly, the BPAs of the third attribute are combined with the combined BPAs of the above two attributes to get the combined BPAs for the three attributes. Combining the fourth with the combined BPAs of the three attributes generates the combined BPAs of four attributes. Finally, by combining the fifth basic attribute with the four combined BPAs the combined BPAs for the five basic attributes can be obtained as follows:

$m_{I_2(5)}^{H_1} = 0.02$, $m_{I_2(5)}^{H_2} = 0.08$, $m_{I_2(5)}^{H_3} = 0.39$, $m_{I_2(5)}^{H_4} = 0.04$, and $m_{I_2(5)}^{H_5} = 0.02$,

$m_{I_2(5)}^{H}$= 0.46

Then, following a similar approach to D-S theory, in Yager's rule, the final condition rating for the environmental sustainability index is (*$E_2$*) is {(poor, 0.03), (fairly poor, 0.15), (average, 0.72), (good, 0.07), (excellent, 0.03)}. It is found that, the degree of confidence for the evaluation grade or condition state 'average' is 72%, which is the highest in the environmental sustainability index. From this calculation, it is found that, for the environmental sustainability index, the unassigned degree of belief is 0.00%.

### 5.5.3. Interpretative Evaluation of Economic Sustainability Index Using Yager's Rule

The only difference between the Yager and D-S rule is the elimination of normalization by non-conflicting evidence. The conflict represented by the factor '*K*' is shifted to ignorance during data combination.

$$K_{I_1(2)} = \left(\sum_{s=1}^{4}\sum_{l=1,l\neq s}^{4} m_{I_1(1)}^{s} m_{1,2}^{l}\right)$$

$$= (0 + \cdots + 0 + m_{1,1}^{H_4} m_{1,2}^{H_2} + m_{1,1}^{H_4} m_{1,2}^{H_3} + 0 + m_{1,1}^{H_5} m_{1,2}^{H_2} + m_{1,1}^{H_5} m_{1,2}^{H_3} + 0)$$

$$= (0.44 \times 0.04 + 0.44 \times 0.16 + 0 + 0) \ = 0.02$$

For the first two parameters, the combined BPAs are as follows:

$$m_{I_1(2)}^{H_1} = \left(m_{1,1}^{H_1} m_{1,2}^{H_1} + m_{1,1}^{H_1} m_{1,2}^{H} + m_{1,1}^{H} m_{1,2}^{H_1}\right)$$

$$= (0 + 0.0 \times 0.86 + 0.00 \times 0.54) \ = 0.00$$

$$m_{I_1(2)}^{H_2} = \left(m_{1,1}^{H_2} m_{1,2}^{H_2} + m_{1,1}^{H_2} m_{1,2}^{H} + m_{1,1}^{H} m_{1,2}^{H_2}\right) = 0.00$$

$$m_{I_1(2)}^{H_3} = \left(m_{1,1}^{H_3} m_{1,2}^{H_3} + m_{1,1}^{H_3} m_{1,2}^{H} + m_{1,1}^{H} m_{1,2}^{H_3}\right) \ = 0.023$$

$$m_{I_1(2)}^{H_4} = \left(m_{1,1}^{H_4} m_{1,2}^{H_4} + m_{1,1}^{H_4} m_{1,2}^{H} + m_{1,1}^{H} m_{1,2}^{H_4}\right) \ = 0.494$$

$$m_{I_1(2)}^{H_5} = \left(m_{1,1}^{H_5} m_{1,2}^{H_5} + m_{1,1}^{H_5} m_{1,2}^{H} + m_{1,1}^{H} m_{1,2}^{H_5}\right) \ = 0.00$$

$$m_{I_1(2)}^{H} = K_{I_1(2)} + \left(m_{1,1}^{H} m_{1,2}^{H}\right) = 0.09 + (0.56 \times 0.80) = 0.48$$

Similarly, the BPAs of the third attribute are combined with the combined BPAs of the above two attributes to get the combined BPAs for the three attributes. Combining the fourth with the combined BPAs of the three attributes generates the combined BPAs of four attributes. Finally, by combining the fifth basic attribute with the four combined BPAs the combined BPAs for the five basic attributes can be obtained as follows:

$m_{I_1(5)}^{H_1} = 0.01$, $m_{I_1(5)}^{H_2} = 0.01$, $m_{I_1(5)}^{H_3} = 0.05$, $m_{I_1(5)}^{H_4} = 0.46$, and $m_{I_1(5)}^{H_5} = 0.05$,

$m_{I_1(5)}^{H} = 0.43$

Then, following a similar approach to D-S theory, in Yager's rule, the final condition rating for the economic sustainability index is ($E_I$) is {(poor, 0.01), (fairly poor, 0.02), (average, 0.08), (good, 0.80), (excellent, 0.09)}. It is found that, the degree of confidence for the evaluation grade or condition state 'good' is 80%, which is the highest in the economic sustainability index. It is found that, for the economic sustainability index, the unassigned degree of belief is 0.00%.

**5.5.4. Interpretative Evaluation of Supply Chain Sustainability Index Using Yager's rule**

Calculating the condition ratings of the economic, environmental and social sustainability index, and combining these dimensions the overall condition rating for the supply chain sustainability is obtained. The evaluation grade wise subjective judgment or condition rating $S(E_k)$ for each general attribute (i.e. economic, environmental and social) is obtained from the previous calculations as belief percentage or degree of confidence $(H_n, \beta_{n,i})$, where

$S(E_1)$ = *{(P, 0.01), (F, 0.02), (A, 0.08), (G, 0.80), (E, 0.09)}*

$S(E_2)$ = *{(P, 0.03), (F, 0.15), (A, 0.72), (G, 0.07), (E, 0.03)}*

$S(E_3)$ = *{(P, 0.02), (F, 0.08), (A, 0.21), (G, 0.64), (E, 0.04)}*

The relative weights to the general attributes are:

$\lambda_E = \{\lambda_E^1, \lambda_E^2, \lambda_E^3\} = \{0.63, 0.20, 0.17\}$

The condition ratings are multiplied by the weights to get BPA, $m(E\ )$. Here, the difference between one and the summation of weighted degrees of belief or condition ratings denotes the ignorance *(H)*. The aggregation of the basic attributes representing the general attribute (i.e. social sustainability index) is as follows:

Supply chain sustainability index = $S(E_1) \times \lambda_E^1 \oplus S(E_2) \times \lambda_E^2 \oplus S(E_3) \times \lambda_E^3$

Therefore, the basic probability assignments (BPAs) for each basic attribute are as follows:

$$m_{E,1} = \{m_{E,1}^{H_n}, m_{E,1}^{H}\} = \{0.01, 0.01, 0.05, 0.50, 0.06, 0.37\}$$

$$m_{E,2} = \{m_{E,2}^{H_n}, m_{E,2}^{H}\} = \{0.01, 0.03, 0.14, 0.01, 0.01, 0.80\}$$

$$m_{E,3} = \{m_{E,3}^{H_n}, m_{E,3}^{H}\} = \{0.00, 0.01, 0.04, 0.11, 0.01, 0.83\}$$

Using the Yager's rule the combined probability assignments is computed as follows. As per the property of Yager's rule initially let, $m_{I_E(1)} = m_{E,1}$. Now, using Yager rule of combination aggregation of first two basic attributes is performed as follows:

$$K_{I_E(2)} = \left(\sum_{s=1}^{4} \sum_{l=1, l \neq s}^{4} m_{I_E(1)}^{s} m_{E,2}^{l}\right)$$

$$= \left[ (0 + \cdots + 0 + m_{E,1}^{H_4} m_{E,2}^{H_2} + m_{E,1}^{H_4} m_{E,2}^{H_3} + 0 + m_{E,1}^{H_5} m_{E,2}^{H_2} + m_{E,1}^{H_5} m_{E,2}^{H_3} + 0) \right]$$

$$= 0.11$$

Therefore, the combined BPAs for the first two basic attributes are:

$$m_{I_E(2)}^{H_1} = \left( m_{E,1}^{H_1} m_{E,2}^{H_1} + m_{E,1}^{H_1} m_{E,2}^{H} + m_{E,1}^{H} m_{E,2}^{H_1} \right)$$

$$= (0.01 \times 0.01 + 0.01 \times 0.80 + 0.01 \times 0.37) \ = 0.01$$

$$m_{E(2)}^{H_2} = \left( m_{E,1}^{H_2} m_{E,2}^{H_2} + m_{E,1}^{H_2} m_{E,2}^{H} + m_{E,1}^{H} m_{E,2}^{H_2} \right) \ = 0.02$$

$$m_{I_E(2)}^{H_3} = \left( m_{E,1}^{H_3} m_{E,2}^{H_3} + m_{E,1}^{H_3} m_{E,2}^{H} + m_{E,1}^{H} m_{E,2}^{H_3} \right) \ = 0.10$$

$$m_{I_E(2)}^{H_4} = \left( m_{E,1}^{H_4} m_{E,2}^{H_4} + m_{E,1}^{H_4} m_{E,2}^{H} + m_{E,1}^{H} m_{E,2}^{H_4} \right) \ = 0.41$$

$$m_{I_E(2)}^{H_5} = \left( m_{E,1}^{H_5} m_{E,2}^{H_5} + m_{E,1}^{H_5} m_{E,2}^{H} + m_{E,1}^{H} m_{E,2}^{H_5} \right) \ = 0.05$$

$$m_{I_E(2)}^{H} = K_{I_E(2)} + \left( m_{E,1}^{H} m_{E,2}^{H} \right) = 1.09 + (0.36 \times 0.80) = 0.41$$

In the second stage, the combining of the above results is performed with the BPAs of third attributes as follows,

$$K_{I_E(3)} = \left( \sum_{s=1}^{4} \sum_{l=1, l \neq s}^{4} m_{I_E(2)}^{s} m_{E,3}^{l} \right) \quad =0.05$$

Therefore, for the three attributes the combined BPAs are;

$$m_{I_E(3)}^{H_1} = \left( m_{I_E(2)}^{H_1} m_{E,3}^{H_1} + m_{I_E(2)}^{H_1} m_{1,3}^{H} + m_{I_E(2)}^{H} m_{E,3}^{H_1} \right) = 0.01$$

$$m_{I_E(3)}^{H_2} = \left( m_{I_E(2)}^{H_2} m_{E,3}^{H_2} + m_{I_E(2)}^{H_2} m_{E,3}^{H} + m_{I_E(2)}^{H} m_{E,3}^{H_2} \right) = 0.02$$

$$m_{I_E(3)}^{H_3} = \left( m_{I_E(2)}^{H_3} m_{E,3}^{H_3} + m_{I_E(2)}^{H_3} m_{E,3}^{H} + m_{I_E(2)}^{H} m_{E,3}^{H_3} \right) = 0.10$$

$$m_{I_E(3)}^{H_4} = \left( m_{I_E(2)}^{H_4} m_{E,3}^{H_4} + m_{I_E(2)}^{H_4} m_{E,3}^{H} + m_{E(2)}^{H} m_{E,3}^{H_4} \right) = 0.43$$

$$m_{I_E(3)}^{H_5} = \left( m_{I_E(2)}^{H_5} m_{E,3}^{H_5} + m_{I_E(2)}^{H_5} m_{E,3}^{H} + m_{I_E(2)}^{H} m_{E,3}^{H_5} \right) = 0.04$$

$$m_{I_E(3)}^{H} = K_{I_E(3)} + m_{I_E(2)}^{H} m_{E,3}^{H} = 0.39$$

Now, using the following normalization process all $L$ assessments are aggregated and the combined degrees of belief are generated for the supply chain sustainability by assigning $\bar{m}_{H},_{I(L)}$ proportionally back to all individual evaluation grades or condition states;

$\{H_n\}$: $\beta_n = \frac{m_{n,I(L)}}{1-\bar{m}_{H,I(L)}}$  $n = 1, 2, \ldots, N$

Where, $\{H_1\}$: $\beta_1 = \frac{m_{1,I(5)}}{1-\bar{m}_{H,I(5)}}$

$\{H_1\}$: $\beta_1 = \frac{0.01}{1-0.39}$ = 0.01, similarly it is found that, $\beta_2$= 0.04, $\beta_3$= 0.17, $\beta_4$= 0.71, $\beta_5$= 0.07

Therefore, the final condition rating for the supply chain sustainability index is {(poor, 0.01), (fairly poor, 0.04), (average, 0.17), (good, 0.71), (excellent, 0.07)}. In this process the conflict does not contribute much to the combined data, as the conflict between the data is normalized by *K* which might be valuable for good decision making. It is found that the degree of confidence for the evaluation grade or condition state 'good' is 71%, which is the highest in the supply chain sustainability index.

Using the following equation, the degree of belief of associated uncertainty or unassigned degree of belief is calculated as follows:

$\{H\}$: $\beta_H = \frac{\tilde{m}_{H,I(L)}}{1-\bar{m}_{H,I(L)}} = \frac{0.0007}{1-0.39} = 0.0012$

It is found from the Yager's rule based calculation that, for the supply chain sustainability index the unassigned degree of belief is 0.12%.

**5.6. Utility Perspective Calculation of Supply Chain Sustainability based on Yager's rule**

Basically, Yager's theory depicts the distributed descriptions of the sustainability in supply chain. To show the difference between two assessments, there may be occasions where distributed descriptions are not sufficient. Therefore, numerical value generation equivalent to the distributed assessments in a sense is desirable. Here, considering the stated issue, to get a single numerical value for supply chain sustainability (*y*), the maximum, minimum and average expected utilities on y are sequentially calculated by the following equations:

$$u_{max}(y) = \sum_{n=1}^{N-1} \beta_n u(H_n) + (\beta_N + \beta_H) u(H_N)$$

$$u_{max}(y) = \sum_{n=1}^{4} \beta_n u(H_n) + (\beta_N + \beta_H) u(H_N)$$

$$u_{max}(y) = \beta_1 u(H_1) + \beta_2 u(H_2) + \beta_3 u(H_3) + \beta_4 u(H_4) + (\beta_5 + \beta_H) u(H_5)$$

$= (0.01 \times 0 + 0.04 \times 0.25 + 0.17 \times 0.50 + 0.71 \times 0.75) + (0.07 + 0.0012) \times 1$

$= 0.695244502$

$$u_{min}(y) = (\beta_1 + \beta_H) u(H_1) + \sum_{n=2}^{N} \beta_n u(H_n)$$

$$u_{min}(y) = (\beta_1 + \beta_H) u(H_1) + \sum_{n=2}^{5} \beta_n u(H_n)$$

$$u_{min}(y) = (\beta_1 + \beta_H) u(H_1) + \beta_2 u(H_2) + \beta_3 u(H_3) + \beta_4 u(H_4) + \beta_5 u(H_5)$$

$= (0.01 + 0.0012) \times 0 + (0.04 \times 0.25 + 0.17 \times 0.50 + 0.71 \times 0.75 + 0.07 \times 1)$

$= 0.694060538$

$u_{avg}(y) = \frac{u_{max}(y) + u_{min}(y)}{2} = \frac{0.695244502 + 0.694060538}{2} = 0.69465252$

It is observed that the average utility value for the supply chain sustainability index is *0.69465252*, which lies between the unified utility value of the average and good condition.

# CHAPTER 6

## RESULTS AND DISCUSSIONS

The results generated by D-S theory and Yager's rule with relevant discussion is presented in this chapter. This chapter also presents an overall supply chain sustainability assessment of an organization and sensitivity analysis.

### 6.1. Overall Assessment of Sustainability in Supply Chains

The above chapter detailed how the condition rating for the social sustainability attribute is determined based on information regarding basic attributes pertinent to that general attribute. Similarly, the contributions of the remaining two attributes, such as economic and environmental sustainability, are determined. All three general attributes are subsequently combined to get the overall sustainability condition rating. Each general attribute is evaluated using the same aggregation procedure performed earlier. The contributions of each general attributes are expressed as a distribution with degrees of confidence on different evaluation grades. Overall assessment of an organization is performed by obtaining the value for the supply chain sustainability index, e.g. $U_{avg}$, using D-S evidential theory. In this study, to compare the results from the D-S theory, a similar approach of Yager's recursive rule of combination is used to obtain the value of the supply chain sustainability index. The obtained results from both hierarchical evidential reasoning approaches are illustrated in Table 6.1.

Table 6.1: Overall supply chain sustainability index

| **HER approach** | **$U_{avg}$** |
|---|---|
| D-S theory | 0.693977814 |
| Yager's recursive rule | 0.69465252 |

From Table 6.1, it is observed that there are no significant differences between the values, which infers that the results obtained using the D-S theory are very similar. The results in this study is generated in terms of assessments grades. The overall assessment or average utility value demonstrates that the sustainability of the studied organization is above average. The results also denote that there is a notable scope for improvement for the organization. Along with the uncertainty and assessment grades the results are demonstrated in Figure 6.1 as a distribution. In the figure, the symbols CS-1, CS-2, CS-3, CS-4 and CS-5 denote the assessment grades poor, fairly poor, average, good and excellent, respectively. The symbol $\beta_H$ denotes the degree of belief of the associated uncertainty. It also expresses the unassigned degree of belief which is one of the major advantages of using the D-S theory and Yager's rule. The incompleteness in the overall assessment is represented by the unassigned degree of belief.

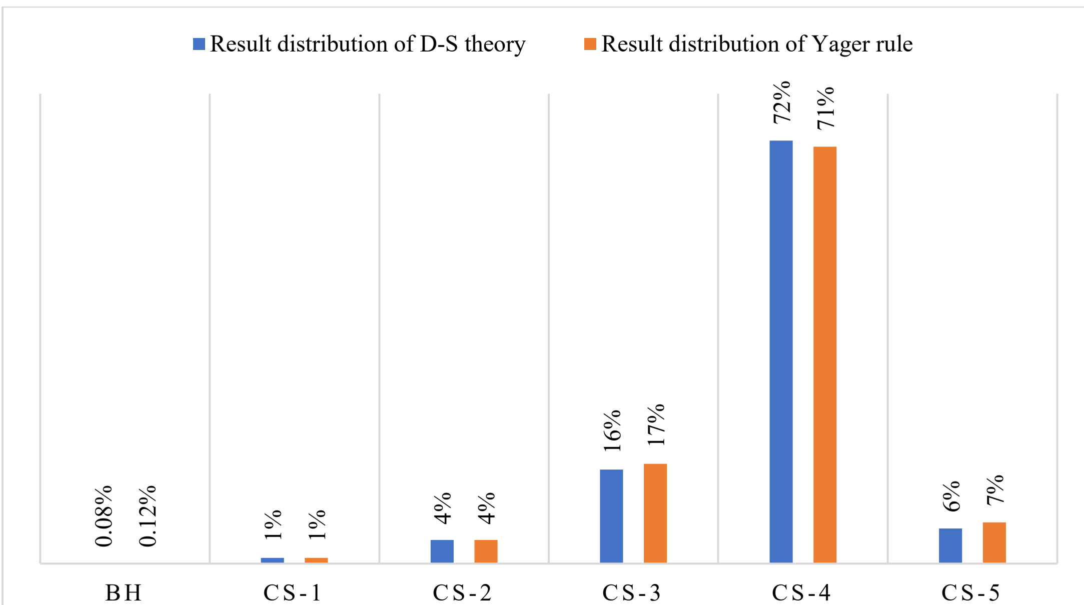


Figure 6.1: Distribution of assessment grades of supply chain sustainability index.

### 6.2. Sensitivity Analysis

To determine the sensitivity of the final results with respect to changes in criteria weights, a sensitivity analysis is conducted. For both the D-S theory and Yager's rule, 20 sets of experiments were conducted to compute the overall supply chain sustainability index. The experiments are presented in Table 6.2. It can be observed from Table 6.2 that

- Experiment 1 provides equal weights = 0.20 to the criteria with high utility values, i.e. C1, C5, C8, C11 and C15. Remaining criteria weights are equal to 0.
- A random allocation of weights to the different criteria is conducted in experiment 2.

- Experiment 3 provides equal weights = 0.25 to criteria with low utility values, i.e. C3, C7, C9 and C13.
- Experiment 4 distributes equal weight = 0.1 to criteria with high utility values, i.e. C1, C5, C8, and C11. Equal value = 0.15 is given to criteria with low utility values, i.e. C3, C7, C9 and C13.
- All criteria weights are set at 0.066 in experiment 5.
- Experiments 6 to 20 provide weight = 0.5 to one criterion and distribute the remaining 0.5 weight over eight criteria making their criteria weight = 0.04.

Table 6.2: Experiments on sensitivity analysis

| Exp. No. | Attributes Weight | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **A1** | **A2** | **A3** | **A4** | **A5** | **A6** | **A7** | **A8** | **A9** | **A10** | **A11** | **A12** | **A13** | **A14** | **A15** |
| 1 | 0.20 | 0 | 0 | 0 | 0.20 | 0 | 0 | 0.20 | 0 | 0 | 0.20 | 0 | 0 | 0 | 0.20 |
| 2 | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 | 0 | 0 | 0.05 | 0.05 | 0.05 | 0 | 0 | 0.1 | 0.05 | 0 |
| 3 | 0 | 0 | 0.25 | 0 | 0 | 0 | 0.25 | 0 | 0.25 | 0 | 0 | 0 | 0.25 | 0 | 0 |
| 4 | 0.1 | 0 | 0.15 | 0 | 0.1 | 0 | 0.15 | 0.1 | 0.15 | 0 | 0.1 | 0 | 0.15 | 0 | 0 |
| 5 | 0.066 | 0.066 | 0.066 | 0.066 | 0.066 | 0.066 | 0.066 | 0.066 | 0.066 | 0.066 | 0.066 | 0.066 | 0.066 | 0.066 | 0.066 |
| 6 | 0.50 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| 7 | 0.04 | 0.50 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| 8 | 0.04 | 0.04 | 0.50 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| 9 | 0.04 | 0.04 | 0.04 | 0.50 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| 10 | 0.04 | 0.04 | 0.04 | 0.04 | 0.50 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| 11 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.50 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| 12 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.50 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| 13 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.50 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| 14 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.50 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| 15 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.50 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| 16 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.50 | 0.04 | 0.04 | 0.04 | 0.04 |
| 17 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.50 | 0.04 | 0.04 | 0.04 |
| 18 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.50 | 0.04 | 0.04 |
| 19 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.50 | 0.04 |
| 20 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.50 |

In Figure 6.2, the results of the sensitivity analysis are presented. From Figure 6.2, it is observed that, due to the change in weights of the attributes the overall sustainability index also changed. In this study for both the D-S theory and the Yager's rule, the sensitivity analysis is performed and compared graphically. It is seen from most of the experiments that computational results of both theories are approximately similar. Furthermore, there is no significant difference within the experimental results. Therefore, it can be deduced that the weights of attributes have impact on sustainability index and the overall sustainability index obtained from D-S theory is approximately similar to the Yager's rule, as there is no significant difference within the experimental result of two hierarchical evidential theory.

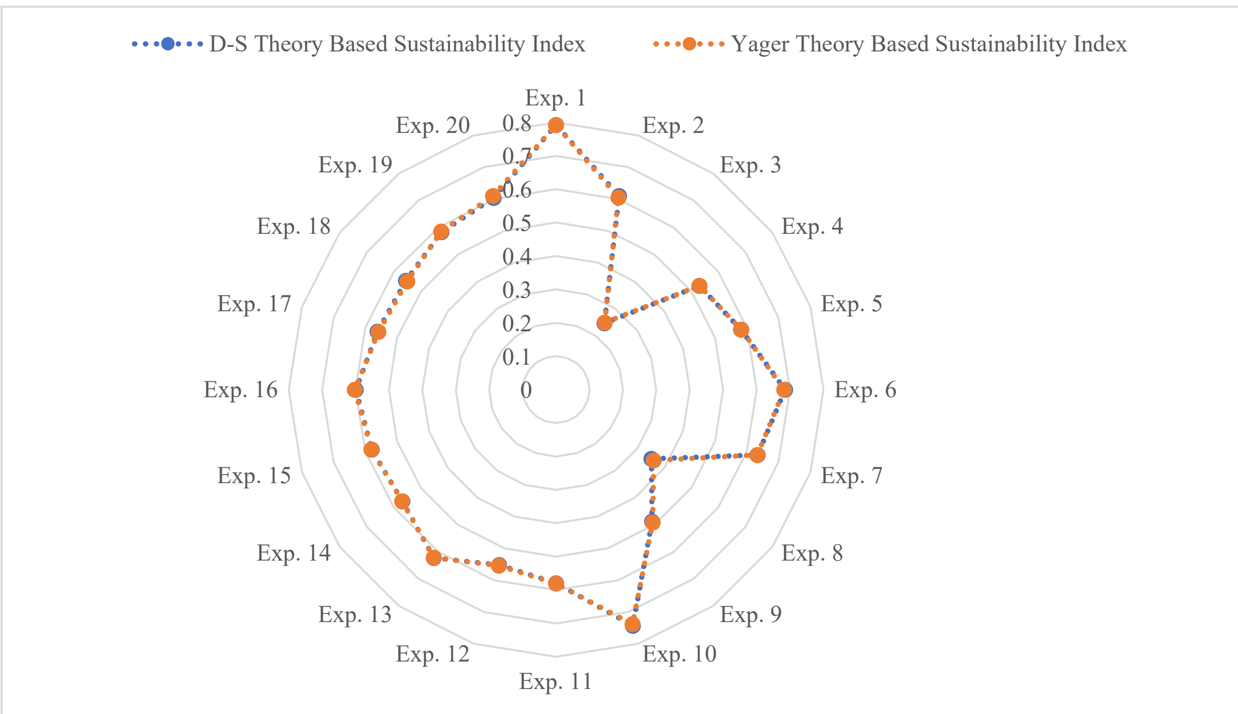


Figure 6.2: Results of sensitivity analysis.

### 6.3. Discussion

The results presented in Table 6.1 denote the condition of an organization regarding supply chain sustainability. By conducting this assessment at a fixed time interval, it is possible to ascertain the supply chain sustainability trend for an organization, by which business conditions can be judged in terms of supply chain sustainability for a designated period. Using the proposed approach, changes to an organization's supply chain sustainability condition over time can be easily evaluated. This is the key strength of the proposed assessment model. The assessment procedure using the proposed model largely depends on the voluntarily reported data. As such, the effectiveness of the supply chain sustainability model greatly relies on the availability of the information provided by the organization under assessment. The organizations that maintain similar attributes and the same measurement philosophy can be evaluated and compared using the proposed methodology. Before comparing multiple organizations, standardized guidelines should be implemented before establishing a proper reporting system relevant to the selected attributes. It is essential to develop a strong supply chain sustainability concept for the use and development of the proposed model. From Figure 6.1, it is observed that, using the proposed approach, the evaluation grade-wise basic probability assignment or belief percentage can be obtained for both D-S theory and Yager's rule. To verify the similarity Yager's rule is used and it is observed that there is no significant difference between the results from the two approaches.

In the previous section, it was shown that to assess sustainability, triple bottom line dimensions like economic, environmental and social sustainability can be calculated and combined using the proposed method. Here, social sustainability is used as the general attribute and, under this attribute, five basic attributes are selected based on the availability of information in the studied organization. Similarly, for the economic and environmental attributes basic attributes are selected. Among the three general attributes, the weight of social sustainability is the lowest, with environmental sustainability being weighted only slightly higher. Economic sustainability is weighted highest. These weights are also set for the basic attributes based on the respondents' review. For the assessment of social sustainability, basic probability assignment or belief data for each basic attribute is collected directly from the studied organization and then combined using D-S theory and Yager's rule. Similarly, the economic and environmental sustainability is calculated. From the computation, it is found that the final rating for the social sustainability index is {(poor, 0.02), (fairly poor, 0.08), (average, 0.21), (good, 0.65), (excellent, 0.03)}. For the condition state 'good', here the degree of confidence is highest at 65%. On the other hand, using Yager's rule the final rating for the social sustainability index is {(poor, 0.02), (fairly poor, 0.08), (average, 0.21), (good, 0.64), (excellent, 0.04)}. In the outcomes of D-S theory and Yager rule there are no significant differences.

Accordingly, based on D-S theory the final rating for economic sustainability index is {(poor, 0.01), (fairly poor, 0.02), (average, 0.08), (good, 0.81), (excellent, 0.08)}, and for environmental sustainability index is {(poor, 0.03), (fairly poor, 0.15), (average, 0.73), (good, 0.06), (excellent, 0.03)}. The degree of confidence for the condition state 'average' is highest for environmental sustainability at 73%. From Yager's rule-based calculation, the final rating of the economic sustainability index is {(poor, 0.01), (fairly poor, 0.02), (average, 0.08), (good, 0.80), (excellent, 0.09)} and for the environmental sustainability index, the final rating is {(poor, 0.03), (fairly poor, 0.15), (average, 0.72), (good, 0.07), (excellent, 0.03)}. Thus, using the two hierarchical calculation approach, the comparison of the outcome is judged.

To get the overall supply chain sustainability index, the three basic attributes are combined. After this, to get a single value regarding supply chain sustainability, a utility perspective calculation is conducted. The final rating for overall supply chain sustainability index based on D-S theory is {(poor, 0.01), (fairly poor, 0.04), (average, 0.16), (good, 0.72), (excellent, 0.06)} and based on Yager's rule is {(poor, 0.01), (fairly poor, 0.04), (average, 0.17), (good, 0.71), (excellent, 0.07)}. The degree of belief or confidence for the condition state 'good' is highest and the condition state 'average' is second highest. The unassigned degree of belief for the overall assessment is .08% from D-S theory and 0.12% from Yager's rule. The incompleteness in the overall assessment is represented by this value. The utility perspective supply chain sustainability index value from D-S theory is 0.693977814 and from Yager's rule 0.69465252. The utility perspective value for the overall supply chain sustainability index denotes that the overall sustainability condition in the supply chain is above 'average' or moderate state.

From the distribution of the supply chain sustainability index, the management of the organization can easily perceive the tendency towards supply chain sustainability. The distributed results also express the degree of incompleteness or uncertainty of an organization to express their supply chain sustainability condition; this being another key benefit of the model. Due to the ease of use, the proposed sustainability model is a good tool for decision and policy makers to monitor sustainability conditions. Accordingly, it can be used as a key performance measurement tool by an organization.

On the other hand, by adopting the proposed supply chain sustainability assessment methodology, the organization can sense how it is focusing and acting upon the triple bottom line dimensions (i.e., economic, environmental and social) of supply chain sustainability. The results from the sustainability assessment of the supply chain enable the strategic decision maker to understand the position of the organization in terms of sustainability, which is crucial in the competitive business arena. Finally, in the same platform, if a board of management wishes to compare homogeneous organizations based on the sustainability of supply chains, then the adoption of the proposed methodology would constitute an effective approach.

# CHAPTER 7

## CONCLUSIONS AND RECOMMENDATIONS

### 7.1. Conclusions

Today, organizations are becoming more dynamic in nature. Moreover, with the involvement of different types of stakeholders, sources of uncertainty have also increased. Therefore, the sustainability assessment of the supply chain of an organization has become a crucial task for the managerial teams to achieve positive business growth. Sustainability assessment methods need a rational, transparent and repeatable approach. Sustainability assessment is a challenging task as it involves incorporating a diverse range of contributing factors to interpret the overall sustainability index of a supply chain. With the uncertainties stemming from the inherent subjectivity of the interpretation process, the problem becomes increasingly complex. However, the necessity for ease of use and simplicity guided the development of proposed model to provide feedback on supply chain sustainability status over time.

In this research, an integrated decision-making model based on AHP, D-S theory and Yager's recursive rule of combination was proposed for assessing supply chain sustainability. The model is the main contribution of this research. To perform multi-criteria decision analysis under uncertainty the model integrated AHP and D-S theory. The proposed approach consists of selecting supply chain sustainability attributes, data collection and data aggregation to get the supply chain sustainability index. To obtain the assessment index, the calculated weights were used in HER approaches of D-S theory and Yager's combination rule. Using a belief structure and belief decision matrix, the D-S theory provided an appropriate and transparent model for establishing a supply chain sustainability assessment index. In this research, the overall condition of an organization is assessed based on supply chain sustainability. As such, the proposed supply chain sustainability assessment model provides a foundation further research considering the triple bottom line economic, social and environmental dimensions.

The developed framework can combine subjective, imprecise, incomplete and conflicting data or information and can aggregate multiple bodies of evidence incorporating both aleatory and epistemic uncertainty. HER approaches can deal with incomplete and conflicting data without having to make strong assumptions in place of missing data, as required in other soft computing methods. D-S theory-based combination is more important because lesser data is lost during normalization as compared to Yager's rule where conflicting data is shifted to ignorance. Due to the similarity of the two approaches, Yager's rule of combination is used to compare the results of the D-S theory in this research. It is found that, the results of the D-S theory and Yager's rule are approximately similar. Sensitivity analysis is performed to determine the responses of computational models in decision making by changing the weights of attributes. Because of the strong mathematical foundation of the framework the model can be modified at any hierarchical level without changing the recursive combination approach. In this research, the results depict supply chain sustainability as a value as well as in a distributed manner using the robust and integrated framework.

### 7.2. Recommendations

There are many attributes under the three dimensions of supply chain sustainability. Uncertainties are associated with these attributes. In this thesis, only fifteen basic attributes are selected under three sustainability dimensions for assessing supply chain sustainability. So, this research can be expanded considering more attributes. Based on random samples the data is collected from experts' feedback. The model can be enhanced by incorporating more experts to participate in answering the designed questionnaires or survey. In this study, AHP method is used whereas to determine the weights of attributes fuzzy AHP can be used to capture the uncertainty. In the assessment process different stakeholders can be involved to get more accurate results. In this research, D-S theory of HER is used but in further study for assessing sustainability additional mathematical theories like fuzzy sets theory and rough sets can be applied. To verify the similarity of the D-S rule of combination besides Yager's rule, the Kim and Park method, Duboi's and Prade's as well as the simple multi-attribute rating technique method could be used. For assessing sustainability of supply chain by finding organizations who are very willing to share belief structure data regarding selected sustainability attributes can be adopted further. Assessment of the sustainability of multiple organizations can also be performed for comparison within a unified platform.

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# APPENDICIES

**Appendix A: Questionnaires survey covering the process of data collection.**

**Phase 1,** Identification of most relevant factors/ attributes relevant to Supply Chain Sustainability (SCS).

Q.1 What is your designation and experience/role in the organization?

Q.2 Are the listed factors relevant to Supply chain sustainability (SCS)?
Please write Yes if you think the mentioned factors are relevant to SCS, otherwise write No. You are also free to add/delete any of the factors mentioned in the list.

Table A-1: Response sheet for respondents.

| General Factor | Basic Factor | Yes/No |
|---|---|---|
| Economic | | |
| | Profitability | |
| | Market Competitiveness | |
| | Research & Development expenditures | |
| | Local procurement | |
| | Operating costs | |
| Environmental | | |
| | Energy Efficiency | |
| | Waste Management | |
| | Water Management | |
| | Supplier assessment | |
| | Emissions | |
| Social | | |
| | Human Rights | |
| | Health and Safety | |
| | Training and Education | |
| | Consumer Issues | |
| | Supplier Relationship | |

Please mention any other main sustainability factor in this column. Please mention any other basic factors in this column.

**Phase 2,** prioritizing the identified factors with the help of expert's inputs.

Q.3 Are you realize the assessment scale which is provided below to assess the selected attributes?

Table A-2: Scale to be used for making pair wise comparison.

| Intensity of importance | Definition | Explanation | Preference Judgements |
|---|---|---|---|
| 1 | Equal importance | Two elements contribute equally to the objective | Factor i and j are both equally important |
| 3 | Moderate importance | Experience and judgment slightly favor one element over another | Factor i is moderately important to risk j |
| 5 | Strong Importance | Experience and judgment strongly favor one element over another | Factor i is strongly important to risk j |
| 7 | Very strong importance | One element is favored very strongly over another, it dominance is demonstrated in practice | Factor i is extremely important to risk j |
| 9 | Extreme importance | The evidence favoring one element over another is of the highest possible order of affirmation | Factor i is extremely more important to risk j |
| 2,4,6,8 can be used to express intermediate values between the two adjacent judgements. Reciprocals: When activity i. compared to j is assigned one of the above numbers, then activity j compared to i. is assigned its reciprocal. | | | |

Q.4 Please fill the following comparison matrices using above mentioned scale. Please compare the importance of the factors and fill in the table.

Table A-3: Pairwise Comparison Questionnaires for main/general factors.

| **Factor (ij)** | Economic | Environmental | Social |
|---|---|---|---|
| Economic | 1 | | |
| Environmental | | 1 | |
| Social | | | 1 |

In the same way, please also fill the pair wise relation matrix for the basic or sub factors.

Table A-4: Pair wise comparison relation matrix for economic related sub/basic factors.

| Factor (ij) | Profitability | Market Competitiveness | Research & Development expenditures | Local procurement | Operating costs |
|---|---|---|---|---|---|
| Profitability | 1 | | | | |
| Market Competitiveness | | 1 | | | |
| Research & Development expenditures | | | 1 | | |
| Local procurement | | | | 1 | |
| Operating costs | | | | | 1 |

Table A-5: Pair wise comparison relation matrix for environmental related sub/basic factors.

| Factor (ij) | Energy Efficiency | Waste Management | Water Management | Supplier assessment | Emissions |
|---|---|---|---|---|---|
| Energy Efficiency | 1 | | | | |
| Waste Management | | 1 | | | |
| Water Management | | | 1 | | |
| Supplier assessment | | | | 1 | |
| Emissions | | | | | 1 |

Table A-6: Pair wise comparison relation matrix for social related sub/basic factors.

| Factor (ij) | Human Rights | Health and Safety | Training and Education | Consumer Issues | Supplier Relationship |
|---|---|---|---|---|---|
| Human Rights | 1 | | | | |
| Health and Safety | | 1 | | | |
| Training and Education | | | 1 | | |
| Consumer Issues | | | | 1 | |
| Supplier Relationship | | | | | 1 |

**Phase 3,** Collecting data of degree of confidence/Belief percentage or basic probability assignment for the selected attributes from the studied company to assess sustainability in supply chain.

Q.5 Please fill the following table with belief percentage by subjectively judging the attributes based on evidence.

Table A-7: Subjective Judgments for Assessing Economic Sustainability

| | Degree of belief (β) | Evaluation Grades | | | | |
|---|---|---|---|---|---|---|
| | | Poor | Fairly Poor | Average | Good | Excellent |
| Basic Attribute | Profitability (%) | | | | | |
| | Market Competitiveness (%) | | | | | |
| | Research & Development expenditures (%) | | | | | |
| | Local procurement (%) | | | | | |
| | Operating costs (%) | | | | | |

Table A-8: Subjective Judgments for Assessing Environmental Sustainability

| | Degree of belief (β) | Evaluation Grades | | | | |
|---|---|---|---|---|---|---|
| | | Poor | Fairly Poor | Average | Good | Excellent |
| Basic Attribute | Energy Efficiency (%) | | | | | |
| | Waste Management (%) | | | | | |
| | Water Management (%) | | | | | |
| | Supplier assessment (%) | | | | | |
| | Emissions (%) | | | | | |

Table A-9: Subjective Judgments for Assessing Social Sustainability

| Basic Attribute | Degree of belief (β) | Evaluation Grades | | | | |
|---|---|---|---|---|---|---|
| | | Poor | Fairly Poor | Average | Good | Excellent |
| | Human rights (%) | | | | | |
| | Health and safety (%) | | | | | |
| | Training and education (%) | | | | | |
| | Consumer issues (%) | | | | | |
| | Supplier relationship (%) | | | | | |

**Appendix B: List of experts with job position and year of experience are tabulated in this section.**

Table B-1. Industry Experts or Respondents' Details

| Companies | Experts | Affiliation | Experience (Years) |
|---|---|---|---|
| DBL Group | Expert 1 | Manager, Sustainability | 16 |
| DBL Group | Expert 2 | COO, Supply Chain | 20 |
| DBL Group | Expert 3 | COO, Operations | 25 |
| Coats BD. Ltd. | Expert 4 | Director, Supply Chain | 25 |
| East West Industrial Park | Expert 5 | Executive Director | 14 |
| Best Shirts Ltd. | Expert 6 | Executive Director | 18 |
| G-STAR RAW | Expert 7 | Country Manager | 17 |

Table B-2. Academic Experts or Respondents' Details

| Name | Affiliation | Organization | Specialization |
|---|---|---|---|
| Expert 1 | Professor Industrial & Production Engineering Department | Shahjalal University of Science and Technology | Supply Chain Management |
| Expert 2 | Associate Professor Industrial & Production Engineering Department | Shahjalal University of Science and Technology, Casual Academic at RMIT University | Sustainable Supply Chain Management |

**Appendix C: Multiple respondents' or stakeholder's subjective judgement for the basic attributes with respondent's job position are tabulated in this section.**

Table C-1: Multiple respondents' subjective judgement for the attribute of 'Human rights'

| Respondent 1 | Respondent 2 | Respondent 3 |
|---|---|---|
| A (0.8), G (0.2) | A (0.6), G (0.4) | G (1.0) |

Table C-2: List of respondents or stakeholder for the attribute of 'Human rights'

| Respondent no. | Organization | Position |
|---|---|---|
| 1 | DBL Group | Asst. manager – planning |
| 2 | DBL Group | Work Study officer |
| 3 | DBL Group | Delivery Man |

Table C-3: Multiple respondents' subjective judgement for the attribute of 'Supplier relationship'.

| Respondent 1 | Respondent 2 | Respondent 3 |
|---|---|---|
| G (0.6), E (0.4) | G (1.0) | G (0.7), E (0.3) |

Table C-4: List of respondents or stakeholder for the attribute of 'Supplier relationship'.

| Respondent no. | Organization | Position |
|---|---|---|
| 1 | Coats BD. Ltd | Territory manager |
| 2 | Square Group | General manager |
| 3 | Thermax Group | Manager -supply chain |

Table C-5: Multiple respondents' subjective judgement for the attribute of 'Consumer issues'

| Respondent 1 | Respondent 2 | Respondent 3 |
|---|---|---|
| A (0.1), G (0.9) | A (0.5), G (0.5) | A (1) |

Table C-6: List of respondents or stakeholder for the attribute of 'Consumer issues'

| Respondent no. | Organization | Position |
|---|---|---|
| 1 | G-star raw | Country Manager |
| 2 | H & M | Merchandiser |
| 3 | Target Sourcing | Auditor |

Table C-7: Multiple respondents' subjective judgement for the attribute of 'Health and safety'.

| Respondent 1 | Respondent 2 | Respondent 3 |
|---|---|---|
| F (0.3), A (0.7) | A (0.5), G (0.5) | G (1.0) |

Table C-8: List of respondents or stakeholder for the attribute of 'Health and safety'.

| Respondent no. | Organization | Position |
|---|---|---|
| 1 | DBL Group | Manager- logistics |
| 2 | DBL Group | Executive -planning |
| 3 | DBL Group | In charge – production |

Table C-9: Multiple respondents' subjective judgement for the attribute of 'Training and education'.

| Respondent 1 | Respondent 2 | Respondent 3 |
|---|---|---|
| F (0.5), A (0.5) | A (8.0) | P (0.2), F (0.3), A (0.4) |

Table C-10: List of respondents or stakeholder for the attribute of 'Training and education'.

| Respondent no. | Organization | Position |
|---|---|---|
| 1 | DBL Group | Executive- Supply Chain |
| 2 | DBL Group | Asst. Manager- planning |
| 3 | DBL Group | Executive- Operations planning |

## Appendix D: Evidential data for the quantitative attributes are tabulated in this section.

Table D-1: Evidential data for the selected attributes from the studied company.

| Factors | Company's Current State | Standard for Comparison |
|---|---|---|
| Profitability | 363.96 million USD (gross revenue) | Targeted percent* |
| Market competitiveness | In 49% market volume, contributing 1.42% | Targeted percent* |
| Local procurement | 10%-15% | 25%-30% expected |
| Operating costs | 229.61 million USD | Targeted percent* |
| Energy efficiency | For operations 39075517 $m^3$ CNG and 15266824 $m^3$ diesel used. | Targeted percent* |
| Waste management | Hazardous 256675 kg<br>Non-Hazardous 8410423 kg | Targeted percent* |
| Water management | Target 50 liters/kg dyeing-2020<br>(Now at 55 lit/kg)<br>2164292 lit Ground water used. | Targeted percent* |
| Emissions | From operational facilities *120,704 tons CO2,* | Targeted percent* |

| | | |
|---|---|---|
| | From transportation *2574 tons* $CO_2$ emitted | |
| Health and safety | A total of 246 non-fatal accidents; 239 occupational diseases reported.<br>1033 lost days recorded. | Targeted percent* |
| Training and education | 13.91 hrs/Female/Year<br>8.14 hrs/Male/Yr<br>Overall average is 10.26 hrs | Targeted percent* |

***Note:** *For comparing current condition of the organization, the management sets baseline. For a particular period of time, the management of the organization set some percentage of improvement for each factor as the target. Then the current condition value is compared to that target to judge the condition of the organization.*