ANALYSIS OF THE SUSTAINABLE SUPPLY CHAIN STRUCTURE UNDER UNCERTAINTY ENVIRONMENT

(SÜRDÜRÜLEBİLİR TEDARİK ZİNCİRİ YAPISININ BELİRSİZLİK ORTAMINDA ANALİZİ)

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Gizem Çifçi, B. S.,

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Supervisor : Prof. Dr. Gülçin Büyüközkan Feyzioğlu

Committee Members: Asst. Prof. Dr. M. Ebru Angün

Asst. Prof. Dr. A.Gül Öncel

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List of Symbols

CR : Customer Requirements
DfE : Design for Environment
DM : Decision Maker
DR : Design Requirements
Eco : Economic
Env : Environmental
ECQFD : Environmentally conscious QFD
GDM : Group Decision Making
HOQ : House of Quality
IOWG : Induced Ordered Weighted Geometric
LCA : Life Cycle Assessment
LCC : Life Cycle Costing
MA-OWA : Majority Additive-Ordered Weighting Averaging
OWG : Ordered Weighted Geometric
QFD : Quality Function Deployment
QFDE : Environmentally conscious QFD
QGID : Quantifier Guided Importance Degree
OWA : Ordered Weighting Averaging SC: Supply Chain
SCM : Supply Chain Management
Soc : Social
SQFD : Sustainable Quality Function Deployment
TRIZ : Theory of Inventive Problem Solving
a_y : Intermediate Alternative
CL_{ij} : Consistency Level
CP_i, CP_j : Completeness Values

cp_{ij}^{yl} : Estimation of Preference

H_{ij}^{l} : The Sets of Intermediate Alternative that can be used to Estimate p_{ij}

$\widetilde{p}_{ij}$: Fuzzy Preference Relation

p_{ij} : Preference value

$\#EV$: The number of Preference Values Known

εp_{ij} : Error

α_{ij} : A Parameter to Control the influence of Completeness

W : Exponential Weighting Vector

Q : Fuzzy Quantifier

$QGID_i$: Quantifier Guided Importance Degree

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Abstract

Integration of sustainable development in the business and supply chain is potentially a source of competitive differentiation for firms. Academic and corporate interest in sustainable supply chain management (SCM) has also risen considerably in recent years. Sustainable SCM is the management of material, information and capital flows as well as cooperation among companies along the SC while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements. This paper examines the components and elements of sustainable SCM and how they serve as a foundation for an evaluation framework. By using the quality function deployment (QFD) as a product or process development tool, an effective sustainable SCM structure can be obtained. The traditional QFD structure requires individuals to express their preferences in a specific scale. However in practice, people contributing to the process generally tend to give information about their personal preferences linguistically and even incompletely, depending on their background. Therefore, the objective of this study is to apply an extended QFD methodology in sustainable SCM by introducing a new group decision making (GDM) approach that takes incomplete preference relations into account, and fuses different preferences into one uniform group decision by means of fuzzy set theory. This methodology is compatible with the requirements of the various stakeholders involved in the SC. To assess the validity of the proposed approach, applications in two specific companies are given.

Résumé

L’intégration du développement durable dans la chaîne d’approvisionnement est potentiellement une source de différenciation concurrentielle pour les entreprises. De nos jours, l’intérêt académique et institutionnel pour la gestion de la chaîne d’approvisionnement durable a augmenté considérablement. La gestion de la chaîne d’approvisionnement durable est la gestion du matériel, de l’information, des mouvements de capitaux en même temps que la gestion de la coopération des entreprises comprises dans la chaîne en tenant compte des objectifs de toutes les trois dimensions du développement durable qui dérivent des besoins des clients et des parties prenantes, c’est-à-dire, des objectifs économique, de l’environnement et sociales. Ce travail observe les composants de la gestion de la chaîne d’approvisionnement durable et comment ils servent de base à une structure d’évaluation. On peut obtenir une structure efficace de la gestion de la chaîne d’approvisionnement durable en utilisant le déploiement fonction qualité (QFD) comme un instrument de développement d’un produit ou d’un processus. La structure traditionnelle du déploiement fonction qualité exige des individus d’exprimer leurs préférences en une échelle spécifique. Pourtant, les gens qui participent au processus ont tendance à exprimer leurs préférences personnelles avec des mots au lieu des nombres même parfois imparfaitement selon leur expérience. Dans ce contexte, le but de ce travail est d’appliquer la méthode prolongée du déploiement fonction qualité dans la gestion de la chaîne d’approvisionnement durable en introduisant une nouvelle technique de prise de décision par consensus qui tient compte des relations des préférences incomplètes et qui fusionne les différentes préférences en une décision uniforme par consensus en utilisant la théorie des ensembles flous. Cette méthode est compatible avec les besoins de différents acteurs de la chaîne d’approvisionnement. On a présenté aussi une partie d’applications exécutées dans deux entreprises spécifiques pour évaluer la validité de la méthode proposée.

Özet

Sürdürülebilir gelişmenin iş ve tedarik zinciri ile bütünleşmesi, firmalar için potansiyel bir rekabetçi farklılaşma kaynağıdır. Son yıllarda sürdürülebilir tedarik zinciri yönetimine (TZY) akademik ve tüzel ilgi de dikkate değer derecede artmaktadır. Sürdürülebilir TZY malzeme, bilgi ve sermaye akışının, hem de TZ boyunca şirketler arası işbirliğinin; müşteri ve paydaşların gereksinimlerinden türeyen sürdürülebilir gelişmenin üç boyutunun (ekonomik, çevresel ve sosyal) göz önünde bulundurularak yönetimidir. Bu çalışma sürdürülebilir TZY'nin öğelerini ve onların bir değerlendirme yapısı için nasıl temel olacaklarını incelemektedir. Ürün ya da süreç geliştirme aracı olan kalite fonksiyon göçerimi (KFG) kullanılarak, etkili bir sürdürülebilir TZY yapısı elde edilebilir. Geleneksel KFG yapısı, bireylerin tercihlerini belirlenmiş bir skalada ifade etmelerini gerektirir. Fakat pratikte sürece dahil olan kişiler genellikle, tercihleri hakkında altyapılarına dayanarak sözel ve hatta tam olmayan bilgi verme eğilimindedirler. Bu yüzden çalışmanın amacı, sürdürülebilir TZY'de tamamlanmamış tercih ilişkilerini göz önüne alan ve bulanık küme teorisi ile farklı tercihleri tek bir grup kararına kaynaştıran yeni bir grup karar verme (GKV) yaklaşımı sunarak geliştirilmiş bir KFG metodolojisi uygulamaktır. Bu metodoloji TZ'de yer alan çeşitli paydaşların gereksinimleri ile uyumludur. Önerilen yaklaşımın geçerliliğini ölçmek için, belirli iki firmada uygulamaya yer verilmiştir.

1. INTRODUCTION

In the current business environment, global competition is an unpreventable fact and customer demands are diversified. Thereby, supply chain management (SCM) has received greater attention by manufacturing organizations. Firms increasingly rely on their supply network to handle more complex technologies and higher customer expectations. Supply chain (SC) performance measures have conventionally been orientated around cost, time and accuracy. However, organizations are now coming under increased scrutiny from customers and governments regarding their compliance with environmental and social responsibility [1]. Industrial production can have a great impact and damage on the sustainability of the natural environment and human life such as the impacts include depletive resource use, global environmental impacts, local environmental impacts, health impacts, and safety risks. These environmental issues have received more and more attention in recent years and SC operation with sustainability and environmental consideration has become an increasingly important issue. Thereby, these growing interest and importance to the supply function raise the importance of the sustainable SC practices.

Notwithstanding these pressures, great efforts have recently resulted in increasing the environmental performance of SCs [2–9]. In this paper, an overview of sustainability issues, sustainability focused SCs, their drivers and their influence on decision-making and how sustainability is affecting (or is going to affect) the organization of the SC. In more general terms, the link between traditional (financial) performance criteria and sustainability is under discussion. However, to obtain more sustainable solutions, organization properties must meet sustainable SC and customer requirements. Especially, quality function deployment (QFD) is one of these techniques to design the needs of customer and into practical measures. This approach enables the firms to become proactive to quality problems rather than taking a reactive position by acting on customer complaints. The approach bases on total quality management, which offers a vast techniques to ensure the improvement of quality and productivity.

QFD is comprised of major group decision making (GDM) processes. In practice, determining the weights of customer requirements (CRs) is a GDM process. This mainly because of the ‘danger’ of relying on a single decision maker (DM) with his/her limitations of experiences, preferences or biases about the issues involved, and the fact that individuals are often unable to clearly identify their own states. Multiple DMs, thus GDM, are often preferred rather than a single DM to avoid the bias and minimize the partiality in the decision process [10–13]. However, it is more difficult to assess the performance of this process with accurate quantitative evaluation due to its uncertain nature. In a GDM process, generally different and/or even subjective opinions are quite often due to the limitations of experience and impreciseness. Moreover, due to constraints as time pressure, lack of expertise in related issue, etc.; DMs may develop incomplete preferences in which some of the elements cannot be provided. The fact that the judgments of DMs usually cannot be obtained completely shows us that the GDM process needs to derive a single group preference from a number of incomplete individual preferences.

Under such circumstances, an analytical tool for perceiving and prioritizing the quantitative and qualitative, sometimes vague and imprecise or/and even incomplete preference of the customer is offered. The objective of this study is to apply an extended QFD methodology in sustainable SC by introducing a GDM approach that takes incomplete information [14–20] into account, and fuses different preferences into one uniform group decision by means of fuzzy set theory [21]. As incomplete preferences are not widespread yet, there exists no study in the literature that neither combines them with QFD or any other approaches, nor applies it in sustainable SCM field.

The paper is organized as follows. Section 2 gives a comprehensive literature survey about sustainable SCM and discusses why sustainability should be incorporated in SCs.

Section 3 provides information about QFD structure and proposed sustainable QFD model. Section 4 presents the essence of the analytic approach and computational procedure step by step. Applications in two companies which encourage sustainability practices in their structure, namely HAVI Logistics Turkey and ABC A.Ş., are then given in Section 5. While Section 6 indicates case study results and discussions, Section 7 concludes the study and gives future directions.

2. SUSTAINABLE SCM

2.1. SUSTAINABILITY – AN OVERVIEW

Sustainable development is a rich area for academic research that is still in its infancy for field and has the potential to affect future government policy, current production operations, and identify new business models. While the first consideration of sustainability can be traced back to practices of many ancient cultures, more recent attention toward sustainability and the environment can be found in the literature [22–36]. As management principles and theories associated with sustainable SCs continue to advance, the need for additional investigation and critical analysis arises to further understand the field. Historically, the concept of SCs and the environment can be traced back over decades. This early period was a foundation building time for environmental SCM by integrating the practices and developing frameworks and models. Much of the early work was identifying and describing what it meant to have environmentally sound SC systems [37].

During this period, the concept of sustainability started to incrementally enter the corporate environmental management lexicon. The term sustainability also has its own history and definition ranging from an inter-generational philosophical stance to a multi-dimensional and multi-scale term for business management. The inter-generational philosophy focuses on making sure that future generations are not negatively impacted by decisions we make today. The multi-dimensional focus includes topics related to the 'triple-bottom-line' of balancing corporate social responsibility including balancing economic, environmental and social components of sustainability [37]. The multi-scale focus includes geographical, institutional, and temporal scales. That is, sustainability has been applied to regions and countries as well as individual organizations and partnerships including both short-term (months, years) and long-term (decades) dimensions. Thereby, not only the academic field, but also communities, governments, businesses, international agencies, and non-government organizations are increasingly concerned with establishing a means to monitor performance and to assess progress towards sustainable development [23]. This broadening of the topic, and its many meanings and dimensions have made a coherent industrial research agenda in this field difficult. With the additional complexities of SCM, research and investigation becomes much more than a trivial exercise.

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." This definition was created in 1987 at the World Commission on Environment and Development [38]. The notion of sustainable development has attracted a lot of attention over the last few decades particularly since the publication of this report. A wide range of issues are covered under the umbrella of sustainable development including public policies, political systems, corporate citizenship, international trade, social equity/justice, economic growth/development. Many companies have discovered that there are economic advantages to changing designs towards being more sustainable, whether because they are easier to market or cheaper to produce. The most applicable benefits are better organization and documentation of their environmental activities, increased legal certainty, improved image, greater employee motivation, reductions in resource use, enhanced plant safety, and optimization of process flows [23], [39], [40].

Integration of sustainable development in the business is potentially a source of competitive differentiation. Discussions of sustainability are driven by the basic notion that a SC's performance should be measured not just by profits, but also by the impact of the chain on ecological and social systems [26–28], [41]. Different authors and researchers have defined sustainability from similar and different perspectives, driving forces and purposes. However, all sustainability structures have commonly three main pillars as shown in Figure 2.1 (adapted from [42]), namely economical, environmental and social.

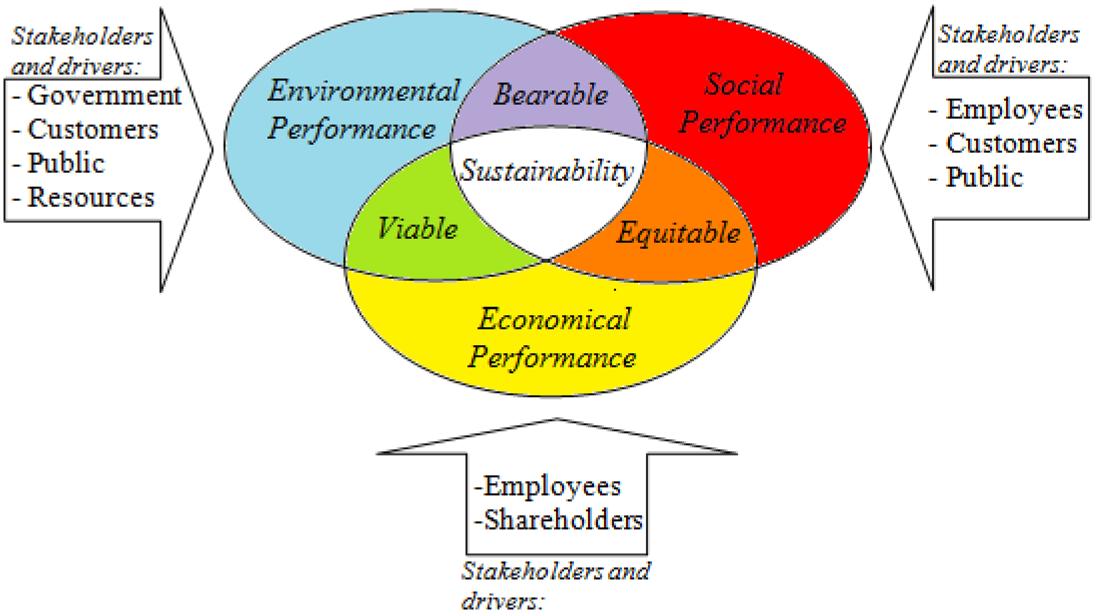

Figure 2.1 Components of sustainability

Accordingly, within the sustainable development framework, economic growth goes hand-in-hand with environmental and social consciousness [44]. Environmental awareness is one of the defining issues of this, and future decades. The following quote from Gordon Brown [45] clearly demonstrates this point in his speech delivered to the United Nations Ambassadors on April 20, 2006:

"Environmental sustainability is not an option – it is a necessity. For economies to flourish, for global poverty to be banished, for the well-being of the world's people to be enhanced – not just in this generation but in succeeding generations – we have a compelling and ever more urgent duty of stewardship to take care of the natural environment and resources on which our economic activity and social fabric depends."

The interrelationships among the environment, society, and economic/industrial development are integral to the concept of sustainability. In order to achieve sustainable development in both industrialized and developing nations, we must characterize the connections and interactions among these three ''pillars'' of sustainability. This is because a balance among the pillars cannot be achieved without an adequate understanding of how societal and industrial actions affect the environment or how today's decisions may impact future generations. Therefore, increased knowledge and awareness of the issues encompassed by sustainable development are needed [31]. Figure 2.2 (adapted from [43]) depicts the characteristics of main three pillars for the sustainability of products, services, and other activities.

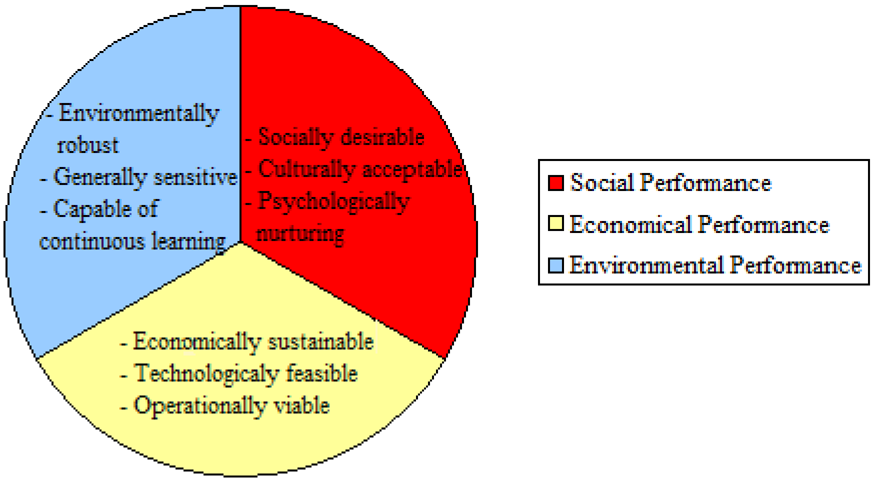

Figure 2.2 Characteristics of sustainability pillars

2.2. LITERATURE SURVEY FOR SUSTAINABLE SCM

SC is a modern business organization that integrates related companies, stages, and possible resources to strengthen business competitiveness, speed and capacity [44]. It encompasses all activities associated with the flow and transformation of goods from raw materials stage (extraction), through to the end user, as well as the associated information flows. Material and information flow both up and down the SC. SCM is the integration of these activities through improved SC relationships to achieve a sustainable competitive advantage [30]. As SC operation with sustainable consideration has become an increasingly important issue, both academic and corporate interest in sustainable SCM has risen considerably in recent years. In the literature, the terminology about the SC with sustainable consideration includes green SC [4], [7–9], environmental SC [1], [24], [25], and sustainable SC [29], [30], [32]. Figure 2.3 (adapted from [35]) depicts the evolution of SCs over time.

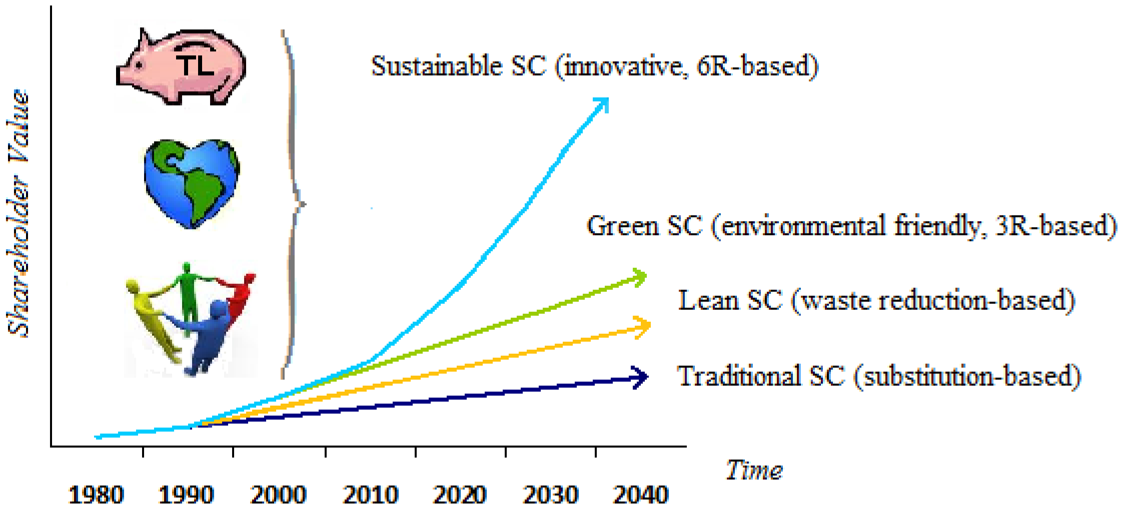

Figure 2.3 Evolution of SC

Typical environmental and social impacts of SC activities are [47]:

- Damage to ecosystems,
- Disruptions to communities due to inefficient logistics,
- Energy consumption,
- Community congestion,
- Development of agricultural land,
- Waste from obsolescent or damaged inventory,
- Waste from packaging or shipping containers,
- Hazardous material exposure,
- Excess waste in landfills from premature disposal,
- Air and water emissions,
- Traffic congestion, noise, and accidents.

Beyond these environmental and social impacts, the financial implications for business of congested transportation infrastructure, high fuel and energy costs and logisticrelated health and safety incidents are significant. The answer to reducing these impacts is not to constrain SC activities, but to manage them proactively through sustainable SC practices.

Companies are perceived as important actors in the drive for sustainability. Linked to this, and in response to increasing demands from various stakeholder groups, companies start to look at their SC to enhance their overall sustainability profile. In response to such demands, companies have to find ways to incorporate environmental and social aspects into their SCM [48]. Based on this, operations, purchasing and SC managers have seen the integration of environmental and social issues, including those embedded in related standards (e.g., ISO 14001) into their daily tasks [49]. Such triggers have increased interest in green/environmental or sustainable SCM. As the public awareness increases, buyers today are learning to purchase goods/services from suppliers that can provide them with low cost, high quality, short lead time, and at the same time, with environmental responsibility [50]. Money, components, and information flows might establish a sustainable SCM system but simultaneously with increasing government regulation and stronger public awareness in environmental protection, firms today simply cannot ignore environmental issues if they want to survive in the global market.

It is common practice for DMs to address the economic pillar of sustainability, and over the last decade, increasing effort has been directed at the environmental pillar through attention to environmental and social pillars. According to Zsidisin and Siferd [51], sustainable SCM is the set of SCM policies held, actions taken and relationships formed in response to concerns related to the natural environment with regard to the design, acquisition, production, distribution, use, reuse, and disposal of the firm's goods and services. Seuring and Müller [30] define sustainable SCM as "the management of material, information and capital flows as well as cooperation among companies along the SC while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements". Another definition comes from Pagell and Wu [32]: "sustainable SCM is one that performs well on both traditional measures of profit and loss as well as on an expanded conceptualization of performance that includes social and natural dimensions". Ciliberti et al. [52] gave a direct definition as: "management of SCs where all the three dimensions of sustainability, namely the economic, environmental, and social ones, are taken into account". Such conceptualizations are generally referred to the triple bottom line. If a sustainable chain is one that performs well on all elements of the triple bottom line, sustainable SCM is then the specific managerial actions that are taken to make the SC more sustainable with an end goal of creating a truly sustainable chain [32].

There are numerous definitions of the terms 'Sustainable' and 'SC/SCM'. A simplistic, but practical, definition can be: "Planning and management of raw materials and services from suppliers to manufacturer/service provider to customer and back with improvement of the social and environmental impacts explicitly considered". According to Linton et al., sustainability also must integrate issues and flows that extend beyond the core of SCM: product design, manufacturing by-products, by-products produced during product use, product life extension, product end-of-life, and recovery processes at end-of-life [29]. Since manufacturing is the core operation in a product's SC, when considering physical products, designing the system and promoting sustainability in its operations must center on a sustainable manufacturing approach by focusing on a broader, innovation-based 6R methodology (reduce, reuse, recycle, recover, redesign, remanufacture) [35].

One main objective is the economic success of a company's SC by complying with environmental and social standards on the basis of collaboration and corporate development between buyer and supplier [53]. Environmental impacts and violations of human rights should be discovered and stopped early in the SC. Thus, a rising influence of environmental and social standards on product and production decisions is expected for the future [54].

The starting points of sustainable SCM are generally external pressure and incentives set by different groups. While stakeholders form the widest possible description, two groups are of particular relevance. On the one hand, customers are of great importance, as operating the SC is only justified if the products and services are finally ''accepted'' by customers. On the other hand, all modes of governmental control, being from local municipalities, national or multi-national governments, are of great relevance [30]. Figure 2.4 introduces the frequently listed triggers for sustainability in SCs [4], [24], [29], [30], [50], [54].

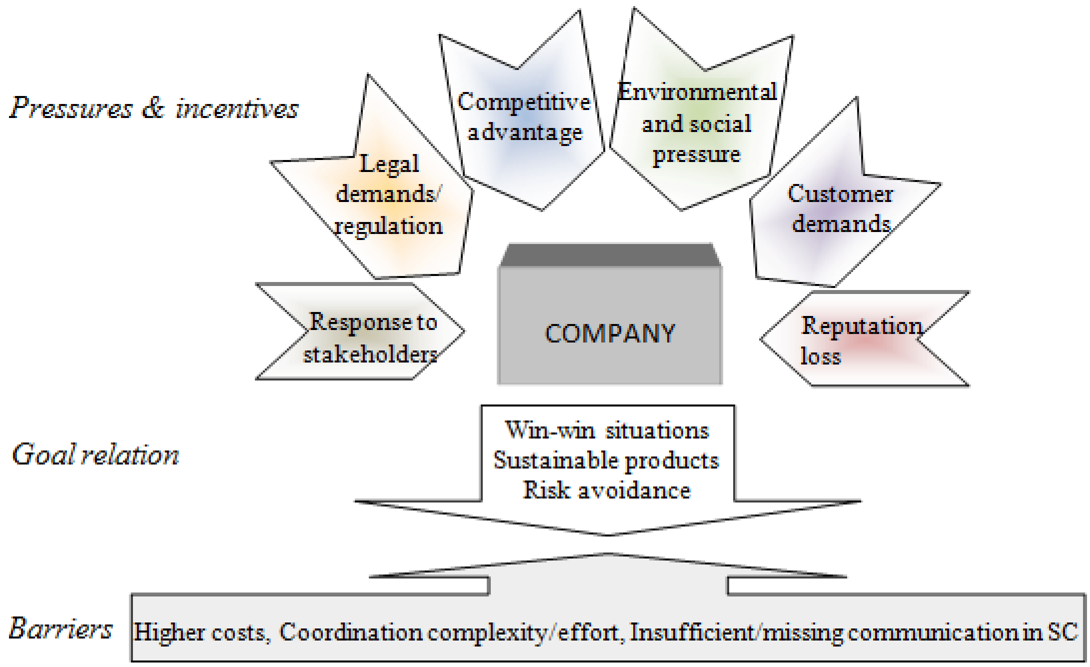

Figure 2.4 Trigger categories for sustainable SCM

When the company is pressured, it usually passes this pressure on to suppliers. As a response to the above-mentioned pressures and incentives, a number of companies have introduced supplier evaluation schemes which integrate environmental and social criteria [30], [48], [49]. An important means for implementing this are environmental and social standards which set minimum requirements. This often captures a kind of double aim: the first objective is to avoid related risk, which can be related to all three dimensions of sustainability [55], [56]. The second one is to enhance the overall SC performance, where the focus is commonly on the relation between environmental and economic performance [4], [30], [54]. Based on the triggers as goals, pressures and incentives, barriers are listed which hinders the cooperation for sustainability in a SC. Related to this, supporting factors for sustainable SCM can also be mentioned as [30]:

- ✓ Company-overlapping communication
- ✓ Management systems (e.g., ISO 14001, SA 8000)
- ✓ Monitoring, evaluation, reporting, sanctions
- ✓ Training education of purchasing employees and suppliers
- ✓ Integration into the corporate policy.

Most of the existing research on sustainable SC design-related aspects has a narrow focus on cost minimization, profit maximization or some form of economic value-addition (single objective). Recently, increasing effort has been directed at the environmental focus through attention to environmental life cycle impacts. Comprehensive models that integrate environmental and societal considerations, in addition to economic benefits, are necessary to promote the design and managing of sustainable SCs. One of the major challenges in developing such models is the lack of metrics to quantify the extent of environmental and societal impacts on SC operations [35]. Table 2.1 presents overview of some study focuses in the literature associated with “sustainability” and “SC”.

Table 2.1a Several study focuses associated with “sustainability” and “SC

Author	Ref.	Paper Name	Sustainability Focus		
			Financial	Environmental	Social
Côté et al.	[57]	Influences, practices and opportunities for environmental supply chain management in Nova Scotia SMEs			
Darnall et al.	[58]	Environmental management systems and green supply chain management: complements for sustainability?			
de Brito et al.	[44]	Towards a sustainable fashion retail supply chain in Europe: Organisation and performance			
Filho	[59]	Supply chain approach to sustainable beef production from a Brazilian perspective			
Georgiadis & Besiou	[60]	Sustainability in electrical and electronic equipment closed-loop supply chains: A system dynamics approach			
Holt & Ghobadian	[8]	An empirical study of gren supply chain management practices amongst UK manufacturers			
Hutchins & Sutherland	[31]	An exploration of measures of social sustainability and their application to supply chain decisions			
Ilbery & Maye	[22]	Food supply chains and sustainability: evidence from specialist food producers in the Scottish/English borders			
Kovács	[61]	Corporate environmental responsibility in the supply chain			
Lai et al.	[62]	An economic and environmental framework for analyzing globally sourced auto parts packaging system			
Matos & Hall	[63]	Integrating sustainable development in the supply chain: The case of life cycle assessment in oil and gas and agricultural biotechnology			

Table 2.1b Several study focuses associated with “sustainability” and “SC

Author	Ref.	Paper Name	Sustainability Focus		
			Financial	Environmental	Social
Mele et al.	[64]	Optimal Planning of the Sustainable Supply Chain for Sugar and Bioethanol Production			
Mollenkopf et al.	[9]	Green, lean, and global supply chains			
Pagell & Wu	[32]	Building a more complete theory of sustainable supply chain management using case studies of 10 exemplars			
Rao & Holt	[4]	Do green supply chains lead to competitiveness and economic performance?			
Sarkis et al.	[65]	E-logistics and the natural environment			
Seuring & Müller	[66]	Core Issues in Sustainable Supply Chain Management – a Delphi Study			
Shaw et al.	[67]	Developing Environmental Supply Chain Performance Measures			
Sigala	[68]	A supply chain management approach for investigating the role of tour operators on sustainable tourism: the case of TUI			
Thun & Müller	[69]	An Empirical Analysis of Green Supply Chain Management in the German Automotive Industry			
Tsoulfas & Pappis	[23]	A model for supply chains environmental performance analysis and decision making			
Vachon and Mao	[70]	Linking supply chain strength to sustainable development: A country-level analysis			

The consequences of seemingly simple SC decisions can become quite complex from a sustainability perspective. For example, the decision for the type of packaging can have profound implications on how organizations' sustainability manages their SCs. Lai et al. [68] in their study titled "An economic and environmental framework for analyzing globally sourced auto parts packaging system", provide a prescriptive, operational framework to help organizations and managers begin to grasp and make sense of the complexities involved in the management of sustainable SCs. Using various models and databases they show how an integrative perspective can be completed for a packaging and transportation decision [37].

In an analogous context to Lai et al., Tsoulfas and Pappis [23] provide some valuation and decision models that rely on a comprehensive definition of environmental performance indicators. In their paper titled "A model for supply chains environmental performance analysis and decision making", they focus on the more complete internal SC ranging from product design and manufacture to transportation and logistics. According to Lozano and Huisingh [71], during the last decade, sustainability reporting has been increasingly adopted by corporations worldwide. Therefore they introduced a paper that analyses sustainability reports from three companies with the help of Grounded Theory's constant comparative analysis. This analytical framework helped the authors to systematically assess the degree to which the companies addressed economic, ecological and social issues separately or in an integrated and inter-linked manner.

To be truly sustainable, a SC would at worst do no net harm to natural or social systems while still producing a profit over an extended period of time; a truly sustainable SC could, customers willing, continue to do business forever [72]. As far as we know, no such SC exists today. In addition to complying with the environmental regulations for selling products in certain countries, firms need to implement strategies to voluntarily reduce the environmental impacts of their products. Researchers suggest a few specific behaviors to support the sustainability in SCs. Collaborative behaviors with suppliers and customers are a component of creating a sustainable SC [72], [73]. Also to create a sustainable SC, organizations need to integrate sustainability goals, practices and cognitions into day-to-day SC management. Responsibility for sustainability cannot be given to a separate entity; it must be part of everyone's job in a SC as suppliers, top management, etc. If there is one key driver for all of the participating companies it is that sustainable development is driven from the top down within each organization. If senior management is unconvinced – it won't happen. Therefore, to create a sustainable SC seems to require proactive top management that understands that sustainability is an organizational commitment.

2.3. BENEFITS OF SUSTAINABLE SCM

Many of the benefits of sustainable SCM are measurable at the company level. Re-evaluating a company's SC, from purchasing, planning, and managing the use of materials to shipping and distributing final products, with an emphasis on improving environmental and social performance, has had real benefits for the companies. These include [47], [74]:

- *Risk management*. The growing demand for sustainable products particularly by retailers and the response by manufacturers are due in part to recognition that one bad story can do lasting damage to a brand. Damage control is more costly than proactively managing an issue.
- *Appealing to markets* for financial benefit.
- *Appealing to customers* for increased sales and brand security.
- *Increased efficiency.* Driving out inefficiency from processes is good business practice and reduces costs.
- *Increased brand differentiation.* Visible, proactive management of the environment and social consequences of business operations can increase customer loyalty and brand good will, as well as mitigate the risks and financial impacts of avoidable environmental incidents and increasingly strict environmental regulations.

- *Strengthened customer relationships* through collaboration on sustainability solutions or provision of value-added services such as product waste take-back programs.
- *Demonstrated corporate citizenship and responsiveness* to community, employee, public interest group, and regulator concerns.
- *Improved ability to hold up to increasing scrutiny and due diligence* of a company's environmental and social practices.
- *Improved community health* through better air quality, particularly urban neighborhoods located near busy freight delivery zones.
- *Improved health and safety conditions* for employees or business partners.
- *Reduced impact on natural habitat and ecosystems.*

3. DEVELOPMENT OF SUSTAINABLE SCM STRUCTURE USING QFD METHODOLOGY

At a glance in the literature, publications can be found mainly as literature survey. Fewer focus on different approaches, methods for sustainability. Among them, authors generally use statistical approaches and try to validate the relationships and linkages between sustainable SCs and different components. Rao and Holt [4] presented a statistical approach to validate the causal relationships between the different latent constructs of: greening the inbound function; greening production; greening the outbound function; competitiveness and; economic performance. This research concluded that greening the SC has the potential to lead to competitiveness and economic performance. Vachon and Mao [70] introduced a paper named “Linking supply chain strength to sustainable development: a country-level analysis”. The regression analysis results indicated that SC strength is positively linked to all three considered dimensions of sustainable development namely environmental performance, corporate environmental practices, and social sustainability.

Very small numbers of studies focused on non-statistical approaches or provide case studies based on sustainability and SC. Kainuma and Tawara [75] proposed a multiple attribute utility theory approach to lean and green SCM. By this means they evaluated the performance of a SC not only from a managerial viewpoint but also from an environmental performance viewpoint. Hutchins and Sutherland [31] in their contribution titled “An exploration of measures of social sustainability and their application to supply chain decisions”, tried to evaluate social sustainability of a SC through an illustrative example with value-weighted social sustainability measure. They also studied input–output modeling of social impacts in their study. Tsai and Hung [7] proposed a fuzzy goal programming approach for green SC optimization under activity-based costing and performance evaluation with a value-chain structure.

They focused on optimal green SC supplier selection and flow allocation, and a green supply chain of a mobile phone is used as an illustrative case.

Recently there has been increasing emphasis on the necessity for introducing environmental or sustainable requirements into design and development of products/systems. Industries and designers have therefore found themselves faced with the necessity to adopt opportunely new tools and reference parameters for production and design. The question of applying how to infuse these criteria into product/system design and how to compare sustainable requirements with traditional design requirements is gaining vital importance and it can effectively be solved by QFD approach [76]. In particular by using the QFD multi-criteria matrices, an 'environmental compromise' can be reached [77].

3.1. QFD

QFD has been around for over four decades but it has begun to realize its full potential as a powerful tool to improve companies' strategic position only since 1990s. QFD was conceived in Japan in the late 1960s, during an era when Japanese industries broke from their post-World War II mode of product development through imitation and copying and moved to product development based on originality. QFD was born in this environment as a method or concept for new product development under the umbrella of Total Quality Control. "Quality Function Deployment: A Company Wide Quality Approach" [78], the very first book on the topic of QFD written by the late Shigeru Mizuno and Yoji Akao, illustrates this relationship.

QFD is an interdisciplinary team process that aids in planning for new or improved designs and processes such that [79]:

- focus is on customer requirements;
- competitive environment and market/customers are factored into all decisions;
- the inter-functional teamwork is strengthened;

- customer requirements are translated into measurable goals for each department; and
- the involvement of all employees is garnered towards "listening to the voice of customer".

QFD methodology is a useful tool to identify customer preferences during the product design process. QFD can be described as an approach to product quality design, which attempts to translate the voice of the customer into the language of the engineer and subsequently into design characteristics [80]. The design features are transformed into part features during a parts development process. In the work preparation phase crucial operating procedures are defined on the basis of the specified part features. The crucial operating procedures in turn serve to determine the production requirements in great detail. The core principle of this concept is a systematic transformation of customer requirements and expectations into measurable product and process parameters [81].

Much has been published about QFD since the concept was initiated in the mid-1960s [82–87]. QFD is mainly a tool to help companies focus on what customers perceive as important and certify that these desired abilities exist in the final product or service. The work is usually documented in a series of matrices. Its primary benefits are reduced design costs and development time [88], [89]. Other benefits include improved communication and cohesion within a product development or improvement team and solidifying design decisions early in the development cycle [81], [90]. QFD helps organizations seek out both spoken and unspoken needs, translate these into actions and designs, and focus various business functions toward achieving this common goal, empowering organizations to exceed normal expectations and provide a level of unanticipated excitement that generates value.

Sullivan [91] indicated that QFD brings efficiency to companies because of the minimization of misinterpretation and need for changes. Brown [92] emphasizes that QFD leads to superior product quality and design, shorter design cycles with fewer engineering changes, higher potential for radical innovations, lower product and project costs, and more satisfied customers. Strategic benefits of QFD includes better understanding of customer needs, increased quality of advertising and communication, and faster decision making [93].

The QFD process promotes not only effective communication but also close cooperation among functional managers and business units. Because group consensus on the assignments of numerical values is essential, QFD participants are required to communicate extensively about both customer needs and management requirements. This process is likely to help in enhancing cross-functional relationships within a service organization, which is essential for maintaining a healthy organization. Beside these more qualitative and intangible benefits, Bicknell and Bicknell [94] provide empirical evidence for tangible benefits related to QFD. They denote that if QFD is properly used, then 30-50% less engineering changes, 30-50% shorter design cycles, 20-60% lower start up costs, and 20-50% fewer warranty are expected.

Despite the strong potential of QFD for the industry, several potential limitations must be considered. In the first place, QFD intensely relies on data gained from the customers through market research and from functional managers through formal and informal discussions. Thus, inaccurate input data due to such reasons as response bias and wrongful research methods may provide unreliable guidelines. Finally, another limitation might be that the chart may quickly become too large to handle. This problem may be resolved by reducing the number of attributes and design/management requirements to a smaller set of key items.

Although originally developed in a product context, the method has been adapted and gainfully applied to services as well. It can also be used for both tangible products and non-tangible services, including manufactured goods, service industry, software products, IT projects, business process development, government, healthcare, environmental initiatives, and many other applications. Although there have been many QFD studies and applications in the literature over the past decades, different authors use different terms and methods and they also focus on different parts of the QFD system. There have been no consistent or unified accounts of the QFD concepts and procedures, which is uncommon for such a popular methodology and may be quite confusing for non-specialists [95].

One of the products and also heart of QFD is a "house of quality" (HOQ) matrix, which enables a quick visual comparison of "what customers want" versus "how suppliers can give it to them". The HOQ correlates desired qualities (variously referred to as customer requirements, quality requirements) to a large variety of means (the so-called design elements) by which customer desires can be satisfied. The HOQ matrix contains information about what to do (e.g., what customers want), how to do it (e.g., how technically customer requirements can be achieved), and the relationships between each of these aspects; prioritization of CRs and technical/design requirements (DR); and what are the company's target levels. Quality functions are deployed by carrying "how to do" into the successive HOQ as "what to do" [96]. The basic format of the HOQ consists of six different major parts which are explained in Figure 3.1. Detailed description of the HOQ steps applied in this study is given in Section 4.

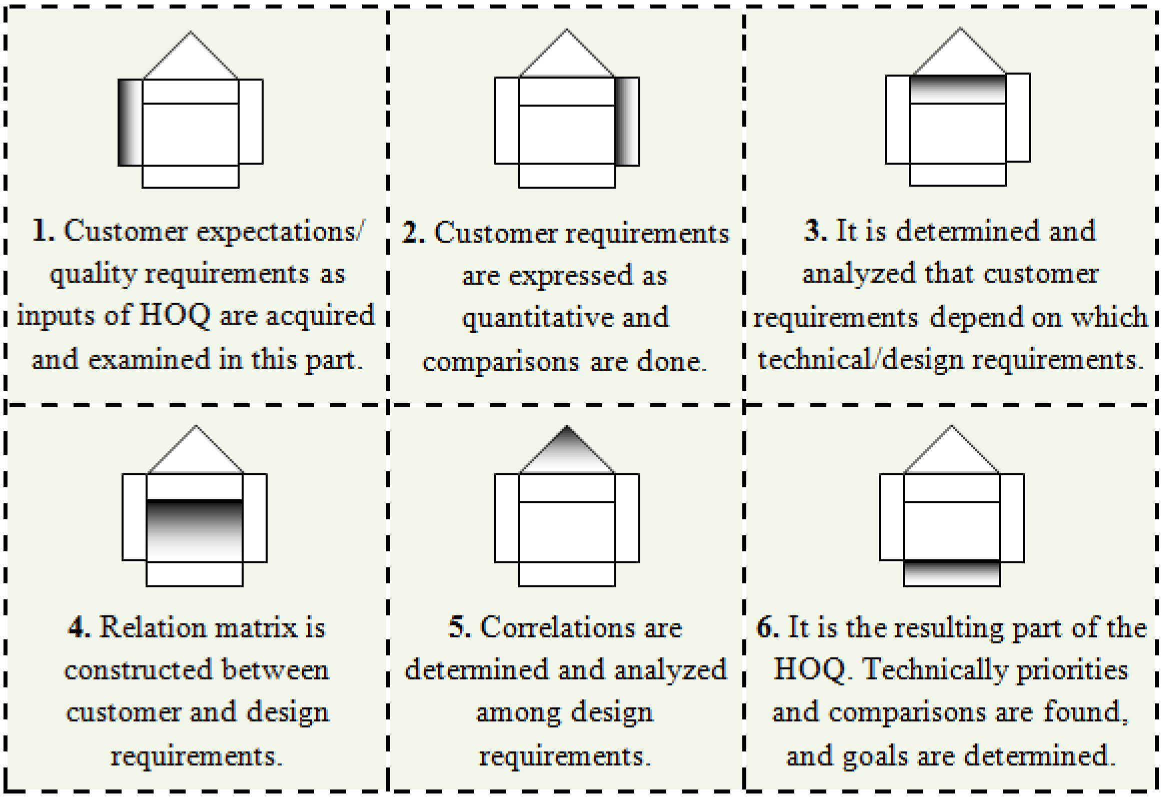

Figure 3.1 Common parts of HOQ

3.2. LITERATURE SURVEY ON SUSTAINABLE QFD (SQFD)

Traditional product (or process, project, etc.) development cycle at least consists of gathering customer requirements, identification of design objectives, design, and engineering analysis. In the sustainable structure development cycle, financial, environmental, and social requirements need to be introduced into the development phases. The various issues associated with sustainable structure development cycle consist of introduction of environmental awareness to customer requirements, assessment of sustainable performance as a design objective and evaluation of the potential of the structure for sustainability performance indicators.

Some researchers have been working on incorporating environmental aspects into QFD. Cristofari et al. [97] introduced the concept of Green QFD (GQFD) by integrating QFD with a life cycle approach to product development. This aids in evaluating different product concepts, and deploys environmental requirements throughout the development process. Zhang et al. [98] proposed a method called GQFD-II which includes the integration of life cycle assessment (LCA) and life cycle costing (LCC) into QFD. They integrated LCC into QFD matrices and suggested the deployment of quality, environmental and cost requirements throughout the entire product development process to evaluate different product concepts. Halog et al. [99] in their contribution titled “Using quality function deployment for technique selection for optimum environmental performance improvement”, tackle how a given process or technique can be improved to qualify as an environmentally-conscious one at a given budget constraint. Masui et al. [100] presented a concept called QFDE in which QFD has been applied to environmentally-conscious design. Bovea and Wang [101] identified environmental improvement options by combining LCA and fuzzy set theory. According to their study, to obtain more sustainable solutions, environmental properties must meet customer requirements. Therefore they introduced an approach for identifying environmental improvement options by taking into account customer preferences with the aid of fuzzy approach based HOQ. Pun [102] introduced the determinants of environmentally-responsible operations and suggested GQFD as one of the tools for environmentally-responsible operations. Sakao [103] has presented a QFD centered design methodology for environmentally-conscious product design. He combined LCA, QFDE and Theory of Inventive Problem Solving (TRIZ) and applied the combination to a hair dryer to effectively support the product planning and conceptual design stages.

Recently, Bevilacqua et al., [77] propsed a study named “Design for environment as a tool for the development of a sustainable supply chain”. In this work, they used design for environment (DfE) methodologies as a tool for the development of a more sustainable SC by combining LCA techniques and by using the QFD. Kuo et al. [104] propounded a paper that examines integration of environmental considerations in QFD by using fuzzy logic. The authors state that with an interactive approach, the optimal balance between environmental acceptability and overall customer satisfaction can be obtained. Vinodh and Rathod [76] in their paper titled ‘‘Integration of ECQFD and

LCA for sustainable product design'', aimed to report a research carried out for ensuring sustainable product design by the integration of environmentally conscious QFD (ECQFD) and LCA approaches. Another study is proposed by Lin et al. [36], namely "Using QFD and ANP to analyze the environmental production requirements in linguistic preferences". This study is to apply fuzzy QFD model with interdependence relations of environmental production requirements aspects and sustainable production indicators criteria for original equipment manufacturing firm in Taiwan.

Typically, the papers available in sustainability literature only take into account a single product. The procedure proposed in this work, using QFD matrices, allows the definition of guidelines for the whole SC. This is useful in order to provide 'Engineering Design Characteristics', information about the sustainable SC design for decision makers who are involved in the SC.

3.3. PROPOSED SQFD STRUCTURE

According to literature survey based on sustainability related studies, the characteristics of effective sustainability indicators are determined as follows.

Drivers for a sustainable SC (CRs):

✓ Economical Requirements:

The requirements of the firm arising from advanced environmental management practice can include: *cost reduction* (reduction in fines, risks or insurance costs, etc.); *asset use/utilization* (efficient use of raw materials); *quality improvement*; and *enhanced customer service*. There is no doubt that cost reduction and continuing financial benefit are fundamental goals of a SC. A number of studies have found that an increased emphasis on sustainability in the SC is related to lower costs and a neutral or positive effect on value [4], [24], [29], [105–108]. Asset utilization is another important concern in sustainable SC [77], [101], [105], [106]. Reducing the materials used is needed for efficiency of the SC. Quality level should be maximized because quality is sine qua non for environmental protection and sustainable development. Quality is a widely accepted performance indicator for sustainable SCs and it represents a common driving force for sustainable supply activities [4], [50], [70], [107]. Finally, to enhance customer service is one the main focus of sustainable SCs. Several studies identified a trend that organizations are integrating environmental processes to their SCs to reduce operating costs and improve their customer service [107], [108].

✓ Environmental Requirements:

The major four economical requirements dimensions are *waste reduction*, *emission reduction*, *energy efficiency* and *natural resource conservation*. The environmental based expectations of companies and their stakeholders from a sustainable SC are reduction of waste produced, material substitution through environmental sourcing of raw materials, waste minimization of hazardous materials (hazmat), efficient use of energy, and resource conservation and management [5], [23], [35], [50], [70], [77], [101], [109]. The environmental practices are dependent on wider aspects to be integrated in order to achieve firm's goal of waste elimination and lower environmental impact. Hence, firms must integrate environmental aspects to ensure corporate survival and toward sustainable development. Rothenberg [110] noted that pollution prevention-environmental activities are often value-added for the firm since they reduce costs through material use reduction or through the avoidance of waste management costs. To replace non-renewable and polluting technologies, it is crucial to support the use of renewable energy resources, as well as to reduce energy consumption. Major improvements in energy efficiency can often be achieved at little or no cost, even with net savings, through the use of targeted programs. For instance, installed water-saving techniques and the use of closed re-circulating systems can lead to reduction of water use [23].

✓ Social Requirements:

Social requirements comprise four main dimensions such as *reduced impact on community*, *health and safety*, *strengthened relationships* and *laws and regulations*. In response to governmental regulations [25], [29], [54], and increasing public awareness & customer pressure [24], for the effect of industrial production on the environment; organizations are now taking major initiatives on to transform their SC processes. The aims to comply with legal requirements and to create a systematic management system have been reported as important driving forces for companies to implement sustainable/environmental activities [4], [24], [111]. Commitment to health and safety which meets minimum legal requirements is also needed as a social responsibility in a sustainable SC. Improved health and safety conditions for employees or business partners [35], [44]; improved community health through better air quality; reduced impact on community through less noise etc. composes important drivers for companies to improve sustainable SC activities. As final target, strengthened customer and business partner relationship [44] management is an important requirement for a sustainable SC. By this means, firms can gain competitive advantage and improve firm performance.

Key practices for a sustainable SC (DRs):

✓ *Price strategy* [27], [47], [74], [63], [107]: As a customary criterion, price strategy is again an important practice as in traditional SC. The objective is to ensure a minimum price of the product to increase the customer satisfaction and profitability. However with trends in the SC such as price competition, the adoption of sustainable initiatives might be at risk. For example, relocation strategies make more difficult the control of working conditions in the offshore production sites; smaller size of deliveries deriving from shorter delivery times may increase the amount of transport, thus raising its environmental impact [44]. This strategic decision should be given attentively.

- ✓ *SC optimization* [4], [35], [47], [74]: During the last two decades, the focus on optimizing operations has moved from a specific facility or organization to the entire SC. Optimization of SC logistics network design; warehouse layout and workflow; transportation loads and routes are common incentives for a sustainable SC. Optimization of such networks can allow companies to reduce environmental and social impacts while still achieving financial objectives. In sustainable SCs the strategic optimization of the SC design and product design must be intrinsically linked. This enables the design of a sustainable product and the system infrastructure to produce, deliver, recover, and rechannel these products through multiple life-cycles [35].

- ✓ *Inventory management* [47], [65], [74]: Inventory effectiveness and supply steadiness are important factors in a SC to gain sustainability. Excess inventory and low inventory turnover can result from poor management of reorder points, order quantities, storage locations, or data. Improving inventory management will increase turnover and reduce obsolescence or degradation.

- ✓ *Forecast accuracy* [47], [65], [74]: Forecasting and demand management Increasing the accuracy of supply and demand forecasts can reduce waste and inventory along the SC, increase SC visibility and responsiveness and enhance customer service.

- ✓ *Lifecycle management* [30], [32], [47], [65], [74], [77], [101], [112]: According to Hagelaar and van der Vorst [111] life-cycle assessment can be seen as the main instrument of environmental SCM; it is a technique for gathering data on environmental care issues, which can be used to restructure SCs in order to improve their environmental performance. Lifecycle management takes the view that products need to be managed throughout design, production, operation, maintenance, and end of life reuse of disposal. The necessity of considering the total product life-cycle in order to evaluate a product's sustainability is well recognized [35]. Using lifecycle cost analysis, can reduce the total cost and increase efficiency.

- ✓ *Supplier management* [4], [8], [23], [30], [65]: Duty for supplier qualification, supplier selection and monitoring (motivating and developing), supplier integration in sustainability, supporting suppliers with environmental and social problems are some key practices for supplier management. Managing suppliers will undoubtedly result in improved sustainable SC activities. Suppliers' environmental and social impacts contribute to company's own lifecycle impacts.

- ✓ *Flexible & cleaner technology* [4], [23], [50], [70], [109]: Production capacity, production capability using minimum energy and material, high level of technical capabilities are some vital characteristics of a sustainable SC to meet the current and future demands. Technology of the company should be flexible enough to handle environmental activities and environmental friendly products. Cleaner technologies extract and use natural resources more efficiently, generate products with fewer harmful components, minimize pollutant releases to air, water and soil during manufacturing and product use, and design durable goods that can be reused or recycled [113].

- ✓ *Delivery performance* [50], [65], [70]: The ability to follow the predefined delivery schedule is always an important criterion for the selection. Capability of on time delivery and on time response to request is traditionally important factors for a qualified sustainable SC. The manufacturer should access the complete SC network on time and have the ability to follow the exact delivery schedule according to the customer's demand.

- ✓ *Usage of effective systems and tools* [23], [47] ,[74]: Using effective accounting systems and management tools, using decision support tools play important role in sustainable SC design. By using software such as load planning tools (to optimize loads); route planning tools (to minimize transport distances), capacity can be used more efficiently. The use of accounting systems that account for the full life cycle costing of a product or service, and the environmental impacts it creates, can be expected to provide additional information that will influence the design process [23].

- ✓ *Environmental management system* [50], [105], [109], [114]: The environmental management has become the most concern of manufacturing firms, which seek for higher levels of green product quality and continuous improvement to keep up with the change throughout the world [77]. This factor should include environmental policies, implementation and certification of ISO 14001 [115]. One of the most widely utilized standards is the environmental management system standard ISO 14001, which was introduced in 1996 and updated in 2004. According to Potoski and Prakash [116], the promise of ISO 14001 is that if a participating organization adheres to the requirements of the standard, it will increase the chance to reduce its environmental impacts relative to non-participating organizations.

- ✓ *Green Innovation* [44], [117], [118]: Research and development (R&D) activities, R&D strategy that explicitly accounts for eco-efficiency of products and technologies compose green innovation. Green innovation should include, but should not be limited to, raw material, design, manufacturing, energy consumption, water consumption, product recovery management, waste management, forward logistics, reverse logistics, etc., to achieve better environmental performance, cost reduction and customer satisfaction enhancement for the entire life cycle of products. As a key member of sustainable SC, a manufacturer should initiate the green innovation. Top management should support and encourage this effort with appropriate resources. Accordingly, higher internal integration between functions is needed in order to develop the required innovation for a sustainable-oriented production model [44].

- ✓ *Environmental product design* [4], [23], [76], [101]: The need to develop environmentally conscious products and processes has meant that design for environment has been the subject of increasing interest in recent years. It is described as a "design which addresses all environmental impacts of a product throughout the complete life cycle of the product, whilst aiming to enhance other criteria like function, quality, and appearance" [119], [120]. Design for environment to make the product more sustainable is referred to as redesign. For instance a good product design have to avoid the need for using hazardous or restricted materials during the manufacturing process and have to minimize waste during the manufacturing process [72], [121].

- ✓ *Environmental activity capability* [4], [23], [35], [109]: It is characterized by the capability to perform activities such as reduce, remanufacture, recover, reuse, recycling. Reduce mainly focuses on the first stages of the product life-cycle and refers to the reduced use of resources in pre-manufacturing, reduced use of energy and materials during manufacturing and the reduction of waste during the use stage [34]. Reuse is 'the use of a product or component part in its same form for the same use without remanufacturing. Remanufacturing involves the re-processing of already used products for restoration to their original state or alike-new form through the reuse of as many parts as possible without loss of functionality [122]. Recycle involves the process of converting material that would otherwise be considered waste into new materials or products [35]. The process of collecting products at the end of the use stage, disassembling, sorting and cleaning for utilization in subsequent life-cycles of the product [122] is referred to as recover.

- ✓ *Efficient handling and storage* [23], [47], [65], [74]: There are significant opportunities to improve the energy efficiency and reduce the environmental and social footprints of handling and storage facilities. Where the use of non-hazardous alternatives is not an option, safe handling and storage of hazmat is essential to prevent worker health and safety issues, operational downtime, environmental contamination from spills or leaks, higher insurance premiums, and higher environmental permitting costs- not to mention damage to a company's brand equity. Automated storage and handling systems also provide financial and sustainability benefits, and improve efficiency.

- ✓ *Eco-friendly transportation* [4], [44], [105]: The "transport" link in the SC involves fleet vehicle management and the inbound and outbound transportation of goods. It is part of the total life-cycle of a product and therefore steps to develop and use more environment-friendly transportation systems are important [50]. Eco-friendly transportation includes shifting to modes or equipment that use less fossil fuel, using reusable or recyclable shipping materials and transporting hazmat safely.

- ✓ *Reverse logistics* [23], [47], [65], [74], [114], [123]: Reverse logistics is one of the least understood and least studied aspects of the SC. It is the process of moving goods back through the system with the purpose of finding another use for the products or for proper disposal. In some businesses, the level of returns is so low that little time and effort is invested in making it work efficiently. Implementing a proactive take-back program and a centralized return centre, building business rules into the returns process are some key practices for reverse logistics.

- ✓ *Green and back packaging* [4], [23], [65], [103], [123]: Packaging characteristics such as size, shape, and materials have an impact on distribution due to their affect on the transport characteristics of the good. Green and back packaging to facilitate safe, efficient, and cost-effective recovery and disassembly for reuse of recycling can reduce materials usage. Systems that encourage and adopt returnable packaging will require a strong customer supplier relationship as well as an effective reverse logistics channel.

- ✓ *Collaboration with partners* [46], [65], [70], [109], [124]: Developing and maintaining a supply relationship can be achieved through either collaboration or compliance. It provides effective management of information across the entire SC. Successful collaboration is based on trust and long-term relationships and can take many forms, including sharing of information, materials, assets, capital, risks, technology, or other resources. Greater collaboration can take place between a company's internal functions as well as between a company and its customer and suppliers.

- ✓ *Employee practices* [23], [44], [70], [109]: Employee practices such as certification programs for employees, labor education, effective precautions for accidents, etc. are also important for a sustainable SC design and it is in relationship with vital factors such as laws and regulation, health and safety, improved quality. The personnel of a company are responsible to incarnate the company's policies. Thus, they should be aware of the environmental impacts of their attitude [23]. At the individual level employees need to be trained in sustainability [32]. Training employees on efficient workflow processes and procedures; safe hazmat handling, labeling, and transportation regulations will improve efficiency and productivity.

- ✓ *Outsourcing* [47], [74]: Third parties can generate economies of scale that individual manufacturers or retailers often cannot, thereby increasing the realized value of returned products and reducing the amount that would otherwise result. Managed well, such partnerships can result in cost reduction, increased efficiency and significant improvement in customer satisfaction. Leading third party logistics companies incorporate environmental and social criteria as standard within their service offering.

- ✓ *Stakeholders' rights* [74], [109], [114]: A successful sustainable SCM should include protecting stakeholder's rights (i.e. suppliers, employees, customers, etc.) as duties of ethics, loyalty and care. Also stakeholders are causing firms to review their environmental supply practices. It's mainly related to corporate governance aspect. In order to inform the different stakeholders regarding the ethical management of their activities, companies can publicize annually the results of their operations, including extensive values reports, such as impact on employees, environment and suppliers.

- ✓ *Monitoring and maintenance* [50], [70], [114]: Monitoring the SC, suppliers, vehicles; maintenance of the vehicles are some critical factors for attaining a sustainable SC. Nowadays, corporations need to implement control and monitoring activities to ensure that their suppliers, partners act in environmentally-sensitive manner. This is usually part of a due diligence and risk minimization strategy [50].

According to these criteria, SQFD scheme can be obtained as Figure 3.2. This generic model is constructed based on most identified indicators in the literature and can be extended according to different companies' sustainability focuses.

	Key Practices for a Sustainable SC (DRs) / Drivers for a Sustainable SC (CRs)	Price strategy	SC optimization	Inventory management	Forecast accuracy	Lifecycle management	Supplier management	Flexible & Cleaner technology	Delivery performance	Usage of effective systems and tools	Environmental management system	Green innovation	Environmental product design	Environmental activity capability	Eco-friendly transportation	Efficient handling & storage	Reverse logistics	Green and back packaging	Collaboration with partners	Employee Practices	Outsourcing	Stakeholders' rights	Monitoring and Maintenance
Economical	Cost Reduction																						
	Asset Use/ Utilization																						
	Improved Quality																						
	Enhanced Customer Service																						
Environmental	Waste Reduction																						
	Energy Efficiency																						
	Reduced Emissions																						
	Conservation																						
Social	Reduced Impact on Community																						
	Health and Safety																						
	Laws & Regulations																						
	Strengthened Relationships																						

Figure 3.2 Proposed SQFD Structure

4. PROPOSED APPROACH FOR EVALUATION OF SQFD

After obtaining SQFD structure, methods for effective evaluation of the SQFD are needed to be considered. The traditional QFD structure requires individuals to express their preferences in a complete manner. However in practice, it is generally hard to obtain such complete information from people contributing to the process. They generally tend to give information about their personal preferences incompletely, depending on constraints such as their background, time pressure, etc. Therefore, an extended methodology is introduced here, using a new GDM approach in QFD that takes lack of information into account. Figure 4.1 provides an analytical perspective for evaluation of the proposed SQFD.

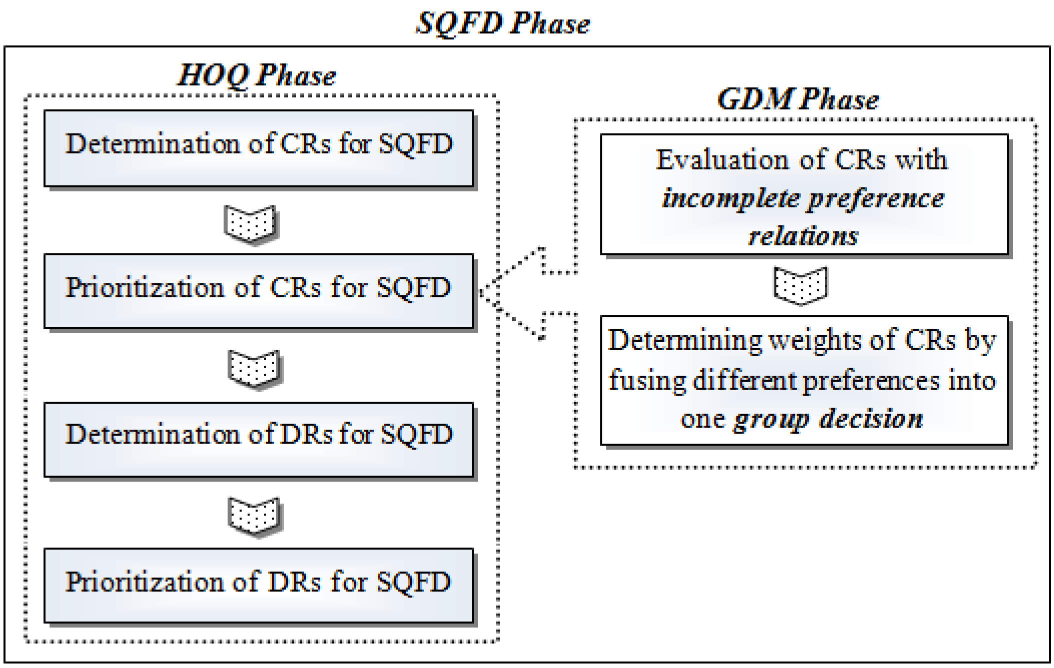

Figure 4.1 Analytical perspective for the evaluation of proposed SQFD

4.1. GDM IN QFD

The traditional QFD structure requires individuals to express their preferences [27], and it requires the involvement of several people. While analyzing priority of CRs, team members usually have difficulty in assigning measures of priority to a list of customer preferences. During the process, the members could have significantly different and subjective opinions based on their past experience. A fusion of GDM with a group-customer preference system is proposed in this research to resolve these issues. The purpose of this method is to enhance group consensus on the GDM outcome. Several authors [12], [96], [125], [126] have previously studied the GDM methodology in QFD. Table 4.1 lists a sample of those studies which used GDM methods in QFD approach.

In the GDM process, to deal with the vagueness of customers' preferences in decision-making, fuzzy GDM approaches have been proposed. The fuzzy set theory has been applied to the field of management science, especially for treating vagueness and ambiguity in decision making problems. Lingual expressions, for example, satisfied, fair, dissatisfied, are regarded as the natural representation of the preference or judgment. Since the evaluation is resulted from the different evaluator's view of linguistic variables, its evaluation must therefore be conducted in an uncertain, fuzzy environment [127–129]. Therefore, this study includes fuzzy GDM to strengthen the comprehensiveness and reasonableness of the decision making process in QFD.

Table 4.1 Several studies make use of GDM in QFD

Author	***Ref.***	***Methodology***	***Topic***	***Area***	***Type***
Bevilacqua et al.	[130]	Fuzzy QFD based on GD	Supplier Selection	Clutch Plate Suppliers	Real World Example
Büyüközkan et al.	[125]	Fuzzy GDM in QFD with multiple preference format	New Product Development	Hatch Door Development of a Car	Illustrative Example
Chen & Weng	[131]	GDM in QFD using fuzzy goal programming	-	Writing Instrument	Illustrative Example
Chin et al.	[132]	Evidential reasoning based GD in QFD	-	-	Illustrative Example
Kuo et al.	[104]	Fuzzy GDM in QFD	Integration of environmental considerations	Toner Cartridge Design	Real World Example
Liu	[133]	Fuzzy GDM and genetic algorithms in QFD	-	-	Illustrative Example
Liu	[134]	Fuzzy GDM in QFD	Customer Attitudes towards Risk	Buying Services or Products	Illustrative Example
Liu & Wu	[135]	Fuzzy GDM in QFD	-	-	Illustrative Example
Wang	[136]	Linguistic based GDM in QFD	Product Development	Notebook Computers	Illustrative Example
Zhang & Chu	[137]	Fuzzy GDM in QFD with multiple preference format	New Product Development	Horizontal Directional Drilling Machine Selection	Real World Example
Zhang & Chu	[13]	Fuzzy GDM in QFD	Complex Product Development	Horizontal Directional Drilling Machine Selection	Real World Example

4.2. GDM WITH INCOMPLETE PREFERENCE RELATIONS

GDM consists of multiple individuals interacting to reach a decision. Each decision maker/expert may have unique motivations or goals and may approach the decision process from a different angle, but have a common interest in reaching eventual agreement on selecting the "best" option(s) [18], [138], [139]. To do this, experts have to express their preferences by means of a set of evaluations over a set of alternatives.

Recently, linguistic preference relations used by decision makers to express their linguistic preferences when comparing decision alternatives have been investigated in the literature [140–145]. These studies focused on linguistic preference relations with complete judgments. A complete linguistic preference relation requires $n(n-1)/2$ judgments for a level with n criteria or alternatives. Sometimes, however, it is difficult to obtain such a preference relation. As each expert has his/her own experience, there can be situation of an expert not having a perfect knowledge about the problem to be solved. In addition, there may be cases where an expert would not be able to efficiently express any kind of preference degree between two or more of the available options. This may be due to an expert not possessing a precise or sufficient level of knowledge of part of the problem or because that the expert is unable to discriminate the degree to which some options are better than others [18]. And since the QFD approach involves multiple DMs and a group decision process, these kinds of problems can occur in the evaluation process of CRs. Thereby, after linguistic preference relations with complete judgments, incomplete judgments are introduced lately. With the use of incomplete preference relations, such constraints for evaluations can be handled effectively and the evaluation would be stronger and healthier. It is inherent that every DM in evaluation group may not have complete information, thus it is necessary to involve incomplete preferences in the evaluation processes.

The literature on the applications using incomplete information is somewhat limited. Alonso et al. [146] proposed a decision aid system to provide consistent linguistic preference relations which deals with incomplete or inconsistent information. Xu [15] studied incomplete linguistic preference relations and their fusion with an illustrative example. Xu [16] also examined integrating multiple types of incomplete linguistic preference relations in multi-person decision making. Herrera-Viedma et al. [17], [18] proposed two studies about a consensus model for group decision making with incomplete fuzzy preference relations. Same year, Fedrizzi and Giove [147] examined incomplete pairwise comparison and consistency optimization with a numerical example.

More recently, Chiclana et al. [148] introduced a study as the comparison of similar methods for estimating missing pairwise preference values ([17] and [147]) based on additive consistency. Wang et al. [149] evaluated the incomplete linguistic preference relations on the performance of web shops. Another study is proposed by Wang and Chen [20] namely, incomplete fuzzy linguistic preference relations under uncertain environments, and they considered the practice of Chan and Kumar [150] for selection of a global supplier. Herrera-Viedma ve Porcel [151] suggested a study that deals with incomplete information in a fuzzy linguistic recommender system to disseminate information in university digital libraries. To the best of our knowledge, there exists no study in the literature that neither combines those with QFD, nor any applications in the sustainable SCM field.

4.3. PROCEDURE FOR THE PROPOSED SQFD EVALUATION APPROACH

4.3.1. Preliminaries

Preference relations enable a decision-maker to give values for a set of criteria and a set of alternatives. The value represents the degree of the preference for the first alternative over the second alternative [20]. Two major kinds of preference relations are multiplicative preference relations, and fuzzy preference relations.

Definition 1: Multiplicative preference relations [152]: A multiplicative preference relation X on a set of alternatives A is represented by a matrix $X \subseteq A \times A, X = (x_{ij})$, Here x_{ij} is the preference ratio of alternative a_i to a_j. Saaty [152] suggests measuring a_j using a ratio scale, and definitely the 1–9 scale. $x_{ij} = 1$ indicates there is no difference between a_i to a_j, $x_{ji} = 1$ indicates that a_i is absolutely better than a_j. In this case, the preference relation, X, is usually assumed to be multiplicative reciprocal, i.e., $x_{ij}.x_{ji} = 1 \;\; \forall\, i, j \in \{1,..., n\}$.

Definition 2: Fuzzy preference relations [153], [154]: A fuzzy preference relation P on a set of alternatives A is a fuzzy set on the product set $A \times A$, which is characterized by a membership function $\mu_p : A \times A \rightarrow [0,1]$. When the cardinality of A is small, the preference relation may be conveniently represented by the $n \times n$ matrix $P = (p_{ij})$ being $p_{ij} = \mu_p(a_i, a_j) \;\; \forall\, i, j \in \{1,..., n\}$. Here p_{ij} is the preference ratio of the alternative, a_i to a_j: $p_{ij} = 0.5$ indicates there is no difference between a_i and a_j; $p_{ij} = 1$ indicates that a_i is absolutely better than a_j, and $p_{ij} > 0.5$ indicates that a_i is better than a_j. In this case, the preference matrix P, is usually assumed to be an additive reciprocal, i.e., $p_{ij} + p_{ji} = 1 \; \forall\, i, j \in \{1,..., n\}$.

Definition 2.1 [155], [156]**:** If a complete fuzzy preference relation P satisfies the additive transitivity $p_{ij} + p_{ji} = 1, p_{ii} = 0.5$, for all i,j, then P is called an additive consistent complete fuzzy preference relation.

Definition 2.2 [157]**:** Consider a set of alternatives, $A = \{a_1,..., a_n\}$, associated with a reciprocal multiplicative preference $X = (x_{ij})$ for $x_{ij} \in [1/9, 9]$. Then, the corresponding reciprocal fuzzy preference relation, $P = (p_{ij})$ with $p_{ij} \in [0,1]$ associated with X is given as $p_{ij} = g(x_{ij}) = 1/2(1 + \log_9 x_{ij})\,.\log_9 x_{ij}$ is considered because x_{ij} is between 1/9 and 9. If x_{ij} is between 1/7 and 7, then $\log_7 x_{ij}$ is used.

Definition 3: It is very important to establish these conditions for ensuring that all the missing values of the incomplete fuzzy preference relation can be estimated [18]. It is assumed that DMs provide their judgments freely by means of the incomplete fuzzy preference relations with preferences degrees $p_{ij} \in [0,1]$ and $p_{ii} = 0.5$, without any other restriction. In the following, sufficient conditions are provided that guarantee the success of the estimation procedure.

- A general condition is that when a complete row or column of preference values are known, then all missing preference values can be estimated in the first iteration of the procedure.
- Under the consumption of additive consistency property, a different condition was given in [156]. This condition states that any incomplete fuzzy preference relation can be completed when the set of $n-1$ preference values $\{p_{12}, p_{23}, \ldots, p_{(n-1)n}\}$ is known.

4.3.2. Computational Steps of the Proposed Approach

Figure 4.2 represents the proposed approach bodily and step by step description is as follows.

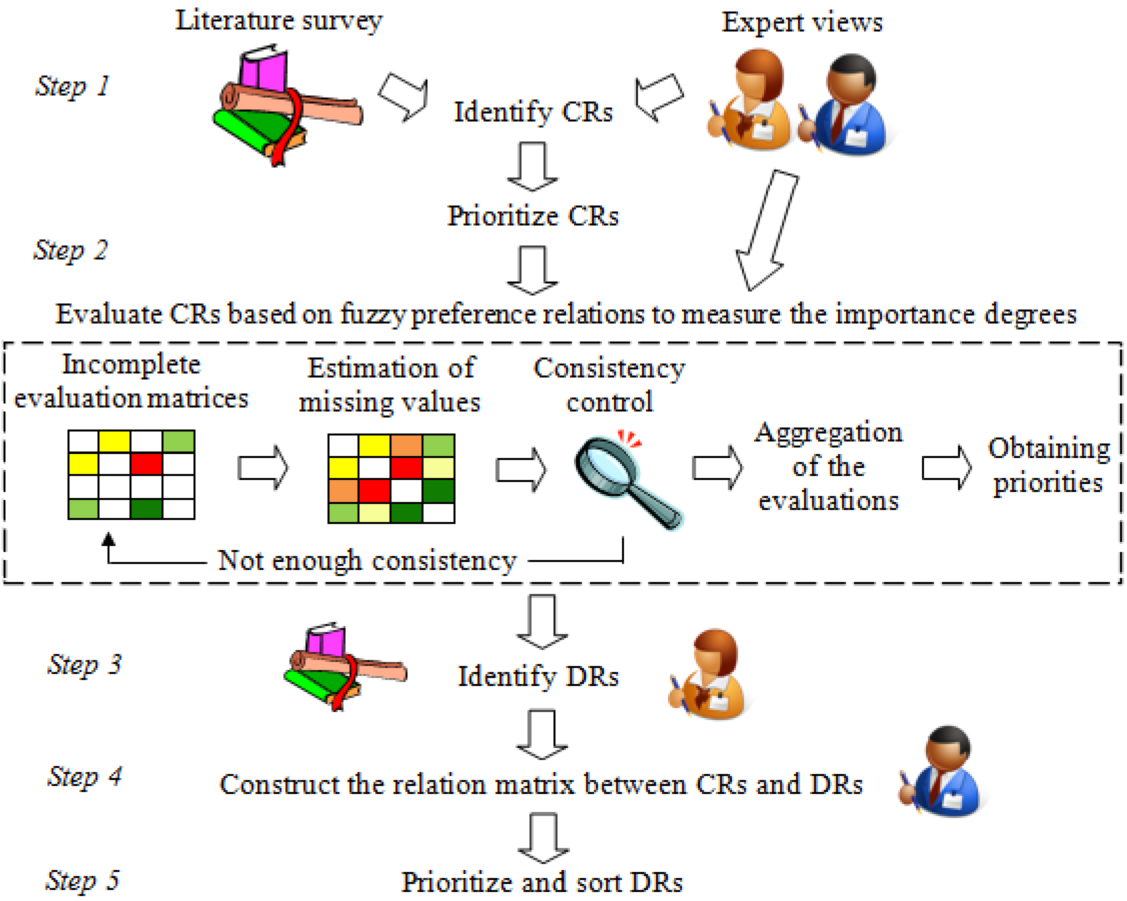

Figure 4.2 Scheme of the proposed approach

Step 1: "Whats - Identifying the CRs". "Whats" can also be called as *the voice of customers*. In this step CRs must be identified and placed on the left side of the house. These requirements can be identified with the aid of questionnaires to customers, literature surveys, or expert views.

Step 2: "Prioritizing CRs": In this step, a comparison of the subjected CRs is used to determine their relative importance degrees. These importance degrees of CRs will aid in the design analysis step. However, the information gained from DMs may not be adequate to accurately assign the importance degrees. We will overcome this obstacle through fuzzy GDM.

Step 2.1: "CR Evaluation". Firstly, it is required to design a comparison scale to measure the importance degrees of the CRs. Initially, fuzzy linguistic assessment variables $\tilde{p}_{ij}$ (Table 4.2) are used to indicate the relative strength of each pair of elements as in Eq. (4.1)., instead of crisp values p_{ij} .

$$\tilde{P} = \begin{bmatrix} \tilde{p}_{11} & \tilde{p}_{12} & \cdots & \tilde{p}_{1n} \\ \tilde{p}_{21} & \tilde{p}_{22} & \cdots & \tilde{p}_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ \tilde{p}_{n1} & \tilde{p}_{n2} & \cdots & \tilde{p}_{nn} \end{bmatrix}. \tag{4.1}$$

Here $\tilde{p}_{ij} = \left(p_{ij}^{l}, p_{ij}^{m}, p_{ij}^{u}\right)$ indicates the importance among the compared criteria (importance of *i* over *j*) where p_{ij}^{l} and p_{ij}^{u} are the lower and upper bounds of $\tilde{p}_{ij}$, respectively, and p_{ij}^{m} is median value where $i = j = 1,2,..., n$.

Table 4.2 Corresponding linguistic terms for evaluation

Linguistic term	Abbreviation	Fuzzy Membership Function
None	N	(0, 0, 1)
Very Low	VL	(0, 0.1, 0.2)
Low	L	(0.1, 0.2, 0.3)
Fairly Low	FL	(0.2, 0.3, 0.4)
More or less Low	ML	(0.3, 0.4, 0.5)
Medium	M	(0.4, 0.5, 0.6)
More or less Good	MG	(0.5, 0.6, 0.7)
Fairly Good	FG	(0.6, 0.7, 0.8)
Good	G	(0.7, 0.8, 0.9)
Very Good	VG	(0.8, 0.9, 1)
Excellent	E	(0.9, 1, 1)

Step 2.2: "Completion of the missing values". Once the DMs construct and evaluate the incomplete pairwise comparison matrices of interdependent components, defuzzify evaluated preferences using Eq. (4.2).

$$F\left(\tilde{p}_{ij}\right) = 1/2\int_{0}^{1}\left(\inf_{x\in\Re}\tilde{p}_{ij} + \sup_{x\in\Re}\tilde{p}_{ij}\right)d\alpha \tag{4.2}$$

Then, missing values in a DM's incomplete preference relation can be computed. The main objective here is to maintain or maximize the expert's global consistency, which is modeled and measured via Tanino's [158] "additive transitivity" property,

$$\left(p_{ij} - 0.5\right) + \left(p_{jy} - 0.5\right) = \left(p_{iy} - 0.5\right), \forall i, j, y \in \{1,2,...,n\}. \tag{4.3}$$

Expression (4.3) can be written as

$$p_{ij} = p_{iy} + p_{yj} - 0.5, \forall i, j, y \in \{1,2,...,n\}. \tag{4.4}$$

Given a reciprocal preference relation, Eq. (4.4) can be used to calculate an estimated value of a preference degree using other preference degrees. Indeed, by using an intermediate alternative a_y, the preference value of p_{ij} $(i \neq j)$ can be calculated in three ways [18]:

1. From $p_{ij} = p_{iy} + p_{yj} - 0.5$, we obtain the estimate

$$cp_{ij}^{y1} = p_{iy} + p_{yj} - 0.5 \tag{4.5}$$

2. From $p_{yj} = p_{yi} + p_{ij} - 0.5$, we obtain the estimate

$$cp_{ij}^{y2} = p_{yj} - p_{yi} + 0.5 \tag{4.6}$$

3. From $p_{iy} = p_{ij} + p_{jy} - 0.5$, we obtain the estimate

$$cp_{ij}^{y3} = p_{iy} - p_{jy} + 0.5 \tag{4.7}$$

The preference value of one alternative over itself is always assumed to be equal to 0.5.

Step 2.3: "Checking the consistency level". When working with the incomplete preference relation, the following sets can be used to estimate its consistency level:

$$H_{ij}^{1} = \{y \neq i, j \mid (i, y), (y, j) \in \text{EV}\} \tag{4.8}$$

$$H_{ij}^{2} = \{y \neq i, j \mid (y, i), (y, j) \in \text{EV}\} \tag{4.9}$$

$$H_{ij}^{3} = \{y \neq i, j \mid (i, y), (j, y) \in \text{EV}\} \tag{4.10}$$

where EV is the set of pairs of alternatives for which the expert provides preference values, and $H_{ij}^1, H_{ij}^2, H_{ij}^3$ are the sets of intermediate alternative a_y ($y \neq i, j$) that can be used to estimate the preference value p_{ij} ($i \neq j$) using (4.7)–(4.9), respectively.

The consistency level CL_{ij}, associated with a preference value p_{ij} ($i \neq j$) $\in$ EV,

$$CL_{ij} = (1-\alpha_{ij}) \cdot (1-\varepsilon p_{ij}) + \alpha_{ij} \cdot \frac{CP_i + CP_j}{2}, \; a_{ij} \in [0,1] \tag{4.11}$$

is defined as a linear combination of the average of the completeness values associated to the two alternatives involved in that preference degree CP_i and CP_j,

$$CP_i = \frac{\# EV}{2(n-1)} \tag{4.12}$$

where $\#EV$ is the number of preference values known. Its associated error εp_{ij}, can be calculated as in Eq. (4.12)

$$\varepsilon p_{ij} = \frac{2}{3} \cdot \frac{\varepsilon p_{ij}^1 + \varepsilon p_{ij}^2 + \varepsilon p_{ij}^3}{\kappa} \tag{4.13}$$

where

$$\varepsilon p_{ij}^{h} = \begin{cases} \dfrac{\sum_{y \in H_{ij}^{h}} \left| cp_{ij}^{yh} - p_{ij} \right|}{\# H_{ij}^{h}}, & if \left(\# H_{ij}^{h} \neq 0\right); h \in \{1,2,3\} \\ 0 & , otherwise \end{cases} \tag{4.14}$$

and

$$\kappa = \begin{cases} 3, \ if \left(\# H_{ij}^{1} \neq 0\right) \wedge \left(\# H_{ij}^{2} \neq 0\right) \wedge \left(\# H_{ij}^{3} \neq 0\right) \\ 2, if \left(\# H_{ij}^{a} = 0\right) \wedge \left(\left(\# H_{ij}^{b} \neq 0\right) \wedge \left(\# H_{ij}^{c} \neq 0\right)\right); a,b,c \in \{1,2,3\} \\ 1, \quad otherwise\,. \end{cases} \tag{4.15}$$

with α_{ij}, a parameter to control the influence of completeness in the evaluation of the consistency levels.

$$\alpha_{ij} = 1 - \frac{\# EV_i + \# EV_j - \#\left(EV_i \cap EV_j\right)}{4(n-1)-2}. \tag{4.16}$$

The lower the value CL_{ij}, the more inconsistent is p_{ij} with respect to the rest of information. CL_{ij} should not be less than 0.5 to be able to say that p_{ij} is consistent. If p_{ij} is not consistent and $\varepsilon p_{ij} \neq 0$, then preferences should be revised by DM. If p_{ij} is not consistent and $\varepsilon p_{ij} = 0$, then known preferences should be increased. The α_{ij} parameter should decrease with respect to the number of preference values known, in such a way that it takes the value of 0 when all the preference values in which a_i and a_j are involved are known, in which case the completeness concept lacks any meaning and, therefore, should not be taken into account; and it takes the value of 1 when no values are known. Detailed information about incomplete fuzzy preference relations and their mathematical formulations are given in [18].

Step 2.4: "Aggregation of the evaluations". This process will reflect the opinions of the majority of the DMs. Each group member is denoted as $\{p^k : k = 1,...,K\}$ where K is the size of the group. Let $\{p_{ij}^1,..., p_{ij}^K\}$ be the set of values to be aggregated for any $i, j \in R$ and K DMs. Then, the ordered weighted geometric (OWG) operator is defined as:

$$\Phi^G \left\{\left(p_{ij}^1, p_{ij}^2,..., p_{ij}^K\right)\right\} = \prod_{k=1}^{K} \left(\bar{p}_{ij}^k\right)^{w_k} . \tag{4.17}$$

where, $W = (w_k,...,w_K)$ is an exponential weighting vector, such that $w_k \in [0,1]$ and $\sum w_k = 1$, and each $\bar{p}_{ij}^k$ is the kth largest valued element in the set $\{p_{ij}^1, p_{ij}^2,..., p_{ij}^K\}$ [11], [159], [160]. The OWG operator reflects the fuzzy majority if we calculate its weighting vector W by means of a fuzzy linguistic quantifier [161], [162]. Traditionally, the majority is defined as a threshold number of the individuals. In this study, we make use of the fuzzy majority which is a soft majority concept expressed by a fuzzy linguistic quantifier. Proportional quantifiers, such as *most*, *at least half*, may be represented by fuzzy subsets of the unit interval, [0,1]. Then, for any $r \in [0,1]$, $Q(r)$ indicates the degree to which the proportion r is compatible with the meaning of the quantifier it represents. For a non decreasing relative quantifier, Q, the weights are obtained as

$$w_k = Q(k / K) - Q((k-1)/ K), k = 1, \ldots, K \tag{4.18}$$

where $Q(t)$ is defined as [154]

$$Q(t)=\begin{cases}0, & if \quad t<s \\ (t-s)/(v-s), & if \ s\le t\le v \\ 1, & if \quad t\ge v.\end{cases} \tag{4.19}$$

Note that $s,t,v\in[0,1]$ and $Q(t)$ indicates the degree to which the proportion y is compatible with the meaning of the quantifier it represents. Some examples for the relative quantifiers are "most" (0.3, 0.8), "at least half" (0, 0.5) and "as many as possible" (0.5, 1). When the fuzzy quantifier Q is used for calculating the weights of the OWG operator Φ_W^G, it is represented by Φ_Q^G. Therefore, the collective multiplicative relative importance relation is obtained as follows;

$$p_{ij}=\Phi_Q^G\left(p_{ij}^1, p_{ij}^2,..., p_{ij}^K\right), 1\le i\ne j\le n. \tag{4.20}$$

Step 2.5: "Obtaining priorities from the judgment matrix". After the group opinion is collected in the matrix *P*, it must be exploited to determine the importance weights of the criteria. Note that in *P*, the element *ij* reflects the relative importance of criterion *i* compared to criterion *j*. Next, calculate the quantifier guided importance degree (QGID) of each criterion, which quantifies the importance of one criterion compared to others in a fuzzy majority sense. By using the OWG operator again, we have

$$QGID_i=\Phi_Q^G\left(p_{ij} : j=1,...,n\right). \tag{4.21}$$

for all $i = 1,\ldots,n$. Finally, the obtained $QGID_i$ values should be normalized, i.e.,

$$QGID_i = QGID_i \,/\, \sum_i QGID_i \qquad (4.22)$$

to have the importance degrees in percentage for the group. These steps need to be pursued in all nodes of the evaluation model. The importance degree of each hierarchy leaf node requirement is calculated by multiplying its importance value with the importance values of its up level requirements. Finally, we calculate the weighted sum of CR's group importance values given group importance weights to obtain the aggregate CR importance.

Step 3: "Hows": This step can also be called as *developing/defining DRs*. The first step of the DR part is transforming CRs to technical attributes. DRs are specified on the basis of the company's operational or managerial resource allocation plans in order to satisfy the customers. In defining the DRs, the most important point is finding direct solutions to defined CRs.

Step 4: "Relation Matrix": Here, a relationship matrix is constructed between CRs and DRs. Each of the DRs is correlated individually to each of the CRs by considering to what extent a requirement contributes to meeting customer needs for the attribute. Depending upon the impact of the DRs in meeting CRs for the attribute, values "Empty=no relationship", "1=possible relationship", "3=moderate relationship", and "9=strong relationship" is assigned.

Step 5: "Prioritizing DRs": The importance of each technical/design requirement is computed using the relationship matrix and the relative importance of each CR. The accuracy of the results in this step relies heavily on the quality of the relationship matrix. This computation process intertwines CRs with DRs. That is, the resulting value determines the relative weight of each DRs as compared to CRs. The importance of each DR is calculated as the sum of each CR importance value multiplied by the quantified relationship between the same CR and the current DR.

5. CASE STUDY

5.1. APPLICATION OF THE PROPOSED APPROACH IN HAVI LOGISTICS TURKEY

5.1.1. About the Case Company

One of the selected companies for application of the SQFD is HAVI Logistics Turkey. The reason why this company is chosen for SQFD application is that HAVI Logistics has been following the goals associated with sustainable development. Being a company with global reach, they are well aware of the impact that their businesses can have on the environments in which we all work and live. The company considers environment and sustainability issues in the framework of social responsibility.

HAVI Logistics is "The Global Lead Logistics Provider" for food and non-food logistics. They handle all services throughout the SC and create genuine added value for their customers through their logistics solutions. With their end to end solution philosophy, their integrated supply and transparency HAVI Logistics frees their customers from all SC related logistics responsibilities. More than 6.000 employees work today for HAVI Logistics worldwide. Besides many brands, company commonly serves McDonald's.

HAVI Logistics has grown to an international network of more than 40 distribution, logistics and service companies over the past 29 years. Distribution companies provide a total and exclusive service for more than 6,111 delivery points in 31 countries.

Service companies:

- Freight Management

- Information, communication and technology expertise for hardware, software and process engineering, software development
- Competence in SC Integration

HAVI Logistics outlined four targets in order to provide its customers with the best possible services:

- Assured supply
- Food safety
- Efficiency (low cost / best value)
- Environmental awareness.

5.1.2. Sustainability in HAVI Logistics: "It's easy to be green"

The principle of sustainability - the equilibrium between and the integration of economic, ecological and social goals and thus the acceptance of social responsibility - is not new terrain for the HAVI Logistics. Naturally, it is not sufficient simply to recognize the consequences of such a responsibility. In contrast, putting the principle of sustainability into practice is a basic part of their business thinking. They have assiduously complied with the duty to exercise such diligence for over 25 years.

Since its founding, the HAVI Logistics has measured itself by the manner in which it has followed the goals associated with sustainable development. Today they are known as a trustworthy partner to the Food Service Industry, and have grown into a strong and competitive international Lead Logistics Provider. They owe this development not least to the fact that they have always been concerned with the consequences of their social and ecological responsibility. The HAVI Logistics lives according to the principle of sustainability on every level, and in the past it has earned itself numerous awards and widespread recognition for this reason.

Protecting the environment is a primary objective of HAVI Logistics. Entering one of the HAVI Logistics premises, you can easy recognize the very high environmental consciousness on almost every corner:

- Approved partner of the EU Green Building program; ISO 14001 and EMAS certifications.
- A large section in the company newspaper only reports about environmental topics and certifications and awards showing the great success.
- Employees using "HAVI Logistics environmental cups" to avoid the use of plastic beaker.
- "Please use duplex copies" is written above the printers and copy machines.
- Paper collection boxes are placed in every office.
- The black boards have special sections only reporting about environmental topics.

Detailed information about HAVI Logistics can be found at http://www.havi-logistics.com/.

5.1.3. SQFD Application of HAVI Logistics

To illustrate the proposed approach, a meeting is arranged with HAVI Logistics. Project team (DM group) especially formed for this application includes two local process engineers and manager director of HAVI Logistics Turkey.

Step 1 - Identifying CRs: Here in this study, CRs can also be considered as company requirements. Either customers/stakeholders or companies have common requirements from a sustainable SC. The generic SQFD structure constructed based on literature survey in Section 3.3, is discussed with respect to company targets. Project team considered the proposed SQFD structure adequate. No revisions are done for CRs.

Step 2 - Priority analysis:

Step 2.1: Table 5.1 gives an example evaluation of the group for the purpose of measuring the importance degrees among first level CRs.

Table 5.1 Incomplete linguistic evaluation of HAVI project group

	DM1			DM2			DM3		
	Eco	Env	Soc	Eco	Env	Soc	Eco	Env	Soc
Economical (Eco)	-	VG	VG	-	x	FG	-	x	x
Environmental (Env)	x	-	x	x	-	M	x	-	x
Social (Soc)	x	x	-	FL	x	-	M	M	-

Step 2.2: To complete the missing values, firstly by using Eq. (4.2), Table 5.2 which shows the defuzzified incomplete preferences of the group is obtained. Then Eqs. (4.4) to (4.7) are used to estimate the missing values shown in Table 5.3.

Table 5.2 Defuzzified incomplete evaluation of HAVI project group

	DM1			DM2			DM3		
	Eco	Env	Soc	Eco	Env	Soc	Eco	Env	Soc
Eco	-	0.90	0.90	-	x	0.70	-	x	x
Env	x	-	x	x	-	0.50	x	-	x
Soc	x	x	-	0.30	x	-	0.50	0.50	-

For instance, defuzzified incomplete evaluation of DM1 is calculated as:

$$F(\tilde{p}_{12}) = F(\tilde{p}_{13}) = 1/2 \int_0^1 (0.8+1)\, d\alpha = 1/2 \left(1.8\alpha \Big|_0^1 \right) = 0.90$$

Table 5.3 Estimated complete evaluation of HAVI project group

	DM1			DM2			DM3		
	Eco	Env	Soc	Eco	Env	Soc	Eco	Env	Soc
Eco	-	0.90	0.90	-	0.70	0.70	-	0.70	0.70
Env	0.10	-	0.50	0.30	-	0.50	0.30	-	0.50
Soc	0.10	0.50	-	0.30	0.50	-	0.30	0.50	-

Iteration 1. Continuing with DM1, The set of elements that can be estimated are $\{(2,3),(3,2)\}$. After these elements have been estimated, we have

$H_{23}^{1} = \emptyset$ as $cp_{23}^{11} = p_{21} + p_{13} - 0.5 =$ unknown

$H_{23}^{2} = \{1\}$ as $cp_{23}^{12} = p_{13} - p_{12} + 0.5 = 0.90 - 0.90 + 0.50 = 0.50$

$H_{23}^{3} = \emptyset$ as $cp_{23}^{13} = p_{21} - p_{31} + 0.5 =$ unknown, thereby $cp_{23} = 0.50$.

$H_{32}^{1} = \emptyset$ as $cp_{32}^{11} = p_{31} + p_{12} - 0.5 =$ unknown

$H_{32}^{2} = \{1\}$ as $cp_{32}^{12} = p_{12} - p_{13} + 0.5 = 0.90 - 0.90 + 0.50 = 0.50$

$H_{32}^{3} = \emptyset$ as $cp_{32}^{13} = p_{31} - p_{21} + 0.5 =$ unknown, thereby $cp_{32} = 0.50$.

Iteration 2. The set of elements that can be estimated are $\{(2,1),(3,1)\}$. After these elements have been estimated, we have

$H_{21}^{1} = \emptyset$ as $cp_{21}^{31} = p_{23} + p_{31} - 0.5 =$ unknown

$H_{21}^{2} = \emptyset$ as $cp_{21}^{32} = p_{31} - p_{32} + 0.5 =$ unknown

$H_{21}^{3} = \{1\}$ as $cp_{21}^{33} = p_{23} - p_{13} + 0.5 = 0.50 - 0.90 + 0.50 = 0.10$, thereby $cp_{21} = 0.10$.

$H_{31}^{1} = \emptyset$ as $cp_{31}^{21} = p_{32} + p_{21} - 0.5 = 0.50 + 0.10 - 0.50 = 0.10$

$H_{31}^{2} = \{1\}$ as $cp_{31}^{22} = p_{21} + p_{23} - 0.5 = 0.10 - 0.50 + 0.50 = 0.10$

$H_{31}^{3} = \emptyset$ as $cp_{31}^{23} = p_{32} - p_{12} + 0.5 = 0.5 - 0.9 + 0.5 = 0.10$, thereby $cp_{32} = 0.10$.

Step 2.3: Consistency is checked once missing values are treated. The corresponding consistency level matrix is shown in Table 5.4.

Table 5.4 Consistency level matrix of HAVI project group evaluation

	DM1			DM2			DM3		
	Eco	Env	Soc	Eco	Env	Soc	Eco	Env	Soc
Eco	-	0.58	0.58	-	0.69	0.81	-	0.50	0.58
Env	0.58	-	0.50	0.69	-	0.75	0.50	-	0.58
Soc	0.58	0.50	-	0.81	0.75	-	0.58	0.58	-

As an instance, for upper side of the DM1's matrix, the consistency level calculated using Eqs. (4.11) to (4.16) is as follows.

$EV_1 = \{(1,2),(1,3)\}$; $EV_2 = \{(1,2)\}$; $EV_3 = \{(1,3)\}$.

CP_1 = 2/4, CP_2 = 1/4, CP_3 = 1/4.

$\alpha_{12} = 1 - [(2+1-1)/4(3-1)-2] = 0.67$.

p_{12} is given by DM and is not estimated, $\varepsilon p_{12} = 0$.

$$CL_{12} = (1-0{,}67)\cdot(1-0) + 0{,}67\cdot\frac{2/4+1/4}{2} = 0.58$$

$\alpha_{13} = 1 - [(2+1-1)/4(3-1)-2] = 0.67$.

p_{13} is given by DM and is not estimated, $\varepsilon p_{13} = 0$.

$$CL_{12} = (1-0{,}67)\cdot(1-0) + 0{,}67\cdot\frac{2/4+1/4}{2} = 0.58$$

$\alpha_{23} = 1 - [(1+1)/4(3-1)-2] = 0.67$.

As there is no intermediate alternative to calculate an estimated value except a_1, $\varepsilon p_{23} = 0$,

$$CL_{23} = (1-0{,}67)\cdot(1-0) + 0{,}67\cdot\frac{1/4+1/4}{2} = 0.50 .$$

Step 2.4: Taking into account all matrices obtained from project group, using of Eqs. (4.18) and (4.19), the OWG operator with fuzzy linguistic quantifier 'at least half – (0, 0.5)' is obtained with weighting vector (0.667, 0.333, 0.000). Then, these weighting vectors are used to compute the group importance relation matrix as shown in Table 5.5 by the aid of Eqs. (4.17) to (4.20).

$w_1 = Q(1/3) - Q(0)$ = ((1/3 – 0)/ (0.5 – 0)) – 0 = 0.667

$w_2 = Q(2/3) - Q(1/3)$ = 1 – 0.667 = 0.333

$w_3 = Q(1) - Q(2/3)$ = 1 – 1 = 0.000

Table 5.5 Importance relation matrix of HAVI project group

	Eco	Env	Soc
Eco	0.50	0.83	0.83
Env	0.42	0.50	0.50
Soc	0.42	0.50	0.50

$$\Phi_Q^G\left(p_{12}^1, p_{12}^2, p_{12}^3\right) = \prod_{k=1}^{3}\left(\overline{p}_{12}^k\right)^{w_k} = 0.90^{0.666} \times 0.70^{0.334} \times 0.50^{0.000} = 0.83$$

$$\Phi_Q^G\left(p_{13}^1, p_{13}^2, p_{13}^3\right) = \prod_{k=1}^{3}\left(\overline{p}_{13}^k\right)^{w_k} = 0.90^{0.666} \times 0.70^{0.334} \times 0.50^{0.000} = 0.83$$

$$\Phi_Q^G\left(p_{21}^1, p_{21}^2, p_{21}^3\right) = \prod_{k=1}^{3}\left(\overline{p}_{21}^k\right)^{w_k} = 0.50^{0.666} \times 0.30^{0.334} \times 0.10^{0.000} = 0.42$$

$$\Phi_Q^G\left(p_{23}^1, p_{23}^2, p_{23}^3\right) = \prod_{k=1}^{3}\left(\overline{p}_{23}^k\right)^{w_k} = 0.50^{0.666} \times 0.50^{0.334} \times 0.50^{0.000} = 0.50$$

$$\Phi_Q^G\left(p_{31}^1, p_{31}^2, p_{31}^3\right) = \prod_{k=1}^{3}\left(\overline{p}_{31}^k\right)^{w_k} = 0.50^{0.666} \times 0.30^{0.334} \times 0.10^{0.000} = 0.42$$

$$\Phi_Q^G\left(p_{32}^1, p_{32}^2, p_{32}^3\right) = \prod_{k=1}^{3}\left(\overline{p}_{32}^k\right)^{w_k} = 0.50^{0.666} \times 0.50^{0.334} \times 0.50^{0.000} = 0.50.$$

Step 2.5: Eq. (4.21) is used to compute group aggregated importance values with weighting vector (0.000, 0.333, 0.667) corresponding to the fuzzy linguistic quantifier ‘as many as possible – (0.5, 1)’.

$w_1 = Q(1/3) - Q(0) = 0 – 0 = 0.000$

$w_2 = Q(2/3) - Q(1/3) = ((2/3 – 0.5)/ (1 – 0.5)) - 0.000 = 0.333$

$w_3 = Q(1) - Q(2/3) = 1 – 0.333 = 0.666$

While the quantifier at least half enables us to aggregate highest scores by ignoring lowest values, the quantifier as many as possible us to aggregate lowest scores by ignoring highest values. Then, the obtained importance values are normalized using Eq. (4.22), and the collaborative importance values are calculated as (0.40, 0.30, 0.30). The procedure is as follows.

$$QGID_1 = \Phi_Q^G(p_{11}, p_{12}, p_{13}) = QGID_1 = \left(0.83^{0.000} \times 0.83^{0.333} \times 0.50^{0.667}\right) = 0.591$$

$$QGID_2 = \Phi_Q^G(p_{21}, p_{22}, p_{23}) = QGID_2 = \left(0.50^{0.000} \times 0.50^{0.333} \times 0.42^{0.667}\right) = 0.446$$

$$QGID_3 = \Phi_Q^G(p_{31}, p_{32}, p_{33}) = QGID_3 = \left(0.50^{0.000} \times 0.50^{0.333} \times 0.42^{0.667}\right) = 0.446.$$

$$QGID_i = QGID_i \,/\, \textstyle\sum_i QGID_i \ , \ QGID_1 = 0.591/\ (0.591+0.446+0.446) = 0.40$$

$$QGID_2 = 0.446/\ (0.591+0.446+0.446) = 0.30$$

$$QGID_3 = 0.446/\ (0.591+0.446+0.446) = 0.30.$$

Using the same reasoning, second level factors are evaluated and priorities are determined as in Table 5.6. Multiplying first level values with each of the secondary importance values produces the global importance vectors.

Table 5.6 Priorities of CRs of HAVI project group

First level CRs	Priority	Second level CRs	Priority	Global Priorities
Economical	0.40	Cost Reduction	0.20	0.08
		Asset Use/ Utilization	0.12	0.05
		Improved Quality	0.20	0.08
		Enhanced Customer Service	0.48	0.19
Environmental	0.30	Waste Reduction	0.16	0.05
		Energy Efficiency	0.30	0.09
		Reduced Emissions	0.30	0.09
		Conservation	0.24	0.07
Social	0.30	Reduced Impact on Community	0.25	0.08
		Health and Safety	0.25	0.08
		Laws & Regulations	0.25	0.08
		Strengthened Relationships	0.25	0.08

Step 3 - Defining DRs: DRs are listed as in the generic SQFD model constructed based on literature survey in Section 3.3. No revisions are done for DRs.

Step 4 - Relation Matrix: Here, project team constructed a matrix and assigned relationship s between CRs and DRs. The accuracy of the results relies heavily on the quality of the relationship matrix. Thereby, project team discussed the relations in depth and reached a consensus decision. Relation matrix can be seen from the final SQFD matrix in Table 5.7.

Step 5 - Prioritizing DRs: The importance of each DRs is computed with respect to the relationship matrix and the relative importance of each CR. As an instance for this computation process, importance weight of "price strategy DR" is calculated as (3*0.08) + (9*0.048) = 0.672 which corresponds to 0.0089 percentile. Step 5 can be seen again from the final HOQ matrix in Table 5.1.3.7. Whole computational matrices can be seen in Appendix.

Table 5.7 The final SQFD scheme of HAVI project group evaluation

	Drivers for a Sustainable SC (CRs) \ Key Practices for a Sustainable SC (DRs)	Price strategy	SC optimization	Inventory management	Forecast accuracy	Lifecycle management	Supplier management	Flexible & Cleaner technology	Delivery performance	Usage of effective systems and tools	Environmental management system	Green innovation	Environmental product design	Environmental activity capability	Eco-friendly transportation	Efficient handling & storage	Reverse logistics	Green and back packaging	Collaboration with partners	Employee Practices	Outsourcing	Stakeholders' rights	Monitoring and Maintenance	Group Opinion
Economical	Cost Reduction	3	9	9		1		9	3	9	1		1	1	3	9	3		3	9	3	3	3	0.080
	Asset Use/ Utilization	9	9	1		9		3	1	9	3		1		9	9	1			9	3		3	0.048
	Improved Quality		9	9	9	1	3	3	9	9	3	3	3	3	3	9	3	1	9	9	1		9	0.080
	Enhanced Customer Service		9	3	9	3	3	3	9	9	3	3	3	3	3	9	9	3	3	9	1	1	3	0.192
Environmental	Waste Reduction		1	1	3	3	1	1		3	9	3	9	9		9	9	9	3	9	1		3	0.048
	Energy Efficiency		3			3		9		1	9	3	3	3		3			1	9			9	0.090
	Reduced Emissions		3			3		9	3	3	9	3	3	3	9	1	1		1	9	3		9	0.090
	Conservation		3	1	1	1		3	3	3	9	9	9	9	3	3	1		3	9	1		3	0.072
Social	Reduced Impact		3	1		3	3	3	1	3	9	3	9	3	9	1	1	1	3	9	1		9	0.075
	Health and Safety		3			3		3	1	3	3	9	9	1	9	9			3	9		3	9	0.075
	Laws & Regulations					1				1	9	1	1		1	1		1	3	9		3	3	0.075
	Strengthened Relationships		1				3		1	1	3	1	1	1	1	1			3	3		3		0.075
	Importance of DRs	0.672	4.929	2.259	2.664	2.449	1.314	4.014	3.447	4.920	5.540	3.198	4.064	2.891	4.014	5.508	2.925	1.238	2.976	8.550	1.121	1.107	5.235	
	Importance %	0.008	0.065	0.030	0.035	0.032	0.017	0.053	0.045	0.066	0.073	0.042	0.053	0.038	0.053	0.073	0.038	0.016	0.039	0.113	0.015	0.014	0.069	
	Ranking	22	5	17	15	16	18	8	10	6	2	11	7	14	9	3	13	19	12	1	20	21	4	

5.2. APPLICATION OF THE PROPOSED APPROACH IN ABC TURKEY

5.2.1. About the Case Company

The other selected company for application of the SQFD is ABC Turkey (The project team did not want the company name to be announced). The reason why this company is chosen for SQFD application is that the company considers sustainability as the basis for their future business success and as a key pillar of their corporate culture. They produce sustainable solutions for problems in industry, energy, environment and healthcare matters.

ABC's history in Turkey dates back to 1856, when the company built the Istanbul Telegraph Center. For 153 years, ABC has been active in Turkey, where it is a center of competence and leading provider of solutions, products, and services in the Information and Communications, Automation and Control, Power, Building Technology, Transportation, and Medical business areas. In 1958, SIMKO A.Ş. was founded as a partnership between ABC and the Koç group. In 2000, after 42 years of partnership with the Koç group, SIMKO A.Ş. became a wholly owned ABC subsidiary and was renamed ABC Sanayi ve Ticaret A.Ş. Other ABC affiliates are also active in the region, including ABC Leasing Turkey, Bosch and ABC Hausgeräte GmbH, and Osram A.Ş.

In fiscal 2009 (October 1, 2008 – September 30, 2009), sales to customers in Turkey amounted to around EUR 750 million. ABC Turkey today works with about 2.400 employees for the aim of complete customer satisfaction.

5.2.2. Sustainability in ABC: "Bringing economic, social and ecological goals into harmony: the global challenge"

ABC pursues a strategy of sustainability – in developing and threshold countries as well as industrial nations. The driving force behind this strategy is the firm belief that, not only governments and international organizations, but also industrial companies with their power of innovation and investment bear a special responsibility to ensure the future viability of global development.

ABC has maintained a presence in many countries around the world ever since its formation. The company has a more than 160-year-old tradition of globalism and high value creation in developing and threshold countries. Many ABC offices are interwoven with their region's history. Most importantly, however, ABC has earned high marks for its expertise in public infrastructure, from water and energy management to transportation and health care. These technologies are of the utmost importance to achieve key Millennium Development Goals. After all, a working infrastructure is the most important requirement for sustainable development – and for achieving the United Nations' primary goal: to fight hunger and poverty.

ABC states that: "In the future, we will intensify our focus on sustainability as an increasingly more important part of responsible corporate governance. We use our technical innovations to spur positive and ethical economic growth in all countries – and thereby open new markets. This strategy will maintain ABC's success as an industrial company over the long term. We firmly believe that sustainable management is the only way to meet our responsibility as a global player toward all parties involved: our shareholders, the global community and the generations to come".

For ABC, fulfilling social and corporate responsibility means, among other things, that they have to take environmental protection seriously, foster human health and help conserve natural resources. Some of ABC's environmental activities are:

- Consulting in energy efficiency (first organization in Turkey that has the authority of consultation in energy efficiency).
- Projects related to energy efficiency and renewable energy resources (especially wind).
- Entertaining students in the company and informing them in environmental issues.

5.2.3. SQFD Application of ABC Turkey

To illustrate the proposed approach, a meeting is arranged with ABC Turkey A.Ş. Project team (DM group) especially formed for this application includes two engineers and quality management systems manager of ABC Turkey.

Step 1 - Identifying CRs: The generic SQFD model constructed based on literature survey in Section 3.3, is discussed with respect to company targets. Project team made some revisions on the proposed SQFD structure for CRs. For environmental dimension of sustainability, they considered reduction of wastes and emissions together, and wanted to change the CR "conservation of natural resources" to "minimization of the use of natural resources". For social dimension of sustainability, they also wanted to change the CR "reduced impact on community" to "contribution to community". The revised CRs are shown in Table 5.8.

Table 5.8 Final CRs of SQFD for ABC Turkey

First level CRs	Second level CRs
Economical	Cost Reduction
	Asset Use/ Utilization
	Improved Quality
	Enhanced Customer Service
Environmental	Waste Reduction
	Energy Efficiency
	Natural Resource Usage Minimization
Social	Health and Safety
	Laws & Regulations
	Contribution to Community
	Strengthened Relationships

Step 2 - Priority analysis:

Step 2.1: Table 5.9 gives an example evaluation of the group for the purpose of measuring the importance degrees among first level CRs.

Table 5.9 Incomplete linguistic evaluation of ABC project group

	DM1			DM2			DM3		
	Eco	Env	Soc	Eco	Env	Soc	Eco	Env	Soc
Economical (Eco)	-	x	MG	-	FG	FG	-	x	x
Environmental (Env)	x	-	M	x	-	x	x	-	M
Social (Soc)	x	x	-	x	x	-	M	M	-

Step 2.2: To complete the missing values, firstly by using Eq. (4.2), Table 5.2.3.3 which shows the defuzzified incomplete preferences of the group is obtained. Eqs. (4.4) to (4.7) are then used to estimate the missing values shown in Table 5.10.

Table 5.10 Defuzzified incomplete evaluation of ABC project group

	DM1			DM2			DM3		
	Eco	Env	Soc	Eco	Env	Soc	Eco	Env	Soc
Eco	-	x	0.60	-	0.70	0.70	-	x	x
Env	x	-	0.50	x	-	x	x	-	0.50
Soc	x	x	-	x	x	-	0.50	0.50	-

For instance, defuzzified incomplete evaluation of DM1 is calculated as:

$$F(\tilde{p}_{12}) = 1/2\int_{0}^{1}(0.50+0.70)d\alpha = 1/2\left(1.2\alpha\,\Big|_{0}^{1}\right) = 0.60$$

$$F(\tilde{p}_{13}) = 1/2\int_{0}^{1}(0.40+0.60)d\alpha = 1/2\left(1.0\alpha\,\Big|_{0}^{1}\right) = 0.50$$

Table 5.11 Estimated complete evaluation of ABC project group

	DM1			DM2			DM3		
	Eco	Env	Soc	Eco	Env	Soc	Eco	Env	Soc
Eco	-	0.60	0.60	-	0.70	0.70	-	0.50	0.50
Env	0.40	-	0.50	0.30	-	0.50	0.50	-	0.50
Soc	0.40	0.50	-	0.30	0.50	-	0.50	0.50	-

Iteration 1. Continuing with DM1, The set of elements that can be estimated are $\{(1,2),(2,1)\}$. After these elements have been estimated, we have

$H_{12}^{1} = \varnothing$ as $cp_{12}^{31} = p_{13} + p_{32} - 0.5 =$ unknown

$H_{12}^{2} = \varnothing$ as $cp_{12}^{32} = p_{32} - p_{31} + 0.5 =$ unknown

$H_{12}^{3} = \{1\}$ as $cp_{12}^{33} = p_{13} - p_{23} + 0.5 = 0.60 - 0.50 + 0.50$, thereby $cp_{23} = 0.60$.

$H_{21}^{1} = \varnothing$ as $cp_{21}^{31} = p_{23} - p_{31} + 0.5 =$ unknown

$H_{21}^{2} = \varnothing$ as $cp_{21}^{32} = p_{31} - p_{32} + 0.5 =$ unknown

$H_{21}^{3} = \{1\}$ as $cp_{21}^{33} = p_{23} - p_{13} + 0.5 = 0.50 - 0.60 + 0.50$, thereby $cp_{32} = 0.40$.

Iteration 2. The set of elements that can be estimated are $\{(3,1),(3,2)\}$. After these elements have been estimated, we have

$H_{31}^{1} = \varnothing$ as $cp_{31}^{21} = p_{32} + p_{21} - 0.5 =$ unknown

$H_{31}^{2} = \{1\}$ as $cp_{31}^{22} = p_{21} - p_{23} + 0.5 = 0.40 - 0.50 + 0.5 = 0.40$

$H_{31}^{3} = \varnothing$ as $cp_{31}^{23} = p_{32} - p_{12} + 0.5 =$ unknown, thereby $cp_{21} = 0.40$.

$H_{32}^{1} = \{1\}$ as $cp_{32}^{11} = p_{31} + p_{12} - 0.5 = 0.40 + 0.60 - 0.5 = 0.50$

$H_{32}^{2} = \{1\}$ as $cp_{32}^{12} = p_{12} - p_{13} + 0.5 = 0.60 - 0.60 + 0.5 = 0.50$

$H_{32}^{3} = \varnothing$ as $cp_{32}^{13} = p_{31} - p_{21} + 0.5 = 0.40 - 0.40 + 0.5 = 0.5$, thereby $cp_{32} = 0.50$.

Step 2.3: Consistency is checked once missing values are treated. The corresponding consistency level matrix is shown in Table 5.12.

Table 5.12 Consistency level matrix of ABC group evaluation

	DM1			DM2			DM3		
	Eco	Env	Soc	Eco	Env	Soc	Eco	Env	Soc
Eco	-	0.50	0.58	-	0.58	0.58	-	0.69	0.75
Env	0.50	-	0.58	0.58	-	0.50	0.69	-	0.81
Soc	0.58	0.58	-	0.58	0.50	-	0.75	0.81	-

As an instance, for upper side of the DM1's matrix, the consistency level calculated using Eqs. (4.11) to (4.16) is as follows.

$EV_1 = \{(1,3)\}$; $EV_2 = \{(2,3)\}$; $EV_3 = \{(1,3),(2,3)\}$.

CP_1 = 1/4, CP_2 = 1/4, CP_3 = 2/4.

$\alpha_{12} = 1 - [(1+1)/4(3-1)-2] = 0.67$.

As there is no intermediate alternative to calculate an estimated value except a_3, $\varepsilon p_{12} = 0$,

$$CL_{12} = (1-0{,}67)\cdot(1-0) + 0{,}67 \cdot \frac{1/4+1/4}{2} = 0.50$$

$\alpha_{13} = 1 - [(1+2-1)/4(3-1)-2] = 0.67$.

p_{13} is given by DM and is not estimated, $\varepsilon p_{13} = 0$.

$$CL_{12} = (1-0{,}67)\cdot(1-0) + 0{,}67 \cdot \frac{2/4+1/4}{2} = 0.58$$

$\alpha_{23} = 1 - [(1+2-1)/4(3-1)-2] = 0.67$.

p_{12} is given by DM and is not estimated, $\varepsilon p_{12} = 0$.

$$CL_{23} = (1-0{,}67)\cdot(1-0) + 0{,}67 \cdot \frac{2/4+1/4}{2} = 0.58 .$$

Step 2.4: Taking into account all matrices obtained from project group, using of Eqs. (4.18) and (4.19), the OWG operator with fuzzy linguistic quantifier ‘at least half – (0, 0.5)’ is obtained again with weighting vector (0.667, 0.333, 0.000). Then, these weighting vectors are used to compute the group importance relation matrix as shown in Table 5.13 by the aid of Eqs. (4.17) to (4.20).

Table 5.13 Importance relation matrix of ABC project group

	Eco	Env	Soc
Eco	0.50	0.66	0.66
Env	0.46	0.50	0.50
Soc	0.46	0.50	0.50

$$\Phi_Q^G\left(p_{12}^1, p_{12}^2, p_{12}^3\right) = \prod_{k=1}^{3}\left(\overline{p}_{12}^k\right)^{w_k} = 0.70^{0.666} \times 0.60^{0.334} \times 0.50^{0.000} = 0.66$$

$$\Phi_Q^G\left(p_{13}^1, p_{13}^2, p_{13}^3\right) = \prod_{k=1}^{3}\left(\overline{p}_{13}^k\right)^{w_k} = 0.70^{0.666} \times 0.60^{0.334} \times 0.50^{0.000} = 0.66$$

$$\Phi_Q^G\left(p_{21}^1, p_{21}^2, p_{21}^3\right) = \prod_{k=1}^{3}\left(\overline{p}_{21}^k\right)^{w_k} = 0.50^{0.666} \times 0.40^{0.334} \times 0.30^{0.000} = 0.46$$

$$\Phi_Q^G\left(p_{23}^1, p_{23}^2, p_{23}^3\right) = \prod_{k=1}^{3}\left(\overline{p}_{23}^k\right)^{w_k} = 0.50^{0.666} \times 0.50^{0.334} \times 0.50^{0.000} = 0.50$$

$$\Phi_Q^G\left(p_{31}^1, p_{31}^2, p_{31}^3\right) = \prod_{k=1}^{3}\left(\overline{p}_{31}^k\right)^{w_k} = 0.50^{0.666} \times 0.40^{0.334} \times 0.30^{0.000} = 0.46$$

$$\Phi_Q^G\left(p_{32}^1, p_{32}^2, p_{32}^3\right) = \prod_{k=1}^{3}\left(\overline{p}_{32}^k\right)^{w_k} = 0.50^{0.666} \times 0.50^{0.334} \times 0.50^{0.000} = 0.50.$$

Step 2.5: Eq. (4.21) is used to compute group aggregated importance values with weighting vector (0.000, 0.333, 0.667) corresponding to the fuzzy linguistic quantifier ‘as many as possible – (0.5, 1)’ again. Then, the obtained importance values are normalized using Eq. (4.22), and the collaborative importance values are calculated as (0.40, 0.30, 0.30). The procedure is as follows.

$$QGID_1 = \Phi_Q^G(p_{11}, p_{12}, p_{13}) = QGID_1 = \left(0.66^{0.000} \times 0.66^{0.333} \times 0.50^{0.667}\right) = 0.550$$

$$QGID_2 = \Phi_Q^G(p_{21}, p_{22}, p_{23}) = QGID_2 = \left(0.50^{0.000} \times 0.50^{0.333} \times 0.46^{0.667}\right) = 0.476$$

$$QGID_3 = \Phi_Q^G(p_{31}, p_{32}, p_{33}) = QGID_3 = \left(0.50^{0.000} \times 0.50^{0.333} \times 0.46^{0.667}\right) = 0.476.$$

$$QGID_i = QGID_i \,/ \textstyle\sum_i QGID_i \;,\; QGID_1 = 0.550/\,(0.550+0.476+0.476) = 0.366$$

$$QGID_2 = 0.476/\,(0.550+0.476+0.476) = 0.317$$

$$QGID_3 = 0.476/\,(0.550+0.476+0.476) = 0.317.$$

Using the same reasoning, second level factors are evaluated and priorities are determined as in Table 5.14.

Table 5.14 Priorities of CRs for ABC project group

First level CRs	Priority	Second level CRs	Priority	Global Priorities
Economical	0.36	Cost Reduction	0.24	0.09
		Asset Use/ Utilization	0.23	0.08
		Improved Quality	0.23	0.08
		Enhanced Customer Service	0.30	0.11
Environmental	0.32	Waste Reduction	0.38	0.12
		Energy Efficiency	0.31	0.10
		Natural Resource Usage Minimization	0.31	0.10
Social	0.32	Health and Safety	0.40	0.13
		Laws & Regulations	0.24	0.08
		Contribution to Community	0.24	0.08
		Strengthened Relationships	0.12	0.04

Step 3 - Defining DRs: DRs are listed as in the generic SQFD model constructed based on literature survey in Section 3.3. Project team only preferred to consider "employee practices" DR as "human resource (HR) management".

Step 4 - Relation Matrix: Here distinctively from HAVI Logistics case, project team constructed different matrices and assigned relationships between CRs and DRs. The OWG operator is used to aggregate DMs' preferences for relation matrix, and as a result, a consensus decision is reached. Relation matrix can be seen from the final SQFD matrix in Table 5.15.

Step 5 - Prioritizing DRs: The importance of each DRs is computed with respects to the relationship matrix and the relative importance of each CR. As an instance for this computation process, importance weight of "forecast accuracy DR" is calculated as (6*0.088) + (4*0.084) + (6*0.110) + (6*0.038) = 1.523 which corresponds to 0.021 percentile. Step 5 can be seen again from the final HOQ matrix in Table 5.15. Whole computational matrices can be seen in Appendix.

Table 5.15 The final SQFD scheme of ABC project group evaluation

	Key Practices for a Sustainable SC (DRs) / Drivers for a Sustainable SC (CRs)	Price strategy	SC optimization	Inventory management	Forecast accuracy	Lifecycle management	Supplier management	Flexible & Cleaner technology	Delivery performance	Usage of effective systems and tools	Environmental management system	Green innovation	Environmental product design	Environmental activity capability	Eco-friendly transportation	Efficient handling & storage	Reverse logistics	Green and back packaging	Collaboration with partners	HR Management	Outsourcing	Stakeholders' rights	Monitoring and Maintenance	Group Opinion
Economical	Cost Reduction		9	4	6	6	6	9	3	9		4	3	3	3	4			6	6	9		6	0.088
	Asset Use/ Utilization			9	4	4	4	6		6		4	4	9	3	4			4	4	6		4	0.084
	Improved Quality		6	1		6	9	6	2	9		4	4	5		3			6	6			9	0.084
	Enhanced Customer Service	9	9	2	6	9	6	6	9	6		6	6	5	2	4	6	4	6	9	2		3	0.110
Environmental	Waste Reduction		2	2			2	6		6	9	9	9	9	4		9	9	2					0.120
	Energy Efficiency		2			3		6		6	6	9	9	9	6	3								0.098
	Min. use of natural resources					4		6		6	9	9	9	9	6	3	9	6	2				3	0.098
Social	Health and Safety							4		3	6	4	6	9	4		4	4				3		0.127
	Laws & Regulations							4		6	9	9	9	9	9		9	6						0.076
	Contribution to community		4			1	4			9		6		5					6					0.076
	Strengthened Relationships		9	4	6	6	6	9	3	9		4	3	3	3	4			6	6	9		6	0.038
	Importance of DRs	0.988	2.873	1.654	1.523	3.083	2.673	6.111	1.420	6.402	4.841	6.134	5.970	6.784	3.766	1.969	4.124	2.874	2.693	2.357	1.515	0.228	2.246	
	Importance %	0.014	0.040	0.023	0.021	0.043	0.037	0.085	0.020	0.089	0.067	0.085	0.083	0.094	0.052	0.027	0.057	0.040	0.037	0.033	0.021	0.003	0.031	
	Ranking	21	11	17	18	9	13	4	20	2	6	3	5	1	8	16	7	10	12	14	19	22	15	

6. OBTAINED RESULTS AND DISCUSSIONS

6.1. RESULTS FOR HAVI LOGISTICS TURKEY

According to the application in HAVI Logistics Turkey, obtained DRs' priorities are depicted in Figure 6.1. The results show that top 5 key practices for the company to design a sustainable SC structure are/ should be:

- Employee practices with 11.34%,
- Environmental management system with 7.35%,
- Efficient handling & storage 7.31%,
- Monitoring & maintenance 6.95%, and
- SC optimization 6.54%.

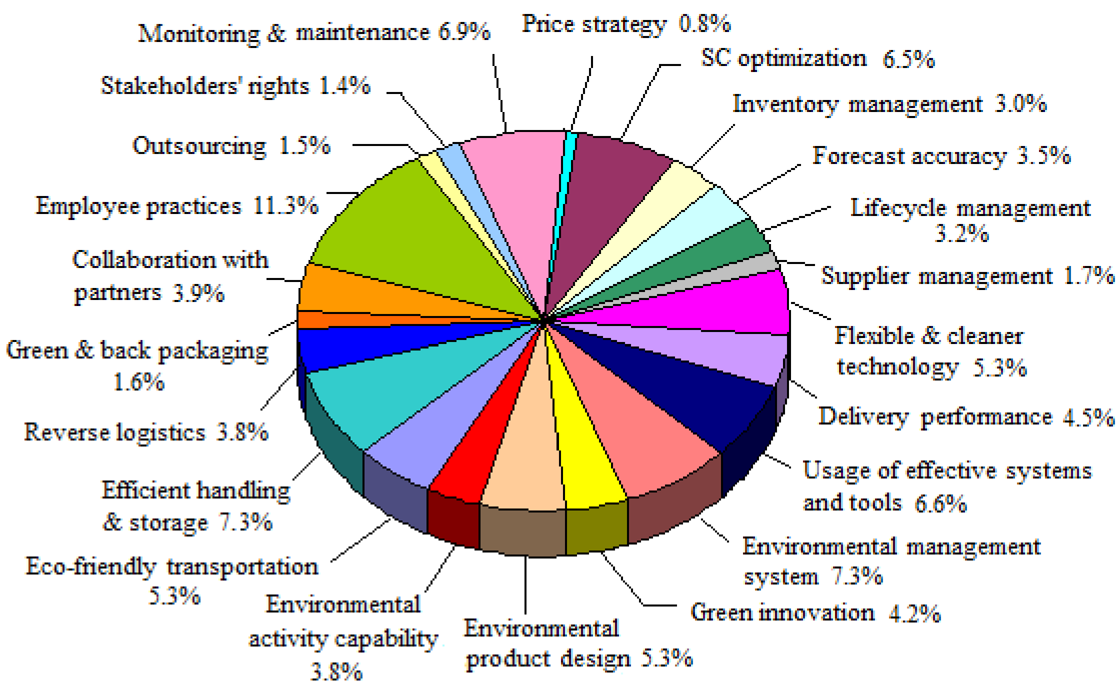

Figure 6.1 Dispersion of DRs for HAVI Logistics Turkey

In terms of the DRs, the results show that the company have formulated an environmental policy, try to integrate environmental issues into other functional areas and care about eco-oriented training of their employees. However, the employee practices are stressed distinctly more. A reason for this result is that companies prefer an internal focus first, before trying to integrate sustainability to their SCs. Also environmental management is still somehow a new concept for many managers.

6.2. RESULTS FOR ABC TURKEY

According to the application in ABC Turkey, obtained DRs' priorities are depicted in Figure 6.2. The results show that top 5 key practices for the company to design a sustainable SC structure are/ should be:

- Environmental activity capability with 9.4%,
- Usage of effective systems and tools with 8.9%,
- Green innovation with 8.5%,
- Flexible and cleaner technology with 8.5%, and
- Environmental product design with 8.3%.

In terms of the DRs, the results show that the company attaches the most importance to using effective systems and tools. Company can expect to gain efficiency in all three pillars of sustainability with this DRs. For instance by using effective tools, route planning can minimize transport distances, therefore fuel consumption, traffic congestion, noise, air pollution, and cost. Managing environmental technologies is also one of the most important DRs to gain continuous environmental improvements and competence for the company. The company also tries to integrate environmental issues with R&D activities and HR management.

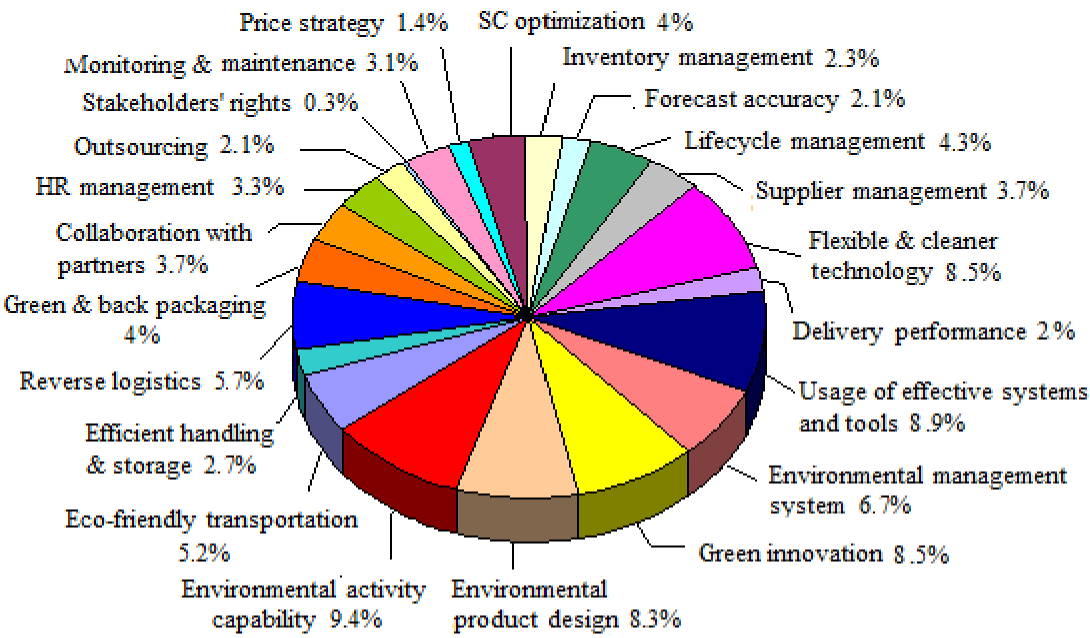

Figure 6.2 Dispersion of DRs for ABC Turkey

6.3. GENERAL DISCUSSION

To obtain and maintain a sustainable SC structure, the factors given in Section 6.1 and 6.2 should take precedence for case companies. Following can be the best actions for improving top 5 DRs.

- Employee practices (HR management): Complying with the international labor standards, ensuring that the workplace and its environment do not endanger the physical integrity or health of employees, action to reduce the causes of accidents and improve working conditions is the object of ongoing programs, ensuring that applicable legal restrictions on working hours are complying with, training employees on eco-friendly workflow processes and procedures.

- Environmental management system: The certification of ISO 14001 standards is an important element of environmental management system. Following "plan, do, check, feedback" cycle of continuous improvement; regularly validating the efficiency of the system by internal and external experts can be key actions.

- Efficient handling & storage: Maximize the energy efficiency of materials handling equipment such as conveyors, palletizers, and automated storage systems (e.g. sensors allow conveyors to be turned off or run at lower speeds when not in use); handle & store hazmats safely (where possible, replace hazmat with non-hazardous alternatives, inspect tanks or containers used to store hazmat to detect and correct the potential for liquid or vapor leaks); use mechanical handling equipment powered by alternative energy sources.

- Monitoring & maintenance: Monitoring the goods and services; maintenance devices and vehicles; monitoring business partners (monitoring can involve interview and visit); monitoring employees health; monitoring social or environmental impacts.

- SC optimization: Optimize SC logistics network design (use SC optimization software, assess the cost and benefit of outsourcing); optimize warehouse layout and workflow (organize warehouse layout for safe and efficient circulation and inventory picking and put-away, to minimize repetitive handling, optimize picking methodology for energy efficiency and productivity); optimize transportation loads and routes.

- Environmental activity capability: Perform activities such as reduce, remanufacture, recover, reuse, and recycling. For instance, reusable trays and pallets are used for shipment, materials with recycled content can be used, an efficient take-back program can be implemented, etc.

- Green innovation: Different components of the innovative organization can be introduced as shared vision, leadership and the will to innovate; effective team working; continuing individual development; and extensive communication. Then R&D strategies that accounts for eco-efficiency of products or technologies can be improved.

- Environmental product design: Preferring materials for products with a high recycling rate and which have the least impact on the environment, both in use and origin. There are many initiatives by private and public organizations who are adopting codes of conduct for themselves and their suppliers.

- Usage of effective systems and tools: Use bar coding, radio frequency identification (RFID) technology, material requirements planning (MRP), enterprise resource planning (ERP), load and route planning tools.

- Flexible and cleaner technology: High level of technical capabilities and capability using minimum energy and material is essential. Alternative energies as biodiesel; ethanol; propane, and technologies such as hybrid vehicles can be preferred.

7. CONCLUSION

This study provides a different point of view to the evaluation the QFD applications. To our knowledge, no previous work has investigated this subject using this kind of integrated method. Though we studied the problem of sustainable SCM with incomplete preferences, this approach can be applied for different kinds of product, system or service development problems.

From the analysis of the literature published so far, both at industrial and scientific research levels, four main conclusions can be drawn:

1. Within the amount of literature available for QFD, scientific working papers, theses or reports has been published only in the form of perfect information,
2. Although there exist certain studies on environmental product design/development, researchers in the product or process design and development arena are probably still not much aware of QFD’s potential for sustainable SC structure development,
3. To date, there are very few incomplete preference structured accounts of the applications in the literature and neither focused on sustainable SCM issue.
4. Finally, there are very few, if any, papers of the applications of QFD in Turkey for sustainable SC structure development, either at an academic or industrial level.

Determining the relative importance of CRs is a fundamental problem in QFD applications. Successful applications of QFD basically rely on effective communication among team members to reach a consensus and assigning importance levels that reflect each individual member’s preferences. Thus, in this study one of the primary aims was to apply GDM in QFD. Generally it is difficult for a DM to provide preferences for all pairs of factors because of time pressure, lack of knowledge or data, and his/her limited expertise. Therefore, another aim was to show the use of incomplete preference relations in GDM applications. As the determination of CR priorities is the key concept in QFD, it is believed that greater emphasis has to be given to analyze and aggregate individual assessments considering lack of information.

The prominent characteristic of the proposed method is that it needs the least judgments provided by the DM to construct a consistent complete linguistic preference relation. The approach combines all individual preferences into the group preferences and merges the overall information to get the ranking of factors. No previous paper in the QFD literature has attempted to aggregate opinions of team members in the case where each individual has incomplete evaluation. To extend the proposed method, future work can involve the use of incomplete linguistic preferences [163] to estimate the missing values or the use of different aggregation operators (e.g. ordered weighted averaging (OWA), majority additive OWA (MA-OWA), induced OWG (IOWG), etc. [161], [164], [165]).

Obviously there is considerable activity and continuing development in the field of sustainability, that it is worthwhile for researchers and practitioners to consider the implications and impacts of sustainability on traditional assumptions and practices in the field of operations management. Another future direction can be the discussion of the results with case company. Thereby ongoing activities in the company can be overviewed, and based on the most important DRs, company's future actions can be observed.

Although not difficult to include, the correlation between DRs is not considered in this study to keep the focus on the proposed GDM approach. This may be a subject of future research.

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BIOGRAPHICAL SKETCH

Gizem Çifçi is born in 1987 in Istanbul. She received her high school education in private Uğur high school. She graduated from Kadir Has University in 2008 with a B.Sc. in Industrial Engineering. She is now a M.Sc. candidate in the Industrial Engineering Department at Galatasaray University. Her areas of interest include: Multi-criteria decision making, performance evaluation and supply chain management.

PAPERS IN PROCEEDINGS:

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HONORS/AWARDS:

2008 – T.C. Kadir Has University Industrial Engineering Department, Championship of Bachelor's Degree Thesis: "A Fuzzy AHP Based Strategic Analysis of Service Quality in Health Care Industry", Supervisor: Prof. Dr. Gülçin Büyüközkan Feyzioğlu.

2008 – B.S. with Honors in Industrial Engineering, Kadir Has University.