國立交通大學

科技管理研究所

博士論文

應用模糊多準則決策分析與模糊集群方法探討綠色工程產業發展策略之研究

Applying Fuzzy Multi-Criteria Decision Analysis with Fuzzy Classification to Explore the Development Strategy of Green Engineering Industry

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指導教授：曾國雄

中　華　民　國　九　十　四　年　五　月

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國立交通大學
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Applying Fuzzy Multi-Criteria Decision Analysis with Fuzzy Classification to Explore the Development Strategy of Green Engineering Industry

合於博士資格水準、業經本委員會評審認可。

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本授權書所授權之論文為本人在 國立交通大學 科技管理研究所 九十三 學年度第 二 學期取得 博士學位 之論文。

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研究生簽名：邱華凱
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日期：民國 94 年 5 月 11 日

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本授權書所授權之論文為本人在 國立交通大學 科技管理研究所 九十三 學年度第 二 學期取得 博士學位 之論文。

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應用模糊多準則決策分析與模糊集群方法探討綠色工程產業發展策略之研究

學生：邱華凱　　　　　　　　　指導教授：曾國雄 教授

國立交通大學科技管理研究所

摘　要

自從 1987 年聯合國世界環境與發展委員會揭示「我們共同的未來」報告，強調人類永續發展的概念，及至 1992 年聯合國環境規劃委員會通過了「二十一世紀議程」及許多重要文件以來，「永續發展」已成為政府與企業追求生存與經營管理之新思維及努力方向，以整合經濟、環境、社會及文化，追求滿足當代及未來世代的優質生活。

為了反應環境保護政策與法規之要求，如何設計符合永續發展之產品已為企業努力之目標，國際上亦有許多的模式、方法及工具陸續被提出，例如「生態設計」、「永續性產品與服務發展」等。根據過去的相關研究顯示，這些方法或模式確實能夠促進企業達到追求永續發展之目標。本研究首先蒐集整理永續發展思維之演進，了解永續發展之產品與服務的規劃流程，並介紹在進行永續性產品與服務發展過程中，應考慮那些構面及擬訂那些評估準則。再者，這些衡量構面與評估準則間通常存在衝突及無法同時滿足之特性，使得問題變得非常複雜，而多目標決策恰可提供適當且客觀評估的結果。

本論文以台灣水產加工業追求永續生存之綠色工程發展策略為實證案例，首先以模糊層級分析法建立評估體系，再以模糊多準則決策方法進行發展策略之評估。考量實際的多目標決策問題中，準則間經常存在非獨立性情況，本研究試圖將傳統分析層級程序法之獨立性假設放寬，並提出非加法型模糊積分方法推導出評估策略之綜合效用值並據以進行優勢排序。再者，考慮資源限制及方案策略間非互斥等因素，本研究進一步以模糊集群分析求解最適化之策略組合，提供企業經營者策略擬定與資源配置之決策參考。

關鍵字：永續發展、綠色工程、多目標決策、模糊理論、模糊積分、模糊集群分析、資源配置

Applying Fuzzy Multi-Criteria Decision Analysis with Fuzzy Classification to Explore the Development Strategy of Green Engineering Industry

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Abstract

Since the World Commission on Environment and Development (WCED) published the so-called Brundtland Report "Our Common Future" in 1987 and the United Nations Environmental Planning Board (UNEP) presented "Agenda 21" in 1992, sustainable development has become an important part of international and national approaches to integrating economic, environmental, social and ethical considerations so that a good quality of life can be enjoyed by current and future generations for as long as possible.

In response to the shift in environmental policy and law towards products, most of enterprises have focus on developing sustainable products. For some time, there are many concepts, approaches and tools have been proposed to help industries to meet this aim such as eco-design and sustainable product development. Past empirical researches indicated that these approaches and tools have successfully encouraged the sustainable products and services development for industry. In this study, we firstly survey the stream of sustainable development and recognize the planning process for sustainable products and services development. We also introduce the considered aspects with evaluated criteria in this planning process. In addition, for the reasons of incommensurability and conflicting within these aspects and criteria for sustainable development, the problems will become more complex. Multiple Criteria Decision Analysis (MCDA) can provide appropriately and objectively analysis results for dealing with these kinds of problem.

In this empirical study, we firstly employ fuzzy AHP to establish hierarchy system for evaluating the sustainable development strategies of green engineering for fishing industry in Taiwan. Secondly, fuzzy multi-criteria decision analysis method was utilized to derive the final synthetic values of the proposed strategies and determine the preferred order according to these values. In order to conform to the situation of non-independence among evaluated criteria in real problem, we relax the required independence assumption of traditional Analytic Hierarchy Process (AHP) for evaluation. This paper applies λ fuzzy measure and non-additive fuzzy integral technique to derive the synthetic values of proposed strategies. Furthermore, considering the limitation on resources and seldom mutually exclusive among these proposed strategies, we introduce fuzzy classification to find the optimal strategy combination. These optimal strategy combinations can be provided the useful information in resources allocation for decision makers.

Keywords: Sustainable Development, Green Engineering, Multi-Criteria Decision Analysis, Fuzzy Set Theory, Fuzzy Integral, Fuzzy Classification, Resource Allocation

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邱華凱 2005 年 5 月

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1. INTRODUCTION

Research background, purposes and methodology are described in this chapter. Additionally, the research process and the organization of this dissertation are introduced as followed.

1.1 Research Background

Sustainable development has become an important part of international and national approaches to integrating economic, environmental, social and ethical considerations so that a good quality of life can be enjoyed by current and future generations for as long as possible. The broad concept of sustainable development gained prominence after the publication of the so-called Brundtland Report 'Our Common Future' (WCED, 1987). At the Earth Summit meeting held in Rio de Janeiro in 1992 many national governments pledged them to making development sustainable by the early years of the new millennium.

Sustainable development, as described by the Brundtland report, is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Although sustainable development is difficult to define using mathematical terms, many researchers recognize that it is a function of two major components, ecological and human (Pearce and Turner, 1990; Milon and Shogren, 1995; Rauch, 1998). That is, sustainable decision-making should have two simultaneous goals:

(1) Achievement of human development to secure high standards of living;

(2) Protection and improvement of the environment now and for the generations to come.

Furthermore, since the Earth Summit in 1992, an increasing number of researchers and international organizations began to consider social sustainability, economic sustainability, community sustainability, and even cultural sustainability as parts of the human dimension of sustainable development (Hardoy et al., 1992; Pugh, 1996). Thus, sustainable development ought to have environmental, economic, political, social, and cultural dimensions simultaneously (Dunn et al., 1995).

Over the last decade numerous governments have pledged themselves to make this concept operational in national and local planning. For instance, in 1996 UNEP proposed the structure and approaches of sustainable development index. The United States developed 10 goals and a related sustainable development index for their country in the same year. The United Kingdom declared 120 sustainable development indices for their country in 1992.

They then integrated these into 13 major indices to evaluate the performance of economic development, social investment, climate change, environmental quality and ecological conservation for their country in 1996 (Mendoza and Prabhu, 2000).

The impact of sustainability on development of national and international policy has increased over the last decade. Sustainability is now a core element of government policies, of university research projects, and of corporate strategies (WRR, 1995; Mebratu, 1998). Sustainability does not represent the endpoint of a process; rather, it represents the process itself (Shearman, 1990; WRR, 1995). Sustainability implies an ongoing dynamic development, driven by human expectations about future opportunities, and is based on present economic, ecological and societal issues and information (Bossel, 1999).

Research has produced numerous indicators of sustainable development so that it is possible to gain some insight into whether or not an area or region or nation is on a trajectory of sustainable development (Moffatt, 1996; Hanley et al., 1998). Amongst the measures developed to indicate sustainability have been economic measures such as genuine savings; ecological measures such as human appropriation of net primary production, ecological footprints and environmental space; and socio-political measures such as *the index of sustainable economic welfare*[1] and *the quality of life indicators*[2]. These different measures can give different messages to policy makers and others interested in measuring sustainable development but, because of their essentially empirical approach, they are unable to inform policy makers about long-term changes to a nation owing to the changing exogenous or endogenous factors, and the consequent implications for the sustainability of its trajectory. One obvious way to explore these complex and long-term changes is to construct quantitative models of sustainable development.

According to US EPA, *Green engineering is defined as the design, commercialization, and use of processes and products, which are feasible and economical while (1)Reducing the*

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[1] The **Index of Sustainable Economic Welfare** (**ISEW**) is an economic indicator intended to replace the Gross domestic product. Rather than simply adding together all expenditure like Gross domestic product. Consumer expenditure is balanced by such factors as income distribution and cost associated with pollution and other economically unsustaining costs. The index is based on the ideas presented by Nordhaus and Tobin (1972) in their Measure of Economic Welfare. It was first coined in 1989 by Daly and Cobb. They later went on to add several other "costs" to the definition of ISEW. *ISEW = personal consumption+non-defensive public expenditures-defensive private expenditures+capital formation+services from domestic labour-costs of environmental degradation- depreciation of natural capita.* (http://www.absoluteastronomy.com/encyclopedia/I/In/Index_of_Sustainable_Economic_Welfare.htm)

[2] The **Quality of Life Indicators** are a contribution to the worldwide effort to develop comprehensive statistics of national well-being and to illustrate the dynamic state of our social, economic and environmental quality of life. The dimensions of life examined include: education, employment, energy, environment, health, human rights, income, infrastructure, national security, public safety, re-creation and shelter. (http://www.calvert-henderson.com/index.htm)

generation of pollution at the source; and (2)Minimizing the risk to human health and the environment[3]. Green Engineering embraces the concept that decisions to protect human health and the environment can have the greatest impact and cost effectiveness when applied early to the design and development phase of a process or product. More precisely, Green Engineering focuses on the design of materials, processes, systems, and devices with the objective of minimizing overall environmental impact (including energy utilization and waste production) throughout the entire life cycle of a product or process, from initial extraction of raw materials used in manufacture to ultimate disposal of materials that cannot be reused or recycled at the end of the useful life of a product (Allen and Shonnard, 2002) .

In addition, *decision-making in sustainable development issues generally involves complex and often ill-defined parameters with a high degree of uncertainty due to incomplete understanding of the underlying issues.* The dynamics of any socio–environmental system cannot be described by traditional mathematics because of its inherent complexity and ambiguity. In addition, the concept of sustainability is polymorphous and fraught with subjectivity. It is therefore more appropriate to employ fuzzy set theory for its assessment. Fuzzy set theory are a mathematical concept proposed by Prof. L.A. Zadeh in 1965, which theory is a scientific tool that permits modeling a system without detailed mathematical descriptions using qualitative as well as quantitative data.

1.2 Research Purposes

According to background and motivation, the multidimensional nature of the concept is not unusual that no single model would be good enough to plan the sustainability of development. It all depends upon how the planners or policymakers understand and interpret the concept of sustainable development, and on the nature of the planning mechanism prevalent in a country. In this study, we propose non-additive fuzzy multi-criteria decision making method to evaluate the development strategy of green engineering industry. Fuzzy integral technique was utilized to derive the synthetic value in evaluating process, which approach is employed to cope with MCDM problems especially for situation of dependence among considered criteria.

Furthermore, we introduce fuzzy c-means clustering to find the optimal strategy combination in order to maximize the effect of resource allocation. In addition, since clustering algorithms are unsupervised, irrespective of the clustering method, the final

[3] http://www.epa.gov/oppt/greenengineering/index.html

partitions of data require some kind of validation in most applications. We further employ some well-konown cluster-validity functions to measure the effectiveness of the clustering algorithms.

1.3 Framework and Research Methods

The framework of this research is shown in Fig. 1.1. For evaluation of sustainable development issues using by multiple criteria decision making methods, we define the sustainable development evaluated criteria, considered aspects and feasible alternatives through brainstorming, scenario writing and discussing with experts in the first stage. After defining the evaluated criteria, aspects and feasible alternatives set, a hierarchy analytic frame was established. In the second stage, in order to identify the relationship among these evaluated criteria, we employ statistical factor analysis to extract some common factors. The other approaches to identify the relationship among criteria includes DEMATEL, ISM. In the third stage is to assess the weights of evaluated criteria utilizing geomeans to integrate the group judgment, which assessment base on fuzzy hierarchical analytic process. In the fourth stageis to calculate the performance score of feasible alternatives corresponding to criteria, and employ fuzzy integral to derive the synthetic values of within each common factor, and then use simple additive weighted method to aggregate the final synthetic value of individual alternative. Finally, determin the preferred order for all alternatives according to the final synthetic value.

Furthermore, we introduce fuzzy c-means clustering for solving the optimized strategy combination of proposed strategies. Which is a popular fuzzy classification approach not only used to pattern recognition, but also be applied on industrial analysis. Finally, we also exploit Discriminant analysis and some widely used cluster validity indice to determine the best number of cluster.

1.4 Organization of Dissertation

The structure of this dissertation is showed in Fig. 1.1. The research motivation, background, purposes, framework and methodos are described in Chapter 1. We will describe the concept of sustainable development and its planning in Chapter 2. Here we introduce the stream of sustainable development, planning and some modeling. In order to identify the sustainable development evaluated criteria with its related dimension, assess the critical factors and evaluate the industrial strategies for sustainable development, we summarize some important widely used concepts of fuzzy set theory and multiple criteria decision making methods in Chapter 3. The empirical study on green engineering industry for sustainable development will demonstrate in Chapter 4. In this chapter, fuzzy hierarchical analytic process was applied to assess the weight of considered criteria, and fuzzy integral with simple additive weighting method was then utilized to derive the synthetic value in evaluating process. Furthermore, fuzzy c-means clustering was employed to find the optimal strategy combination. Finally, some concluding remarks, recommendations and future research are given in Chapter 5.

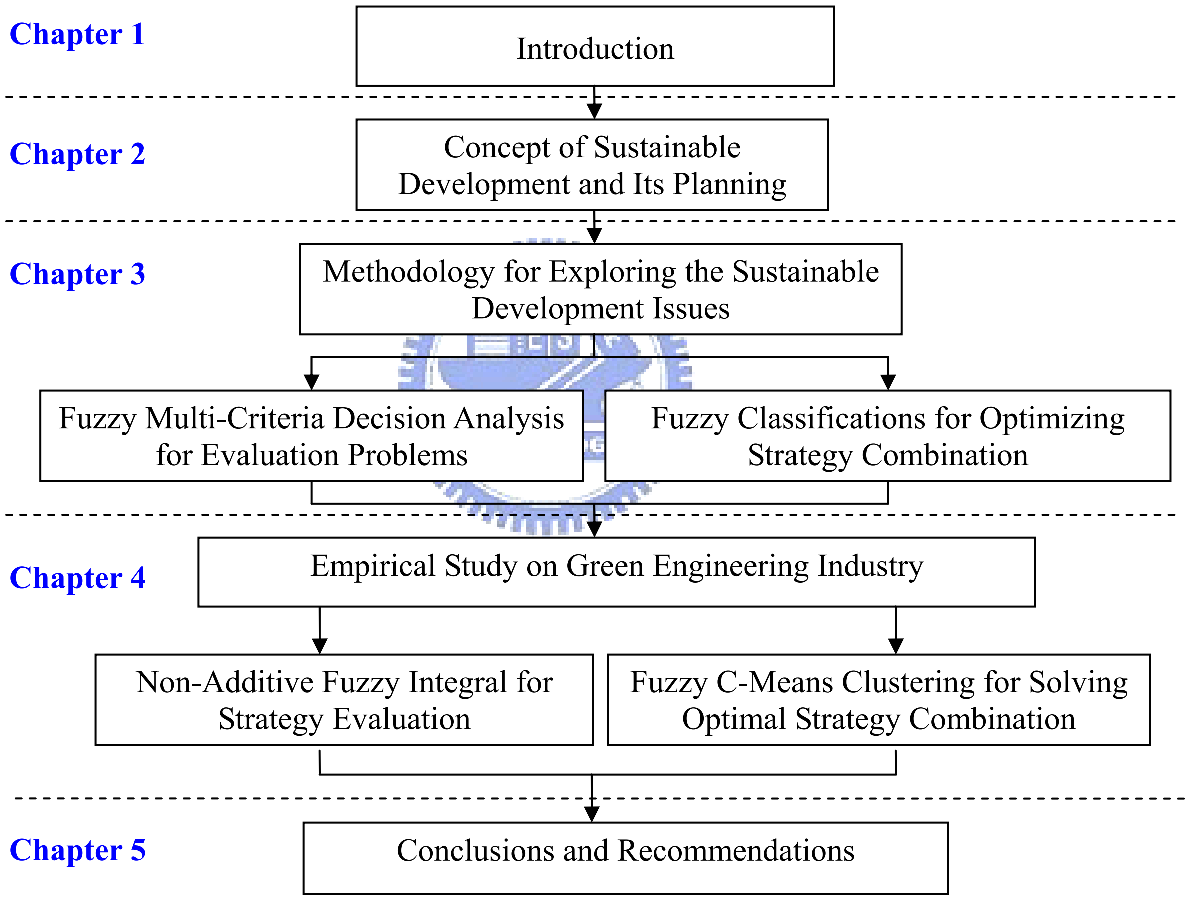


Fig. 1.1 The Research Process and Organization of the Dissertation

2. CONCEPT OF SUSTAINABLE DEVELOPMENT AND ITS PLANNING

In this chapter we describe the streamline concept of sustainable development and its planning, assessment. We also review related methodology about developing sustainable products and service.

2.1 Stream of Sustainable Development

The World Commission on Environment and Development (WCED, 1987) defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The fuller definition given by the Brundtland Commission is worth quoting:

> …Humanity has the ability to make development sustainable — to ensure that it meets the needs of the present without compromising the ability of future generations to meet their needs. The concept of sustainable development does imply limits — not absolute limits, but limitations imposed by the present state of technology and social organization on environmental resources, and by the ability of the biosphere to absorb the effects of human activities. But technology and social organization can be managed and improved to make way for a new era of economic growth … In the end, sustainable development is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with future as well as present needs...

At the Earth Summit in 1992, nations extended the above definition and adopted a set of principles to guide future development. The Rio Declaration on Environment and Development defines the rights of people to development, and their responsibilities safeguard the common environment (World Resources Institute, 1986/1994/1995/1996/1997). The Brundtland Commission also laid special emphasis on the multidimensional aspects of sustainable development:

> There are many dimensions to Sustainability. First, it requires an elimination of poverty and deprivation. Second, it requires the conservation and enhancement of the resources base which alone can ensure that the elimination of poverty is

permanent. Third, it requires a broadening of the concept of development so that it covers not only economic growth but also social and cultural development. Fourth, and most important, it requires the unification of economics and ecology in decision making at all levels (Pearce et al., 1989).

The introduction of the concept of sustainable development sparked environmental debates and environmentalists became a dominant force in decision-making processes in many countries. Environmental protection bodies have been established with legal powers to approve or disapprove of development projects in a number of countries. Policymakers now have to take into consideration not only the size of GDP but also the quality of life, protection of the environment and preservation of natural resources for future generations. Environmental conditionality is also receiving increased attention from bilateral and international donor agencies, we summarize some important international conventions for sustainable development in Appendix A.

2.2 Sustainable Development Planning

For planning purposes, there are several core concepts that underpin sustainable development (Ghosh et al., 2000). First, indefinite population growth in an environment of limited resources cannot surely be sustained. The need for feeding an ever increasing population might lead to deforestation and salinity and the consequent disruption of the ecological system. As a matter of fact, population growth, combined with the demand for a higher and higher material standard for living, has been the single most important factor in the ecological crisis of the present age. The ecological system in which we live evolved slowly over millions of years. It derives its stability and predictability because of its diversity and complexity. In their desire to maintain an ever-increasing population size, human beings are simplifying the complex ecosystem and creating future uncertainties.

Secondly, sustainable development must lead to intergenerational equity. The present generation must not overuse existing resources to adversely affect the potential material living standards of future generations (Siddique, 1997). In this context, it is important that every nation seeks to ensure that its use of renewable resources (such as agricultural methods and technology) is sustainable, and that its exploitation of nonrenewable resources (such as minerals, oil, gas and coal) is geared towards an efficient and optimum intertemporal use (Ghosh, 1977).

Thirdly, sustainable development must ensure elimination of poverty and deprivation.

This is very much linked to the distributional aspect of growth and development. If economic growth and development fail to reduce inequality and reduce poverty at national and international levels, sustainability of development will never be achieved. The World Summit for Social Development (1995) rightly observed:

We are deeply convinced that economic development, social development, and environmental protection are interdependent and naturally reinforcing components of sustainable development, which is the framework for our efforts to achieve a higher quality of life for all people. Equitable social development recognizes that empowering the poor to utilize environmental resources sustainably is a necessary foundation for sustainable development. We also recognize that broad-based and sustained economic growth in the context of sustainable development is necessary to sustain social development and social justice.

The above discussions highlight that sustainability of development is a broader concept that involves multiple criteria. It involves a pattern of economic development that would be compatible with a safe environment, biodiversity, ecological balance, intergenerational and international equity. Incorporation of sustainability into development planning is a precondition for achieving sustainable development.

The question is how to incorporate sustainability in development planning? Literature on sustainable development planning is of recent origin, and modeling sustainable development planning depends on the objectives of the planners. In what follows, we present an overview of recent attempts by researchers to model sustainable development planning.

Milne (1996) did a comprehensive review of sustainability and points out that "sustainability is about integrating social, economic and ecological values". However, the author mentioned that there is less agreement in the literature on how sustainability might be operationalized. The author also develops a relationship between sustainability and decision making. Kelly (1998) takes a systems approach to identify information infrastructure to assess the courses of action for sustainable development projects. The author posits that a system approach identifies the key linkages among the sustainable indicators and thus helps in the better implementation of the development projects.

Minns (1994) discusses the use of mathematical modeling tools for R&D investment decisions within a sustainable development climate. The author develops a concept called "technology impact profiling", which includes various sustainable development indicators. Lesser and Zerbe (1995) discuss how a benefit–cost analysis tool can contribute to sustainable planning. The authors make the point that "values" to be used in benefit–cost analysis have to be found based on preferences. Systematic thinking and the need for value trade-off in sustainable planning are highlighted by McDaniels (1994). The author reports an application in Canadian utility planning. Levy et al. (1995) employ the graph model for conflict resolution over groundwater in Cambridge, Ontario (Canada), and show that their model improves "strategic environmental planning by considering multiple participants, each of whom may have multiple objectives to fulfil with respect to a given dispute". They also claim that by unifying the psychological, social and cultural approaches of risk analysis, management and perception, their model helps to promote a sustainable balance between economic growth and environmental protection.

Herkert et al. (1996) argue that technological innovation plays a critical role in the process of sustainable development. They therefore devise an operational knowledge-based decision support tool in order to assist researchers and technology policymakers in structuring and making decisions in the light of sustainable development goals. Slesser and Moffit (1989) use systems dynamics in order to develop an operational model of sustainable development. Their dynamic model consists of several positive and negative feedback loops interconnected by flows of information, material, and energy to produce long-term scenarios of sustainable and nonsustainable development for the nation state. The authors assert that when applied, their dynamic model can maintain both economic development and ecological evolution within the one conceptual framework.

It should be noted here that planning sustainable development requires special consideration of the environment since the two are interlinked. Environmental planning is a diverse activity, comprising multiple approaches, and based on a range of options for direct action and indirect influence (Selman, 1999). It involves a rational human activity aimed at taking decisions that optimise welfare, both presently and at some time in the future. The literature also suggests that sustainable development planning is typically undertaken by the highest level planning group of a nation, and interests of the group members play significant roles in shaping the final outcome of the sustainable development plans.

The above discussions highlight three important issues of sustainable development planning. These are: (1) consideration of multiple criteria; (2) accommodation of group diversities and (3) the inclusion of group preferences.

2.3 Sustainable Products and Services Development

In response to the shift in environmental policy and law towards products, there are increasing legal, market and financial pressures on manufacturing industries to develop sustainable products. For some time, concepts, approaches and tools have been evolving to help industry meet this aim. These include eco-design and sustainable product development. There have been researching industry requirements for developing sustainable products and the ability of existing approaches and tools to meet these requirements. The research has identified a need for mainstream, pragmatic approaches to sustainable product development, as well as, to service development. In response, the sustainable product and service development (SPSD) method is being developed by many researchers in conjunction with industry and practitioners (Maxwell and van der Vorst, 2003).

Sustainable product and service development is an evolution of existing sustainable product development approaches in that it incorporates services as well as products and all triple bottom line (TBL) elements. Sustainable product development approaches used in industry to date mainly focus on reducing the environmental impacts of products. This is known as *eco-design* or *design for environment* and is well established in research terms and is increasingly seen in innovative product manufacturing companies mainly in the form of eco-design (Gertsakis et al., 1997).

There also design for '*X*' approaches, which have subsets focused on specific areas, e.g. design for disassembly, design for recycling, etc. (Simon et al., 1998). While a number of terms have evolved for this, these approaches all focus to different extents on identifying and reducing or, where possible, eliminating the environmental impacts of a product throughout its life cycle. The sustainable product and service development pyramid is introduced to illustrate the evolution of the design for *X* (Figure 2.1), eco-design and sustainable product and service development approaches towards sustainability.

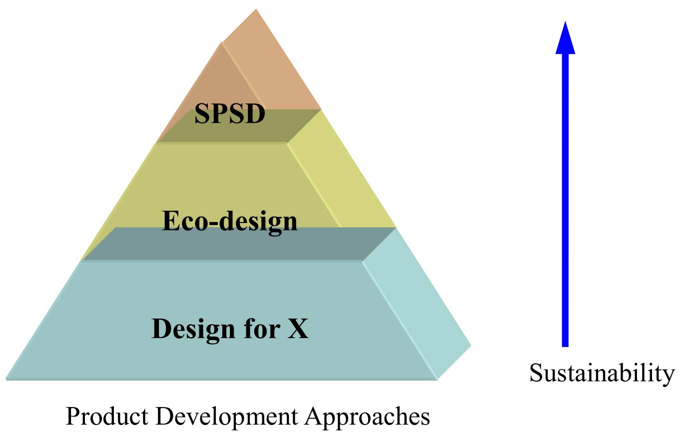


Figure 2.1 Sustainable Product and Services Pyramid (Maxwell and van der Vorst, 2003)

A more sustainable result is likely to be achieved by incorporating the concepts at the top of the pyramid in the sustainable product and service development approach. If these are not incorporated, some of the environmental impacts of the product and/or service proposed may be minimized, but greater opportunities for producing a more sustainable product and/or service may not be realized.

The sustainable product and service development method builds on these existing concepts. sustainable product and service development is proposed as a suitable term for the process as it clarifies that the approach is applicable to both products and services as well as incorporating the all-important product service systems (PSS) concept (Reiskin et al., 2000).

Sustainable product and service development is about assessing the lifecycle of a function to be provided (from conception to end of life) and determining the optimum sustainable (environmental, social and economic) way of providing that function (through a product, service or product service systems) in line with traditional product and/or service criteria. The product and/or service lifecycle shown as Figure 2.2, it starts at conception where there is only a concept and design of a potential product, service or product service systems commences. If a product or product service systems is to be produced the remaining stages include raw materials through end of life as well as potential 'recovery' and 'reuse' options illustrated by the dashed lines.

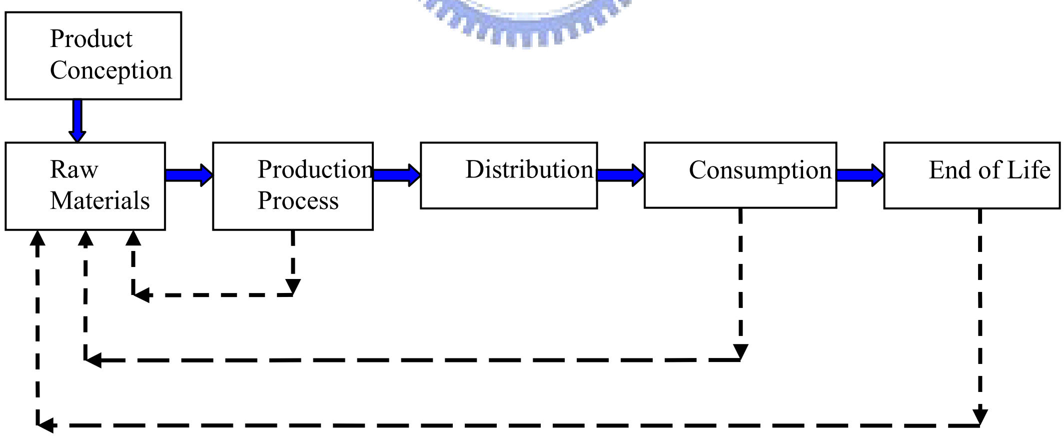


Figure 2.2 Product Life Cycle Stages (Maxwell and van der Vorst, 2003)

Sustainable product and service development can also be applied to an existing product and/or service, but ideally at the concept stage before a commitment to producing a product has been made. With only a concept, greater opportunities for the development of a more sustainable solution may be realized especially regarding environment (Hanssen, 1997; Reiskin et al., 2000; Brezet and van Hemel, 1997). Figure 2.3 illustrates the main sustainable product and service development process steps. Starting at the concept stage, one of the initial steps of sustainable product and service development is to consider how the functional requirement can be met—through a product, a service or some combination of a product service systems and optimizing the sustainability impacts of these options with traditional criteria. The use of sustainable product and service development may result in a product not being produced at all. This is in circumstances where it is more sustainable and feasible to meet the required functionality by the provision of a service.

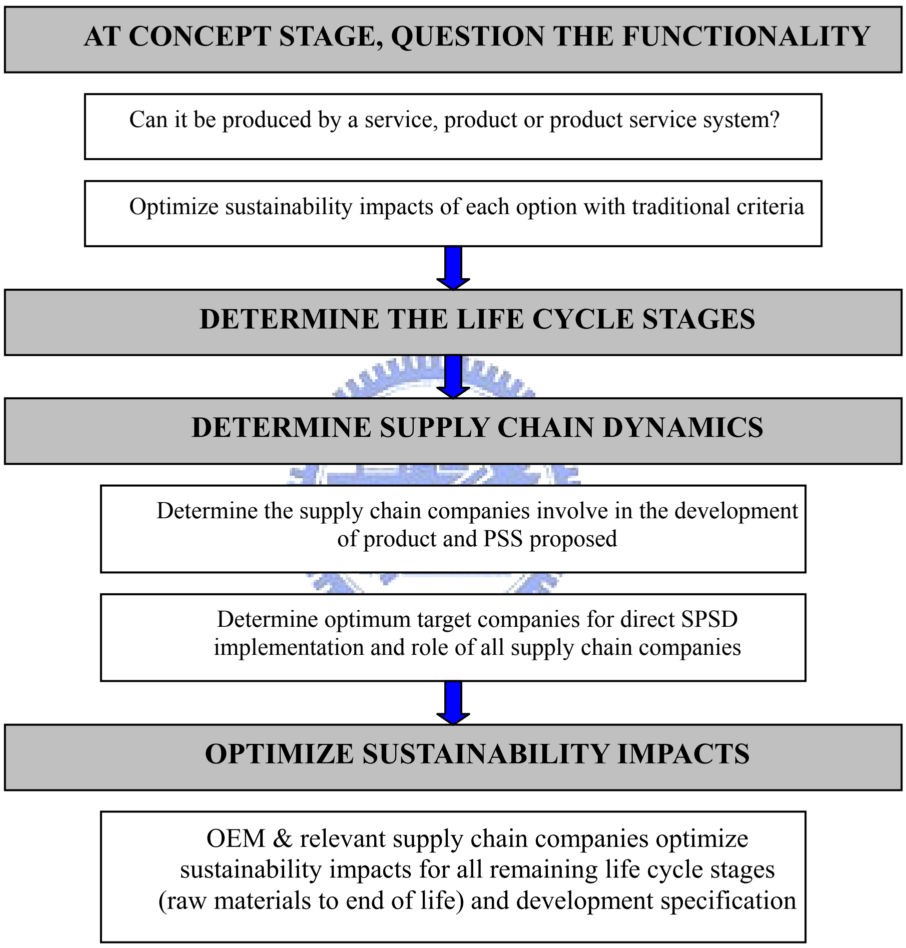


Figure 2.3 Sustainable Product and Service Development Process (Maxwell and van der Vorst, 2003)

In practice, complete replacement of a product by a service is difficult to achieve. Some combination of product service systems is a more likely possibility (van Hemel, 1998). Once it has been determined whether a product, service or product service systems to be developed, the next stage is to identify the lifecycle stages and associated supply chain as relevant. A key element of sustainable product and service development is that it focuses on the supply chain for the product and/or service rather than solely at an individual company level. The entire supply chain is assessed to determine the most effective target organization(s) in the chain for sustainable product and service development and how the supply chain management can be effectively utilized. Once this is determined, sustainable product and service development implementation can commence at the company level.

The next step is to assess the environmental and then social impacts for each product or product service systems life cycle stage from raw materials to end of life. The opportunities for elimination or minimization of these are optimized with the remaining traditional product and service criteria. The specific environmental and social issues to be assessed vary dependant on the product and/or service. To ensure a comprehensive approach, a checklist of typical environmental and social impacts to be considered per lifecycle stage is used.

Figure 2.4 illustrates a proposed structure for integrating sustainable development into product developing process. The requirement to produce sustainable products and/or services as relevant is integrated as one element of the existing corporate strategy. From here it is a core business criterion that can be incorporated into all other business functions for overall sustainability performance improvement. In particular, sustainable product and service development should be incorporated within the product development approaches used by the company. Other functions that traditionally feed into product development, e.g. quality, finance, purchasing, etc. will then be incorporated more easily with the sustainability criteria. Further, where a company operates a system to manage their environmental performance, e.g. environmental management system, sustainable product and service development should be imbedded within it.

Some multinational corporations that have implemented ecodesign have integrated it into their company's existing systems for managing their environmental performance. For example, *Nike* and *IKEA* have integrated eco-design into their TNS (The Natural Step) approach. *Electrolux* and *Philips* include eco-design in their Product Orientated Environmental Management System (POEMS) (Croner, 2000).

Overall, by integrating sustainability in the corporate strategy it is set up as a core element necessary for improving business performance rather than a stand alone programme. The optimization of social, ethical and economic issues is not included in eco-design in its present form. If sustainability is the aim, just reducing the environmental impact of a product using an eco-design approach is not enough (Byggeth et al., 2000; van Weenen, 2000; Byggeth and Broman, 2000). In order to effectively integrate sustainability in product and service development, the environmentally superior products initiative uses this integrated approach and illustrates that optimizing environment with other traditional product criteria works on both an environmental as well as business level for companies.

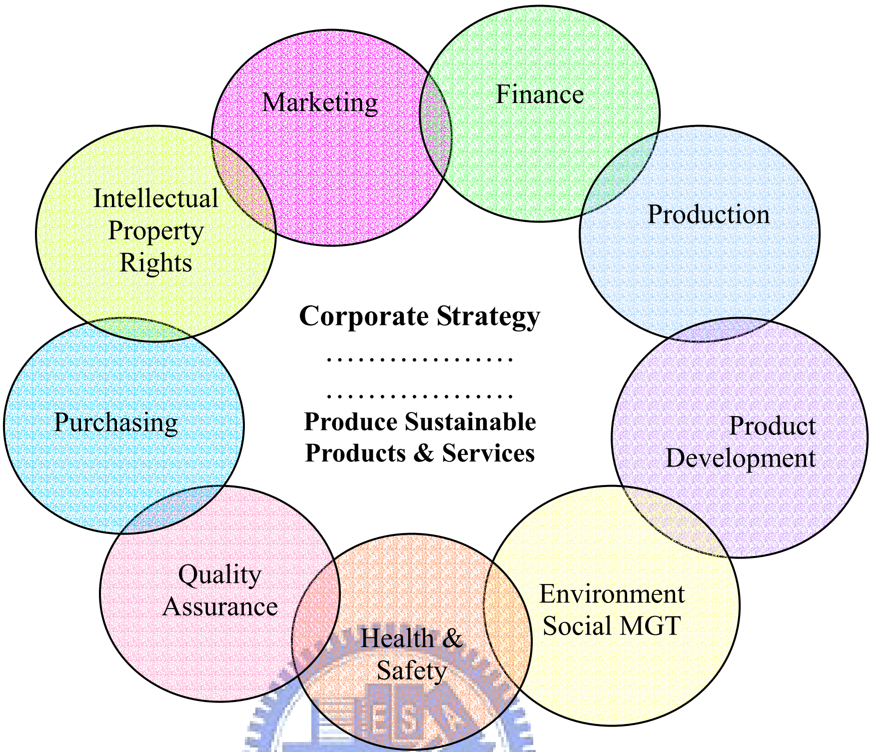


Figure 2.4 Integrating Sustainable Concept into Product Developing Systems (Maxwell and van der Vorst, 2003)

An illustration of the proposed criteria to be optimized in developing sustainable products and services is presented in Figure 2.5. In addition to the traditional product criteria, e.g. economic, quality, market, customer requirements, technical feasibility and compliance issues, the following sustainability criteria have been incorporated: environmental impacts, social impacts and economic impacts. Further, in order to effectively optimize the environmental and social impacts the functionality criterion is included.

The functionality and options for product service system are considered at the product conception phase. This incorporates dematerializations, whereby, the material and energy inputs into a product are reduced or replaced completely by an immaterial substitute for complete dematerialization. In reality, it is difficult to achieve complete dematerialization and still achieve the end product function. However, a combination of a product and service approach that reduces the product element is possible and has been achieved to environmental and commercial benefit by some companies. For example, in 2000, *Xerox* reduced their product material inputs by approximately 72,000 ton with an associated US$ 27 million savings (Xerox, 2001).

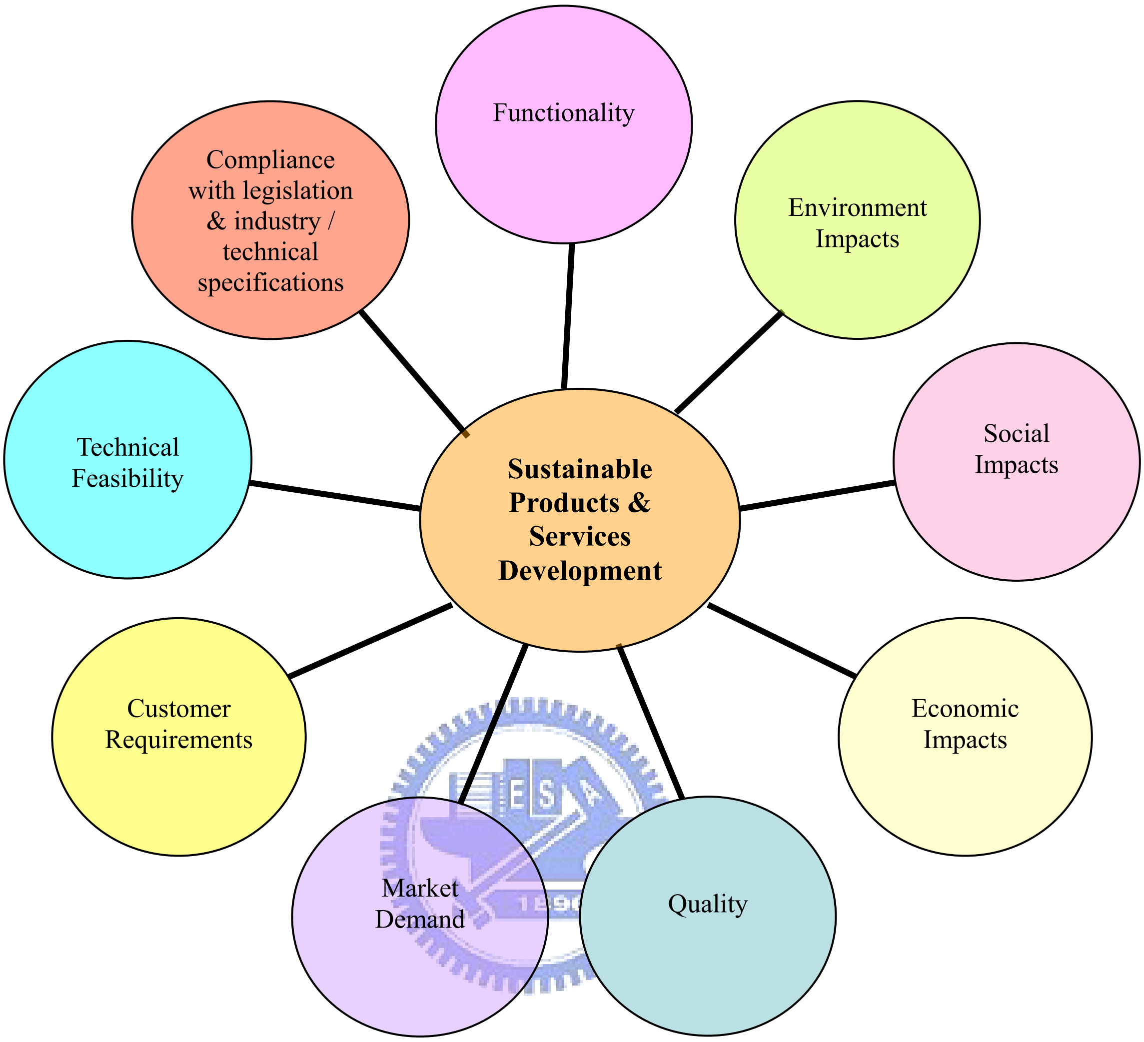


Figure 2.5 Criteria for Optimizing Sustainability in Products and Services (Maxwell and van der Vorst, 2003)

The product service system approach decouples volume (producing lots of products) from profitability and focuses on the functionality, i.e. producing less product and managing it better as a product service system. Value is based on functionality, not on materials content. The environmental benefits resultant from the product service system approach can include:

(1) A reduction in the volume of products produced;

(2) Increased dematerializations of product;

(3) Reduced waste generation due to the reduced volume of products produced as well as the eco efficiencies introduced into the production process.

There are also social impacts associated with product service system. For example the replacement of a product by a service can have implications in terms of employment for company personnel at many lifecycle stages. To date, industry tends to implement an eco(re)design approach whereby they start with an existing product and reduce its environmental impacts (Charter and Tischner, 2001). With the exception of a minority of companies, the need for a product based on the functionality required and the options for product service system are not generally considered. Leaving this step out may result in the application of environmental improvement measures to a product which is inherently unsustainable, whereas the optimum sustainable solution would have been not to produce a product but say a service, or a combination of both in the first place (van Weenen, 2000; Brezet and van Hemel, 1997). Questioning the requirement for a product and consideration of alternative options to meet a functional requirement is an essential component of sustainable product and service development. This relates to assessing the functionality required and the options for realizing this through a product, a service or a product service system.

Overall sustainability as well as business benefits were realized from the environmentally superior products projects. The reduced environmental impacts varied per product and/or service but included dematerializations through a product service system approach as well as a range of eco efficiencies, e.g. (1) reduced volume of raw materials; (2) eliminated and/or reduced hazardous raw materials usage; (3) reduced energy usage; (4) eliminated/reduced waste generation.

3. FUZZY MULTI-CRITERIA DECISION ANALYSIS FOR EVALUATION

Since Zadeh originally proposed fuzzy set theory (1965), and Bellman and Zadeh (1970) subsequently described the decision-making methods in fuzzy environments, growth of applications of fuzzy set theory and relevant approaches cope with uncertain fuzzy problems. Basically, the elements of decision-making problems consist of goal/objective goal, criteria/factors, alternatives/actions, and so on. Usually, there have many criteria, either quantitative or qualitative or mixed, within processing of analytic and evaluating for decision-making problems. Moreover, it is not unusual for many conflicting criteria to be used, how to assess the importance of listed criteria (weight) and how to aggregate which parameters with performance of alternatives (or actions) is the important challenge for the decision maker.

In the past, there are many approaches proposed to deal with multiple criteria decision-making problems. Through this chapter we will pay attention to the methods for decision making in fuzzy environment. We give the overview classification of multiple criteria decision making in fuzzy environment in Section 3.1. In the first part of this dissertation will focus on the application of fuzzy multiple criteria decision analysis. For data processing, we firstly introduce fuzzy hierarchical analytic process in section 3.2, some weighting measurements also briefly summarized in this Section. Considering the vagueness or uncertainty under decision making environment, linguistic variables and fuzzy measure will be discussed in Section 3.3. In order to aggregate the group decision in evaluating process, fuzzy integral for aggregating judgment will be described in Section 3.4. In order to determine the preferred order of considered alternatives, defuzzification of fuzzy synthetic judgment will discussed in Section 3.5. In the second part of this dissertation is to utilize fuzzy classification to solve the optimal strategy combination, which algorithm will introduce in Section 3.6. Finally, we will summarize some widely used cluster validity function for fuzzy classification, which validity indice could provide the useful information to determine the critical number of clusters.

3.1 An Overview of Multiple Criteria Decision Making

If we want to know how to achieve the goal or overall objective of target system, for example pursuing the maximum profit and/or minimum cost and/or more higher satisfactory quality of products in manufactory. The first part of our work is that need to figure out how many attributes or criteria and which how to dominate the way of the target system. On the other hand, we need to collect adequate data that reflect the behavior of attributes or criteria taking into account. The more work is to build a set of possible alternatives or strategies in order to guarantee that the goal will reach. Through the efforts as above, next step is to select appropriate method that helps us to evaluate and outrank the possible alternatives or strategies. This is the context of multi-criteria decision-making (MCDM) problems.

Furthermore, because of the influence by different personal and social characteristic, the perceive values of decision makers to practical problems are diversified. Then, most of MCDM problems in real world take place in fuzzy environment, which consist of goals, aspects (or dimension), attribute (or criteria), and possible alternatives (or strategies). In addition, Hwang and Yoon (1981) suggest that the MCDM problems can classify into two categories (Figure 3.1): Multiple Attribute Decision Making (MADM), and Multiple Objective Decision Making (MODM). The former applied in evaluation facet, which usually associated with a limited number of predetermined alternatives. The later fitted in design/planning facet, which is to achieve the optimal goals by considering the various interactions within the given constrains. Base on the decision makers or participants may comes form different background, they may have greatly different habits or position, so it is very difficult to express identically those same situations by linguistic variables, this is the fuzzy nature of input/output data in decision-making problems. More precisely speaking, we can classify the MCDM problems in fuzzy environment into two categories to conform nature of fuzzy for real world problems, Fuzzy Multiple Attribute Decision Making (FMADM) and Fuzzy Multiple Objective Decision Making (FMODM).

Since Bernoulli (1678) proposed the concept of utility function to reflect human persuading such as maximum satisfactory, and von Neumann and Morgenstern (1947) presented the theory of game and economic behavior model which expanded the studies on human being economic behavior for multiple attribute decision-making problems, from that moment on, more and more literature engaged in this field. On the other hand, Zadeh (1965) presented fuzzy sets theory, and Bellman and Zadeh (1970) were the precursors in applying fuzzy set theory to multiple attribute decision-making problems (see Figure 3.2). There have a great deal of literature and books in this field through last decades, such as Chen and Hwang (1992), Zimmerman (1985; 1987) are good source for fuzzy decision making studies.

Since the last two decades, information technology progressing like bamboo shoots after a spring rain, it push the data process more speedy and efficient. In this dissertation we interpret MADM in Multiple Criteria Decision Analysis (MCDA) to reflect this phenomenon. In addition, Fuzzy Multiple Criteria Decision Analysis (FMCDA) basically comprise two phases (Dubois and Prade, 1980), phase 1 is to aggregate the performance score with respect to each alternative/strategy, then in phase 2 is to rank all alternatives/strategies according to their synthetic value (or utility value) from phase 1. Here we summarize the hierarchical procedure of FMCDA as follows:

Step1. Defining the nature of problem;

Step 2. Building a hierarchy system for evaluating;

Step 3. Selecting the appropriate evaluating method;

Step 4. Determining the relative weights and performance score of each attribute with respect to each alternative, both which data may be in crisp and/or fuzzy.

Step 5. Calculating the synthetic utility values, which are the aggregation value of relative weights and performance scores corresponding to alternatives;

Step 6. Outranking the alternatives refer to their synthetic utility values from Step. 5.

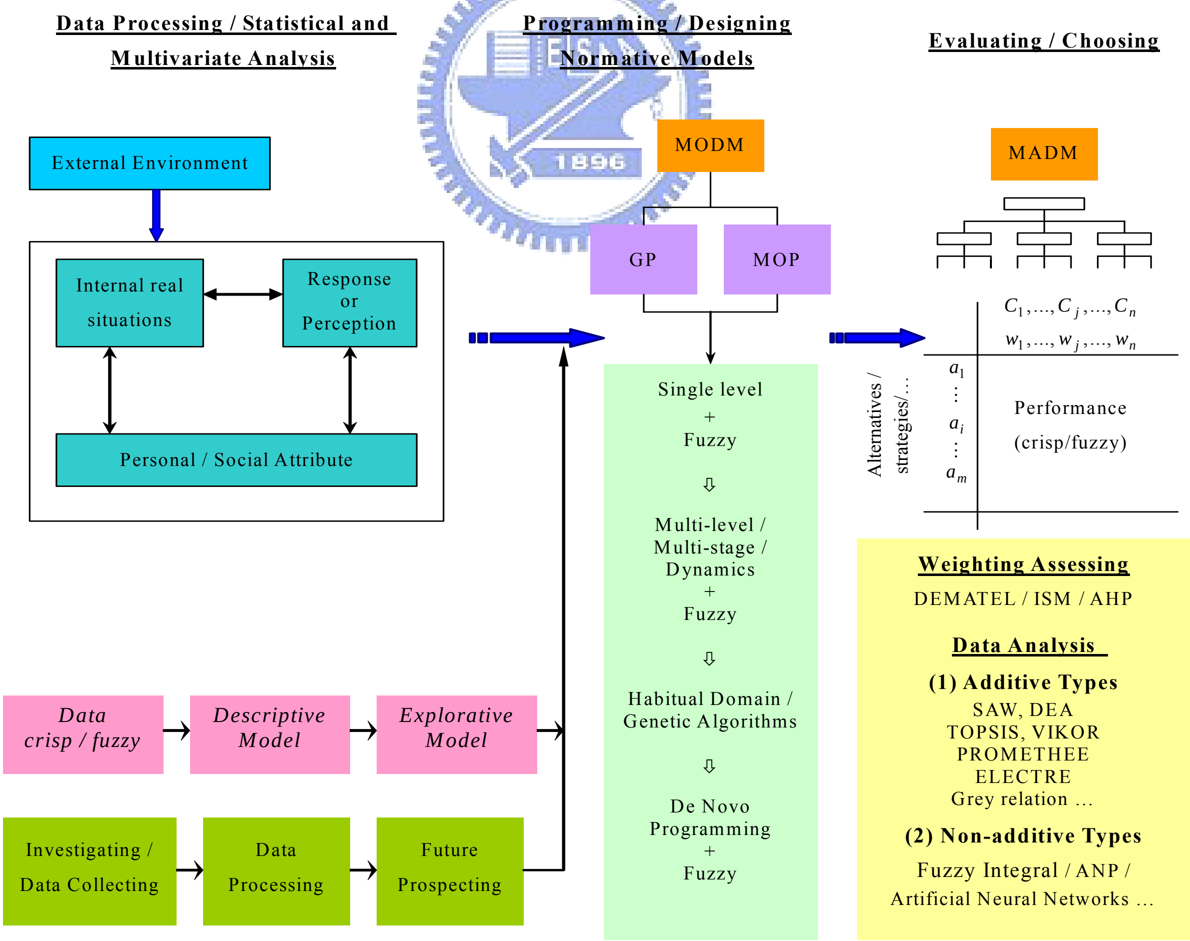


Figure 3.1 Conceptual Structure of MCDM

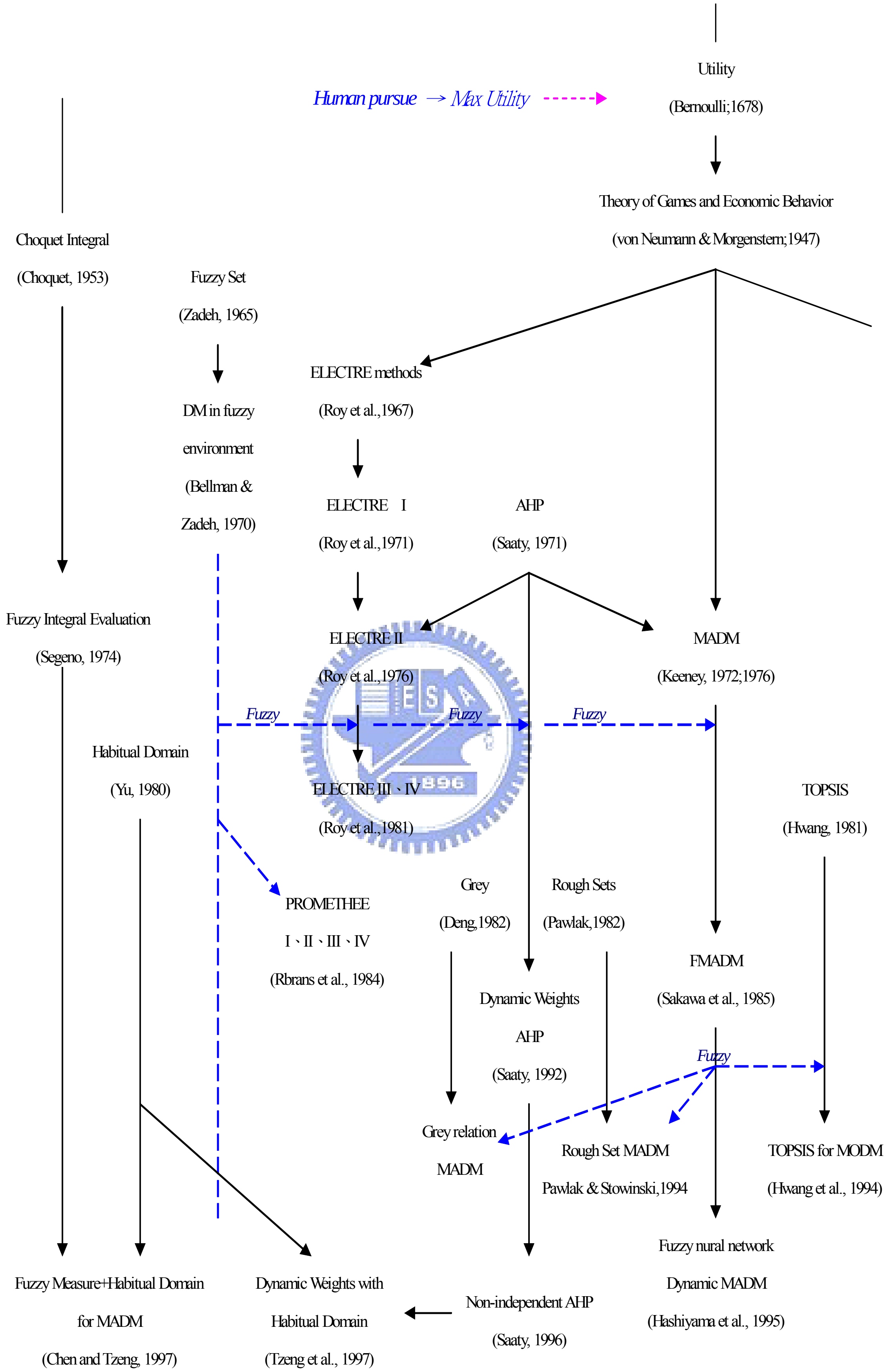


Figure 3.2 Development of Multiple Attribute Decision Making

3.2 Fuzzy Analytic Hierarchy Process

In real MCDM problems, it is necessary to divide the process into distinct stages. Firstly, based on a general problem statement, the various stakeholders are defined, typically including the decision-makers, various interest groups affected by the decision, experts in the appropriate fields, as well as planners and analysts responsible for the preparations and managing the process. The overall objective will be set up in this stage. Secondly, based on various points of view from stakeholders, the problems can be categorized into distinct aspects. Thirdly, defining alternatives/strategies and criteria, a discrete MCDM problem consisting of a finite set of alternatives/strategies can be evaluated in terms of multicriteria. Finally, choosing a suitable method to measure the criteria can help the evaluators and analysts to process the evaluating cases.

3.2.1 Building a hierarchical system for evaluation

Analytic Hierarchy Process (AHP) is a popular technique often used to model subjective decision-making processes based on multiple attributes (Saaty 1977; 1980). From that moment on, it is being widely used in corporate planning, portfolio selection, and benefit/cost analysis by government agencies for resource allocation purposes. And it is being used more widely on an international scale for planning infrastructure in developing countries and for evaluating natural resources for investment.

When all the aspects for consideration have been set up, the final set of criteria should meet the following requirements (1)Completeness; (2)Operationality; (3)Nonredundancy; (4)Minimality (Keeney and Raiffa, 1976).

In this study, we firstly establish a hierarchy system for analysis and evaluation through scenario writing and brainstorming. Phase 1 includes our overall objectives. Secondly, we consider related aspects for achieving goals in Phase 2. Thirdly, list considered in Phase 3. All considered criteria measured by evaluators, consisting of individuals with different viewpoints. Finally, the alternatives/strategies will listed in Phase 4 (Figure 3.3).

3.2.2 Determining the evaluated criteria weights

Because the evaluation of criteria entails diverse and meanings, we cannot assume that each evaluation criterion is of equal importance. There are many methods that can be employed to determine weights (Hwang and Yoon, 1981), such as the eigenvector method, weighted least square method, entropy method, AHP, DEMATEL (Gabus & Fontela, 1972, 1973; Tamura et al, 2002), as well as linear programming techniques for multidimension of analysis preference (LINMAP). The selection of method depends on the nature of the problems to express the preference relation of perception from evaluators. In this section, we introduce a revised AHP method to assess the weights of criteria for our study.

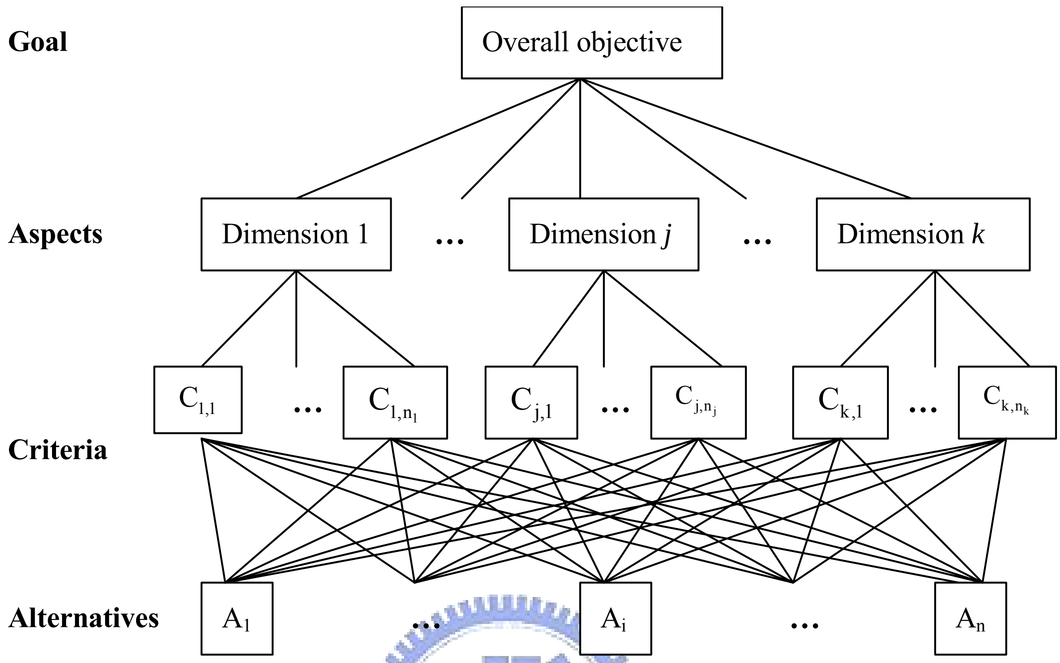


Figure 3.3 Analytic Hierarchy System for Evaluation

Saaty (1980) originally introduced the Analytic Hierarchy Process to systematically cope with complex problems in social system. He used the principal eigenvector of the comparison matrix to find the comparative weight among the criteria of the hierarchy systems. If we wish to compare a set of *n* criteria pairwise according to their relative importance (weights), then denote the criteria by $C_1, C_2, ..., C_n$ and their weights by $w_1, w_2, ..., w_n$. If $\boldsymbol{w} = (w_1, w_2, ..., w_n)^T$ is given, the pairwise comparisons may be represented by matrix A of the following formulation:

$$(A - \lambda_{\max} I)w = 0 \tag{3.1}$$

Eqs.(3.1) denotes that $\boldsymbol{A}$ is the positive reciprocal matrix of pairwise comparison values derived by intuitive judgment for ranking order. In order to derive the priority eigenvector, we must find the eigenvector $\boldsymbol{w}$ with respective $\lambda_{\max}$ which satisfies $\boldsymbol{Aw} = \lambda_{\max}\boldsymbol{w}$. Saaty (1980) suggested the consistency index $(\text{C.I.} = (\lambda_{\max} - n)/(n-1))$ to test the consistency of the intuitive judgment. In general, a value of C.I. is less than 0.1 is satisfactory $(\text{i.e. C.I.} \le 0.1)$.

The procedure for AHP can be summarized in four steps, as follows:

Step 1. Set up the decision system by decomposing the problem into a hierarchy of interrelated elements.

Step 2. Generate input data consisting of pairwise comparative judge of decision elements.

Step 3. Synthesize the judgment and estimate the relative weight.

Step 4. Determine the aggregating weights of the decision elements to arrive at a set of ratings for the alternatives/strategies.

Besides Saaty's method to aggregate the relative weights by participating evaluators, Buckley (1985b) proposed geometric mean method to calculate the final fuzzy weights for each fuzzy matrix. Given a $m \times m$ positive reciprocal matrix $\boldsymbol{A} = [a_{ij}]$ is derived by pairwise comparison from m participating evaluators, then $r_i = \left(\prod_{j=1}^{m} a_{ij} \right)^{1/m}$ represents the geometric mean of each raw. According to Saaty's definition, $\lambda_{\max}$ be the largest eigenvalue of $\boldsymbol{A}$ and the weights, w_i as the components of the normalized eigenvector corresponding to $\lambda_{\max}$, where $w_i = r_i / (r_1 + \cdots + r_m)$.

Buckley (1985b) further considered a fuzzy positive reciprocal matrix $\tilde{\boldsymbol{A}} = [\tilde{a}_{ij}]$, extending the geometric mean method to the fuzzy geometric mean method and exploited which to find the final fuzzy weights of each criterion as follows

$$\tilde{r}_i = (\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \cdots \otimes \tilde{a}_{im})^{1/m} \text{ and } \tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_1 \oplus \cdots \oplus \tilde{r}_m)^{-1} \tag{3.2}$$

where $\oplus$ and $\otimes$ called additive and multiplicative operators of two fuzzy number, respectively. These arithemetic operations will describe in next section.

3.2.3 Driving the fuzzy performance score and fuzzy synthetic value

The evaluators choose a performance score for each participating company based on their subjective judgments. This way of estimating the achievement level of each criterion on each strategy can use the methods of fuzzy theory for treating the fuzzy environment.

In evaluating process, after well define the criteria and their relationship, we have to determine the weights or measure of these criteria, and obtain then performance score of each alternative with respect to evaluated criteria. Furthermore, choose an suitable aggregateing operator to derive the synthetic value of these alternatives respectively, the final step is to assign the preferred order for all alternatives based on their synthetic values.

In general case, we can employ triangular fuzzy number to express the aggregated fuzzy weights of *j-th* criterion as follows:

$$\tilde{w}_i = (l_i, m_i, u_i) \tag{3.3}$$

where $\tilde{w}_i$ is derived by Eqs.(3.2).

It can be assumed that evaluation expert *k* has his fuzzy performance score of $\tilde{E}_{ij}^k$ for the criteria *j* under alternative *i*, and all the items to be evaluated is defined in feasible set *S*.

$$\tilde{E}_{ij}^k = \left(LE_{ij}^k, ME_{ij}^k, UE_{ij}^k\right),\ \ j \in S \tag{3.4}$$

Each expert may has his different academic and business careers, so as his objective understanding on the linguistic variables. This study utilize the average number to integrate the fuzzy judgment values given by *m* experts. That is, $\tilde{E}_{ij}$ express the average fuzzy judgment given by the participated evaluators. Its triangular fuzzy number is shown below:

$$\tilde{E}_{ij} = \left(LE_{ij}, ME_{ij}, UE_{ij}\right),\ \ j \in S \tag{3.5}$$

where

$$\tilde{E}_{ij} = (1/m) \otimes \left(\tilde{E}_{ij}^1 \oplus \cdots \oplus \tilde{E}_{ij}^m\right)$$

Specifically, $\tilde{E}_{ij}$ can be calculated by Buckley (1985a):

$$LE_{ij} = (1/m) \times \left(\sum_{k=1}^{m} LE_{ij}^k\right);\ ME_{ij} = (1/m) \times \left(\sum_{k=1}^{m} ME_{ij}^k\right);\ UE_{ij} = (1/m) \times \left(\sum_{k=1}^{m} UE_{ij}^k\right)$$

Moreover, the fuzzy synthetic matrix $\tilde{\boldsymbol{R}}$ can then be developed from both fuzzy weighting vector and fuzzy performance matrix as following:

$$\tilde{\boldsymbol{R}} = \tilde{\boldsymbol{w}} \Leftrightarrow \tilde{\boldsymbol{E}} \tag{3.6}$$

where

$$\tilde{\boldsymbol{w}} = \left(\tilde{w}_1, \cdots, \tilde{w}_j, \cdots \tilde{w}_n\right)^t;\ \tilde{\boldsymbol{E}} = \left[\tilde{E}_{ij}\right]$$

"⇔" in Eqs.(3.6) indicates the aggregating operator of fuzzy weighting vector and fuzzy performance matrix.

How to assess the measure of evaluated criteria is the critical process. In traditional evaluation methods such as Analytic Hierarchy Process, ELECTRE, PROMETHEE, TOPSIS, VIKOR and Grey Relation Analysis, assume definitely mutually independent between each pair criteria, and the simple additive weighted (SAW) method is appropriately to aggregate the synthetic value from criteria weights with performance scores. However, in most of MCDM problems, dependence or feedback may exist in evaluating structure. This independent relationship can not satisfy the nature of real situations. we can not employ SAW to derive the synthetic values if the relationship among these criteria are not independent, then the other aggregating tools is more suitable. For instance, fuzzy integral will provide appropriate estimate of synthetic values while in dependent situation; Analytic Network Process (ANP) can be applied to estimate the synthetic values while in the situation of feedback exists in considered dimension with its lower level of hierarch system, i.e. criteria.

Finally, the final fuzzy synthetic judgment of individual alternative for j evaluated criteria can be illustrated as follows:

$$\tilde{\boldsymbol{R}}_i = \left(LR_i, MR_i, UR_i\right) \quad \forall i \tag{3.7}$$

where

$$LR_i = \sum_{j=1}^{n} l_j \cdot LE_{ij};\ MR_i = \sum_{j=1}^{n} m_j \cdot ME_{ij};\ UR_i = \sum_{j=1}^{n} u_j \cdot UE_{ij}$$

3.3 Linguistic Variables in Fuzzy Decision Making Environment

According to Dubois and Prade (1978), a fuzzy number $\widetilde{A}$ is a fuzzy subset of a real number, and its membership function is $\mu_{\widetilde{A}}(x):\ R \to [0,1]$, where x represents the criteria, and is described by enshrined with the following characteristics:

(1) $\mu_{\widetilde{A}}(x)$ is a continuous mapping from R to the closed interval [0,1].

(2) $\mu_{\widetilde{A}}(x)$ is a convex fuzzy subset.

(3) $\mu_{\widetilde{A}}(x)$ is the normalization of a fuzzy subset, which means that there exists a number x_0 such that $\mu_{\widetilde{A}}(x_0) = 1$.

It cane be called fuzzy number if all the conditions above are satisfied. The triangular fuzzy number $\mu_{\tilde{A}}(x) = (L, M, U)$ can be defined as Eqs.(3.8) and Figure 3.4:

$$\mu_{\tilde{A}}(x) = \begin{cases} (x-L)/(M-L) & L \le M \le M \\ (U-x)/(U-M) & M \le x \le U \\ 0 & otherwise \end{cases} \tag{3.8}$$

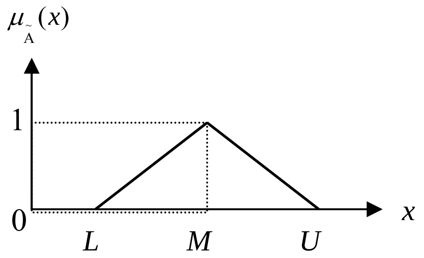


Figure 3.4 Membership Function of Triangular Fuzzy Number

According to the extension principle of triangular fuzzy numbers put forward by Zadeh (1975), the arithmetic operations of two triangular fuzzy numbers $\widetilde{A}=(a_1,a_2,a_3)$ and $\widetilde{B}=(b_1,b_2,b_3)$ can be expressed as follows:

(1) Addition of two fuzzy numbers $\oplus$

$$(a_1,a_2,a_3)\oplus(b_1,b_2,b_3)=(a_1+b_1,a_2+b_2,a_3+b_3) \tag{3.9}$$

(2) Subtraction of two fuzzy numbers Θ

$$(a_1,a_2a_3)\Theta(b_1,b_2,b_3)=(a_1-b_3,a_2-b_2,a_3-b_1) \tag{3.10}$$

(3) Multiplication of two fuzzy numbers $\otimes$

$$(a_1,a_2,a_3)\otimes(b_1,b_2,b_3)\cong(a_1b_1,a_2b_2,a_3b_3) \tag{3.11}$$

(4) Multiplication of any real number *k* and a fuzzy number $\odot$

$$k\odot(a_1,a_2,a_3)=(ka_1,ka_2,ka_3) \tag{3.12}$$

(5) Division of two fuzzy numbers Δ

$$(a_1,a_{2,}a_3)\Delta(b_1,b_2,b_3)\cong(a_1/b_3,a_2/b_2,a_3/b_1)\ \text{ where } b_1\neq 0,b_2\neq 0,b_3\neq 0 \tag{3.13}$$

On the other hand, the concept of linguistic variables is fundamental within fuzzy set theory. In formally, a linguistic variable is a variable whose values are words or sentences rather than numbers. For instance, when we refer to environmental conditions, we may express our observations by statement like *warm* place or, *clean and green* place or, *very wild and quite cute* place, and so on. The state of being *warm* could be translated by the variable *temperature*, with values in a set such as the interval $0-50^{\circ}\mathrm{C}$. Alternatively, temperature could be quantified using labels such as *cold*, *warm*, *hot*. Clearly, a precise numerical value such as $25^{\circ}\mathrm{C}$ seems simpler than the ill-defined term *warm*. But the linguistic label *warm* is a choice of one out of three possible values, whereas $25^{\circ}\mathrm{C}$ is a choice of one out of many, perhaps, in the entire $0-50^{\circ}\mathrm{C}$ range. Linguistic characterizations are, in general, less specific than numerical, but it would certainly be much safer, unless one actually knew the exact temperature, to state that an environment temperature is *warm* than that is $25^{\circ}\mathrm{C}$. The statement could be strengthened if the underlying meaning of *warm* is conceived as around $25^{\circ}\mathrm{C}$. In this setting, whereas the numerical value 25 can be visualized as a point in a set, the linguistic value *warm* can be viewed as a collection of objects (temperatures) within a bounded region whose center is at 25. the situation with the state of being *clean and green* or *very wild and quite cute* is more complex, because the scale involved in their quantification is quite subjective, and is not natural to translate them into numerical values. But they do convey useful information (Pedrycz and Gomide, 1998).

Briefly speaking, the concept of linguistic variable plays a major role in many applications of fuzzy set theory. Specifically, it is very difficult for conventional quantification to express reasonably those situations that are overtly complex or hard to define in the evaluating process for real MCDM problems; thus the notion of a linguistic variable is necessary in such situations. For example, we can use this kind of expression to compare two evaluated criteria by linguistic variables in a fuzzy environment for AHP weighting assessment as "absolutely important", "very strongly important", "essentially important", "weakly important", and "equally important". We also can employ linguistic variables as a way to measure the performance score of considered alternatives/strategies for each criterion as "*very low*", "*low*", "*fair*", "*high*", and "*very high*". In this paper we employ the triangular fuzzy numbers to express the fuzzy scale as above. In order to accomplish the data analysis, we can further define these linguistic variables using a fuzzy five level scale, here we give a typical example as Table 3.1 and Figure 3.5.

Table 3.1 Linguistic Variable Expression in Fuzzy Five Level Scale

Intensity of fuzzy scale	Definition of linguistic variables
$\tilde{1}=(1,1,3)$	Equally important; *Very low*
$\tilde{3}=(1,3,5)$	Weakly important; *Low*
$\tilde{5}=(3,5,7)$	Essentially important; *Fair*
$\tilde{7}=(5,7,9)$	Very strongly important; *High*
$\tilde{9}=(7,9,9)$	Absolutely important; *Very high*
$\tilde{2},\tilde{4},\tilde{6},\tilde{8}$	Intermediate values between two adjacent judgments

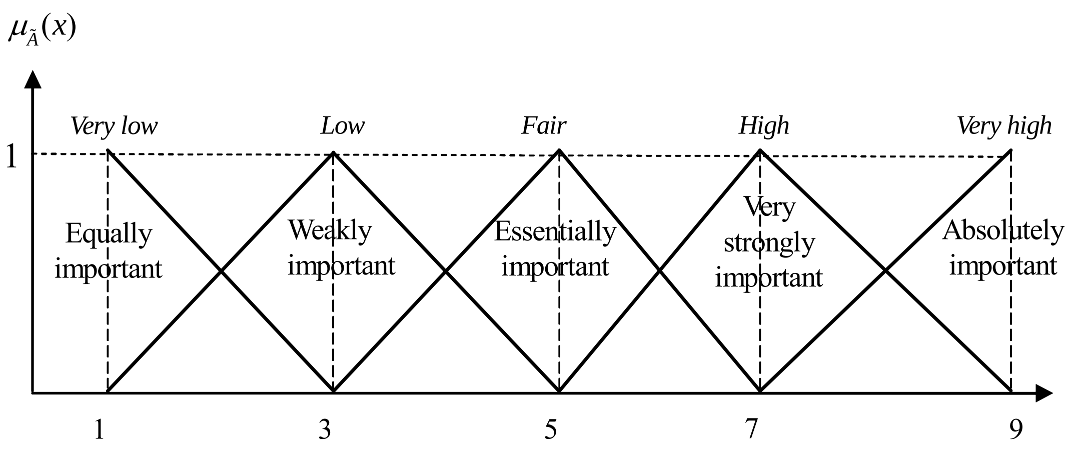


Figure 3.5 Membership Function for the Five-level Linguistic Variables

3.4 Fuzzy Measure and Fuzzy Integral for Synthetic Judgment

Once the mutual dependence exist among the evaluated criteria, it will overestimate or underestimate the synthetic value if we apply traditional simple additive weighting method in this situation. Sugeno (1974) extended fuzzy measure to proposed fuzzy integral for copeing with multiplicative utility function. In this section, we describe the detail procedure about how to use fuzzy integral technique to aggregate synthetic judgment in the evaluation process.

If the evaluated criteria are the situation of mutually independence, we can use SAW to aggregate the relative weights and performance scores for each possible alternative. Actually, this situation seldom holds in real FMADM problems, in this section we refer to multi-attribute utility theory (Keeney and Raiffa, 1976) to demonstrate non-additive aggregating method called fuzzy integral technique to overcome the criteria are non-independent cases.

In 1974, Sugeno introduced the concept of fuzzy measure and fuzzy integral, generalizing the usual definition of a measure by replacing the usual additive property with a weaker requirement, i.e. the monotonicity property with respect to set inclusion. In this section, we give a short introduction to some notions from the theory of fuzzy measure and fuzzy integral. For a more detailed account, please refer to Dubois and Prade (1980), Grabisch (1995), Hougaard and Keiding (1996), etc.

Definition 3.4.1 Let X be a measurable set that is endowed with properties of σ-algebra, where $\aleph$ is all subsets of X. A fuzzy measure g defined on the measurable space $(X,\aleph)$ is a set function $g:\aleph \to [0,1]$, which satisfies the following properties:

(1) $g(\phi)=0, g(X)=1$;

(2) for all $A,B\in\aleph$, if $A\subseteq B$ then $g(A)\le g(B)$ (monotonicity).

As in the above definition, $(X,\aleph,g)$ is said to be a fuzzy measure space. Furthermore, as a consequence of the monotonicity condition, we can obtain:

$$g(A\cup B)\ge \max\{g(A),g(B)\} \quad \text{and} \quad g(A\cap B)\le \min\{g(A),g(B)\}$$

In the case where $g(A\cup B)=\max\{g(A),g(B)\}$, the set function g is called a possibility measure (Zadeh 1978), and if $g(A\cap B)=\min\{g(A),g(B)\}$, g is called a necessity measure.

Definition 3.4.2 Let $h=\sum_{i=1}^{n} a_i \cdot 1_{A_i}$ be a simple function, where 1_{A_i} is the characteristic function of the set $A_i\in\aleph$, $i=1,\cdots,n$; the sets A_i are pairwise disjoint, and $M(A_i)$ is the measure of A_i. Then the Lebesque integral of *h* is

$$\int h \cdot dM = \sum_{i=1}^{n} M(A_i) \cdot a_i \tag{3.14}$$

Definition 3.4.3 Let $(X, \aleph, g)$ be a fuzzy measure space. The Sugeno integral of a fuzzy measure $g : \aleph \to [0,1]$ with respect to a simple function *h* is defined by

$$\int h(x) \circ g(x) = \mathop{\vee}_{i=1}^{n} (h(x_{(i)}) \wedge g(A_{(i)})) = \max_i \min\{a_i^{'}, g(A_i^{'})\} \tag{3.15}$$

where $h(x_{(i)})$ is a linear combination of a characteristic function $1_{A_i^{'}}$ such that $A_1 \subset A_2 \subset \cdots \subset A_n$, and $A_i^{'} = \{x \mid h(x) \geq a_i^{'}\}$.

Definition 3.4.4 Let $(X, \aleph, g)$ be a fuzzy measure space. The Choquet integral of a fuzzy measure $g : \aleph \to [0,1]$ with respect to a simple function *h* is defined by

$$\int h(x) \cdot dg \cong \sum_{i=1}^{n} \left[h(x_i) - h(x_{i-1})\right] \cdot g(A_i) \tag{3.16}$$

with the same notions as above, and $h(x_{(0)}) = 0$.

From the beginning of the application of fuzzy measures and fuzzy integrals to FMCDA problems, it seems to have been felt that there was dependent relation between criteria. Keeney and Raiffa (1976) advocated the multi-attributes multiplicative utility function, called non-additive multi-criteria evaluation technique, to refine the situations do not conform to the assumption of independence between criteria (Ralescu and Adams, 1980; Chen and Tzeng, 2001; Chen et al., 2000).

Let *g* be a fuzzy measure which is defined on a power set *P(x)* and satisfies the definition 3.4.1 as above. For any two disjoint sets *A* and *B*, $A \cap B = \varnothing$, the value of the fuzzy measure it takes upon its union, $g_\lambda(A \cup B)$, is computed as

$$g_\lambda(A \cup B) = g_\lambda(A) + g_\lambda(B) + \lambda g_\lambda(A) g_\lambda(B) \quad \text{for } -1 \leq \lambda < \infty \tag{3.17}$$

where $\lambda \geq -1$. The parameter of the fuzzy measure λ is used to describe an "interaction" between the components that are combined (Pedrycz and Gomide, 1998).

If $\lambda = 0$, then the above expression reduces to the additive measure,

$$g_\lambda(A \cup B) = g_\lambda(A) + g_\lambda(B) \tag{3.18}$$

If $\lambda > 0$, we obtain

$$g_\lambda(A \cup B) > g_\lambda(A) + g_\lambda(B) \tag{3.19}$$

This so-called super-additivity relationship quantifies a synergy effect, meaning that an evidence associated with the union of A and B is greater than the sum of the evidences arising from these two sources support each other.

On the other hand, if $\lambda < 0$, leading to the sub-additivity effect, these two sources of evidence are in competition (or redundancy), and their effect translates into the form

$$g_\lambda(A \cup B) < g_\lambda(A) + g_\lambda(B) \tag{3-20}$$

The value of the parameter of the λ-fuzzy measure is obtained from the normalization condition $g_\lambda(\boldsymbol{X}) = 1$. Generally speaking, setting $\boldsymbol{X} = \{x_1, x_2, \cdots, x_n\}$, the density of fuzzy measure $g_i = g_\lambda(\{x_i\})$ can then be formulated as follows:

$$g_\lambda(\{x_1, x_2, \cdots, x_n\}) = \sum_{i=1}^{n} g_i + \lambda \sum_{i_1=1}^{n-1} \sum_{i_2=i_1+1}^{n} g_{i_1} \cdot g_{i_2} + \cdots + \lambda^{n-1} \cdot g_1 \cdot g_2 \cdots g_n \tag{3.21}$$

$$= \frac{1}{\lambda} \left| \prod_{i=1}^{n} (1 + \lambda \cdot g_i) - 1 \right| \quad \text{for } -1 \le \lambda < \infty$$

Let h is a measurable set function defined on the fuzzy measurable space $(X, \aleph)$, suppose that $h(x_1) \ge h(x_2) \ge \cdots \ge h(x_n)$, then the fuzzy integral of fuzzy measure $g(\cdot)$ with respect to $h(\cdot)$ can be defined as follows (Ishii & Sugeno, 1985; see Figure 3.6).

$$\int h \cdot dg = h(x_n) g(H_n) + [h(x_{n-1}) - h(x_n)] g(H_{n-1}) + \cdots + [h(x_1) - h(x_2)] g(H_1) \tag{3.22}$$

$$= h(x_n)[g(H_n) - g(H_{n-1})] + h(x_{n-1})[g(H_{n-1}) - g(H_{n-2})] + \cdots + h(x_1) g(H_1)$$

where $H_1 = \{x_1\}, H_2 = \{x_1, x_2\}, \cdots, H_n = \{x_1, x_2, \cdots, x_n\} = X$. In addition, if $\lambda = 0$ and $g_1 = g_2 = \cdots = g_n$ then $h(x_1) \ge h(x_2) \ge \cdots \ge h(x_n)$ is not necessary.

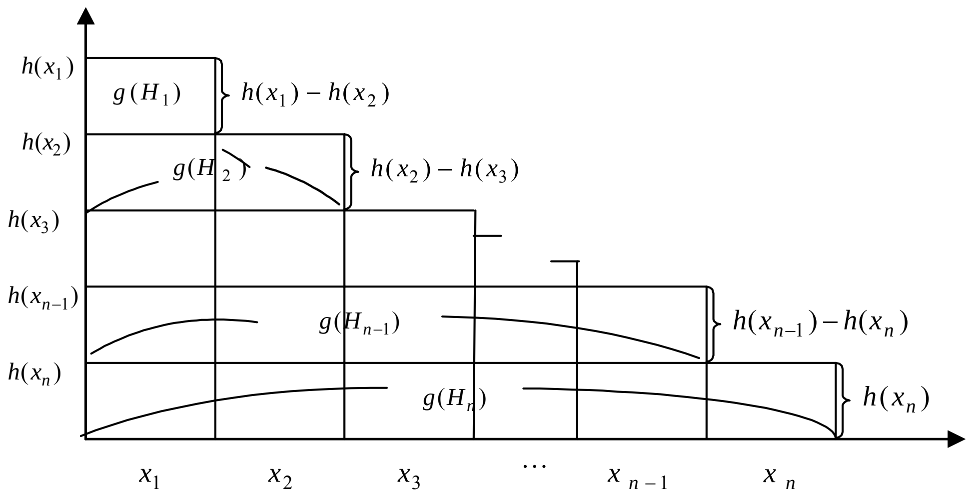


Figure 3.6 Conceptual Diagram of Fuzzy Integral

In order to clarify the operation of the fuzzy integral technique, we give some numerical examples in Appendix B. In practical application of real FMCDA problems, $X=\{x_1, x_2, \cdots, x_n\}$, probably represents the set of criteria, in case the criteria are not necessary mutually independent, in order to drive the synthetic utility values, we first exploit the factor analysis technique to extract the criteria in some common factors. The criteria within the same factor are not independent, a non-additive measurement case, utilizing non-additive fuzzy integral technique as Eqs.(3.22) to find the synthetic utilities of each alternative within the same factor. On the other hand, there is mutually independent between factors, and the measurement is an additive case, so we can utilize the additive aggregate method to conduct the synthetic utility values for all alternatives. In order to clarify the concept of fuzzy measure in evidence theory, we also summarize the generalized fuzzy measure in Appendix C.

On the other hand, the basic assumption of the Analytic Hierarchy Process (AHP) is that it can be used in the circumstances where a problem can be decomposed as a linear top-to-bottom form of a hierarchy, which the upper level is functionally independent from all its lower levels and the elements in each level are also independent. However, many decision problems cannot be structured hierarchically because of the interactions and dependencies of inter-level or intra-level elements. Saaty (1994) further introduced a revised model so called Analytic Network Process (ANP) for dealing with evaluating process while exists dependent or feedback relationship among considered criteria. The ANP was proposed (Saaty, 1996; Saaty and Vargas, 1998) to overcome the problem of interdependence and feedback between criteria or alternatives. The ANP is the general form of the analytic hierarchy process (AHP) (Saaty, 1980) which has been used in multicriteria decision making (MCDM) to release the restriction of hierarchical structure, and has been applied to project selection (Meade and Presley, 2002; Lee and Kim, 2000), product planning, strategic decision (Sarkis, 2003; Karsak et al., 2002), optimal scheduling (Momoh and Zhu, 2003) and so on.

3.5 Defuzzification for Determining Preferred Order

In many applications, we employ some fuzzy-based technique and obtain a fuzzy result. For instance, while the fuzzy synthetic value of each alternative is drived, the next step is how to determine the preferred order for these alternatives. However, the derived fuzzy synthetic value is not a crisp value, it couldn't be used for comparing from each other. Therefore, the defuzzification method for fuzzy numbers will be utilized to obtain comparable crisp value. Actually, in virtually all real world systems it is a crisp (non-fuzzy) result that should be implemented. The most commonly used defuzzification procedure in fuzzy control is certainly the center of area (Centroid), also called center of gravity method. Setting $\tilde{R}_i$ represents the fuzzy result in synthetic decision of *i*-th alternative, then its defuzzified value is illustrated as follows (Kacprzyk, 1997)

$$R_i^{Centroid} = \frac{\sum_{i=1}^{n} x_i \mu_A(x_i)}{\sum_{i=1}^{n} \mu_A(x_i)} \tag{3.23}$$

Here we transform this formula and rewrite the centroid defuzzified value as below:

$$R_i^{Centroid} = \frac{(MR_i - LR_i) + (UR_i - LR_i)}{3} + LR_i = \frac{(LR_i + MR_i + UR_i)}{3} \tag{3.24}$$

As mentioned above, defuzzification is selection of a specific crisp element based on the output fuzzy set, and it also includes converting fuzzy numbers into crisp scores. The commonly used defuzzification method, Center of Area (Centroid), together with several other procedures, are presented by Yager and Filev (1993). The other two widely used defuzzified methods include mean of maximal, and α-cut method (Zhao and Govind, 1991; Tsaur et al., 1997; Teng and Tzeng, 1994), however the operation defuzzification can not be defined uniquely (Opricovic and Tzeng, 2003).

3.6 Fuzzy Classification for Solving Optimal Strategy Combination

Clustering is one of the most fundamental issues in pattern recognition. It plays an important role in many engineering fields such as pattern recognition, system modeling, image analysis, communication, data mining, and so on. In briefly, given a finite set of data, $X = \{x_1, x_2, \cdots, x_n\}$, the problem of clustering in X is to find several cluster centers that can properly characterize relevant classes of X.

The objective of most clustering method is to provide useful information by grouping (unlabelled) data in clusters; within each cluster the data exhibits similarity. Similarity is defined by a distance measure, and global objective functional or regional graphic-theoretic criteria are optimized to find the optimal partitions od data.

Numerous tools investigated for hard and fuzzy clustering have been developed, the most widely used algorithms are the Hard *c*-Means Algorithm (HCMA) and the Fuzzy *c*-Means Algorithm (FCMA) (Dunn, 1974; Bezdek, 1980). However, the user of these algorithms is usually required to specify the number *c* of clusters and some other parameters. Different choices of these parameters may lead to different *c*-partitions, and consequently to different clustering results. Thus, the difficult problem encountered is the evaluation of the quality of the *c*-partitions resulting from the algorithms with different parameters setting. Many functions, called cluster-validity or validity criteria, have been proposed in the literature, which are used to measure the effectiveness of the clustering algorithms.

In what follows we review basic concept of fuzzy classification, and also introduce one of the popular classification, fuzzy c-means algorithms, for finding optimal strategy combination in fuzzy multi-criteria decision analysis problems later, finally we apply some cluster validity function for determining the best number of cluster in data analysis.

3.6.1 Fuzzy c-partitions

In classical cluster analysis, these classes are required to form a *partition* of *X* such that the degree of association is strong for data within blocks of the partition and week for data in different blocks. Let $X=\{x_1,x_2,\cdots,x_n\}$ be a finite set of *n* unlabeled feature vectors (x_k) in a feature space $\mathbb{R}^p$. The *k*-th object has (x_k) as numerical representation, and (x_k^j) is the *j*-th parameter $(1\le j\le p)$ associated with object *k*. A hard clustering of *X* is obtained by organizing this vector set into c disjoint clusters $(c\ge 2)$. For $x_k\in X$, this hard partition is defined using the following characteristic function:

$$\begin{aligned}&\mu_i : X\to\{0,1\}\\&x_k\to\mu_i(x_k)=\mu_{ik}=\begin{cases}1 & x_k\in i-th\ \ cluster\\0 & otherwise\end{cases}\\&1\le i\le c,\ 1\le k\le n\end{aligned}\tag{3.25}$$

This crisp function indicates the membership degree of each object to the different clusters. Conventional clustering procedures assign each object $x_k\in X$ definitely to a unique cluster with a membership degree equal to one. The introduction of fuzzy sets theory (Zadeh, 1965) allow to generalize the concept of characteristic function (3.25) as:

$$\begin{aligned}&\mu_i : X\to[0,1]\\&x_k\to\mu_i(x_k)=\mu_{ik}\in[0,1]\\&1\le i\le c,\ 1\le k\le n\end{aligned}\tag{3.26}$$

Hence, with a fuzzy clustering, an object x_k is said to belong to every cluster μ_i in *X* with a fuzzy membership $\mu_{ik}\in[0,1]$. Thus, a fuzzy *c*-partition of *X* is defined by an $(c\times n)$ matrix; $U=[\mu_{ik}]\in\mathbb{R}^{cn}$ satisfying the following conditions:

$$\mu_{ik} \in [0,1] \quad \forall i,k$$
$$0 < \sum_k \mu_{ik} < n \quad \forall i \qquad (3.27)$$
$$\sum_i \mu_{ik} = 1 \quad \forall k$$

Eqs. (3.26) define the constrained fuzzy *c*-partition. The membership degrees for the *c* fuzzy clusters specifies the strength with which each object belongs to each cluster. The knowledge of all the *c* membership degrees is particularly interesting for ambiguous objects situated in "bounding regions". For example, in the case of two clusters, a membership degree close to 0.5 indicates that the associated object can be considered as member of both clusters. Hence, fuzzy *c*-partition provides much information about the structure in each data than hard *c*-partition.

According to Bezdek (1995), clustering in unlabelled data $X = \{x_1, x_2, \cdots, x_n\} \subset \mathbb{R}^p$ is the assignment of labels to the vectors in *X* and to the objects generating *X*. If the labels are crisp, we hope they identify *c* natural subgroups in *X*. Clustering is also called unsupervised learning, with the word learning referring to learning the correct labels for good subgroups in the data. Figure 3.7 illustrates the process of using c-partition to classify the unlabeled data.

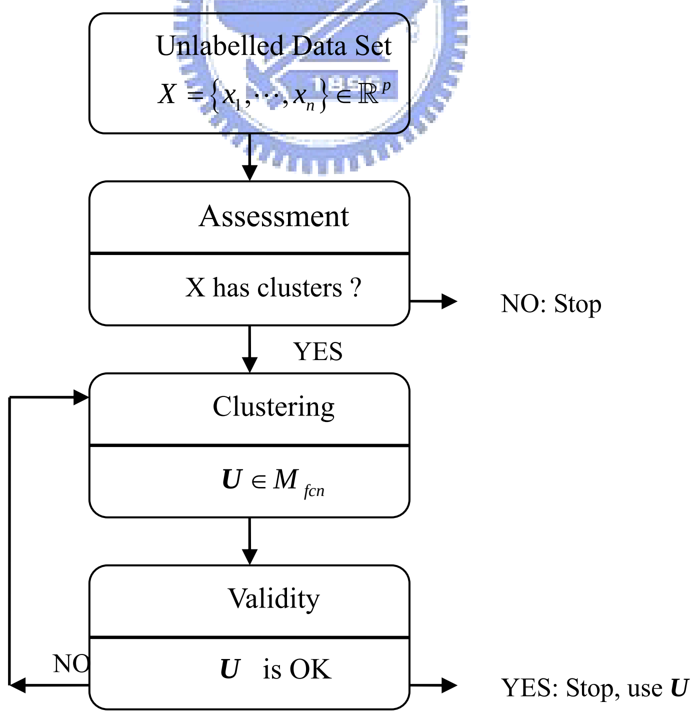


Figure 3.7 Processing Unlabeled Data (Bezdek, 1995)

3.6.2 Fuzzy c-means clustering algorithms

In cluster analysis, many fuzzy clustering algorithms have been developed, but the most widely used is the Fuzzy *c*-Means Algorithm (FCMA). First introduced by Dunn (1974) and generalized later by Bezdek (1980), this family of algorithms is based on an iterative optimization of a fuzzy objective function:

$$\text{Minimize } J_m(U,V) = \sum_i \sum_k (\mu_{ik})^m d^2(x_k, V_i) \tag{3.28}$$

with respect to $U = [\mu_{ik}] \in \mathbb{R}^{cn}$, a fuzzy *c*-partition of *n* unlabeled data set $X = \{x_1, x_2, \cdots, x_n\} \in \mathbb{R}^{pn}$ and to *V*, a set of *c* fuzzy cluster centres $V = \{V_1, \cdots, V_c\} \in \mathbb{R}^{pc}$. $d^2(x_k, V_i)$ is the Euclidean distance between the object x_k $(1 \le k \le n)$ and the cluster centre V_i $(1 \le i \le c)$. The parameter $m \in [1, \infty)$ is a weight exponent for each fuzzy membership. If $m = 1$, then the algorithm reduces to theHard *c*-Means Algorithm (HCMA) (Dunn, 1974; Ball and Hall, 1967).

The convergence to the fuzzy *c*-partition of *X* (U^*) and its representative fuzzy cluster centres (V^*) has been demonstrated in Bezdek (1980). The necessary conditions for the minimizer (U^*, V^*) of $J_m(U,V)$ are defined as

$$\mu_{ik} = \frac{1}{\sum_{j=1}^{c} \left[d(x_k, V_i) / d(x_k, V_j) \right]^{2/(m-1)}} \tag{3.29}$$

$$V_i = \frac{\sum_{k=1}^{n} (\mu_{ik})^m x_k}{\sum_{k=1}^{n} (\mu_{ik})^m} \tag{3.30}$$

The optimal solution (U^*, V^*) is obtained by Picard iteration through Eqs.(3.29) and Eq.(3.30). A brief specification of the iterating process is given as follows, assuming that $d^2(x_k, V_i) > 0 \;\; \forall i, k$ at each iteration of Eq.(3.28).

Fuzzy C-Means Algorithm (FCMA)

Given the unlabeled data set $X = \{x_1, x_2, \cdots, x_n\} \in \mathbb{R}^{pn}$

Initilization: ● Fix $c \ge 2,\; m > 1,\; \|\bullet\|_A \;\; \textit{and} \;\; \varepsilon > 0$

● Choose initial partition matrix $U^0 = \left[(\mu_{ik})^0 \right],\; 1 \le i \le c,\; 1 \le k \le n$

● Set $q = 1$

FCM1: ● Compute all *c* fuzzy cluster centres $(V_i)^q$ using Eqs.(3.30)

● Update all $(c \times n)$ membership degrees $U^q = \left[(\mu_{ik})^q\right]$ using Eqs.(3.29)

FCM2: ● Compute $E_q = \left\| V^{q+1} - V^q \right\|^2$

FCM3: ● If $E_q < \varepsilon$, stop; else $q = q+1$ and go to FCM1

End

$J_m(U,V)$ is a nonconvex function which may possess many local minima (Bezdek, 1973; 1980). Thus, the convergence of the algorithm can be trapped in undesirable "local minimizer". To cope with this problem, the analyst must run the iterative process with di!erent parameters and some initializations of U or V. Different setting of the initial conditions and parameters generally lead to different *c*-partitions. Therefore, the performance of the FCMA depends widely on a good adjustment and suitable choice of these parameters.

3.6.3 Validity criteria for fuzzy c-means clustering algorithms

The fuzzy *c*-partition provided by fuzzy clustering algorithms attempts to identify the structure that is present in the input data set. In these partitions, the objects assigned to the same cluster are more similar to each other than are objects belonging to different clusters.

However, although the environment is fuzzy, the aim of the classification is to generate a well-defined fuzzy *c*partition that is as close as possible to the natural structure of the data (Gath and Geva, 1989). Thus, a difficult question is how a partition fits with the unknown structure of the data set. This problem calls for a cluster-validity analysis using some kind of validity criteria.

A lot of cluster validity were proposed during the last 10 years. They come from different studies dealing with the number of clusters existing in a set of points (Bezdek and Pal, 1998; Gunderson, 1978; Kothari and Pitts, 1999; Trauwert et al., 1991). These studies started with hard partitions. Hardy realised a comparative appraisal of the hard approaches allowing to determine the number of clusters (1996). These ones were translated to the fuzzy partitions (Bezdek 1974; 1981; Windham, 1981). Among the criteria which we can use to determine the number of clusters, we can notably cite the ones which are used with the classical Fuzzy C-Means algorithm. We have chosen to compare our criterion to the most used in the field of fuzzy clustering: partition coeffcient (Bezdek, 1974), partition entropy (Bezdek, 1975) and Xie-Beni cluster-validity index (Xie and Beni, 1991). All these indexes are described as following.

The first fuzzy validity criteria functions associated with the FCMA were introduced by Bezdek (1974), and are defined as follows:

$$v_{PC} = \frac{\sum_{i=1}^{c}\sum_{k=1}^{n}(\mu_{ik})^2}{n} \tag{3.31}$$

for the so-called Partition Coefficient (v_{PC}) to measure the maximum amount of fuzziness in clustering.

The second fuzzy validity functions was also introduced by Bezdek (1975), and are defined as follows:

$$v_{PE} = -\frac{1}{n}\left(\sum_{k=1}^{n}\sum_{i=1}^{c}\left(\mu_{ik}\cdot\log_a\left(\mu_{ik}\right)\right)\right);\ a\in(1,\infty) \tag{3.32}$$

for the Partition Entropy (v_{PE}) to measure the minimum amount of fuzziness in clustering.

For a membership matrix ; and a cluster number equal to *c*, these functions share the following properties:

$$\frac{1}{c} \le v_{PC} \le 1 \ \Leftrightarrow\ 0 \le v_{PE} \le \log_2 c \tag{3.33}$$

$$v_{PC} = 1 \ \Leftrightarrow\ v_{PE} = 0 \ \Leftrightarrow\ U \text{ is a hard } c-\text{partition.} \tag{3.34}$$

$$v_{PC} = \frac{1}{c} \ \Leftrightarrow\ v_{PE} = \log_2 c \ \Leftrightarrow\ U \text{ is the fuzziest } c-\text{partition.} \tag{3.35}$$

Properties (3.33)-(3.35) show that if v_{PC} comes close to 1 or if v_{PE} approaches 0, U is close to the “harder” partition. The ambiguous situation corresponds to condition (3.35) where every object in *X* is assigned to each of the *c* clusters with an equal membership degree 1/*c*. Hence, a valid clustering is obtained by maximizing v_{PC} (or minimizing v_{PE}) for $c = 2, 3, \cdots, c_{\max}$. Furthermore, to evaluate fuzzy *c*partitions, v_{PC} and v_{PE} use only the fuzzy membership degrees μ_{ik}, i.e., the property of the fuzzy matrix U, independently of the data structure. Furthermore, these cluster-validity measures possess monotonic evolution tendency with *c*.

To take into account simultaneously the properties of the fuzzy membership degrees and the structure of the data itself, new cluster-validity functions have been proposed by Xie and Beni (1991) and Fukuyama and Sugeno (1989).

The Xie-Beni cluster-validity criterion is defined as

$$v_{XB} = \frac{\sum_{i=1}^{c}\sum_{k=1}^{n}(\mu_{ik})^2\cdot\left(\left\|x_k - v_i\right\|^2\right)}{n\cdot\min_{i\ne j}\left(\left\|v_i - v_j\right\|^2\right)} = \frac{J_m(U,V)}{n\cdot Sep(V)} \tag{3.36}$$

where J_m is the fuzzy objective function of the FCMA. It is considered as a compactness measure. $Sep(V)$ is a separation measurement between clusters centres.

A small value of v_{XB} means a fuzzy c-partition with compact and well-separated clusters. Hence, the best fuzzy c-partition is obtained by minimizing v_{XB} with respect to $c = 2, 3, \cdots, c_{\max}$.

Both v_{PC} and v_{PE} measure the amount of fuzzyness in clustering and when v_{PC} takes its maximum v_{PE} takes its minimum. Past research has demonstrated that v_{PC} and v_{PE} can show monotonic tendencies with the changes in the number of clusters. Some empirical studies have shown that maximizing v_{PC} (or minimizing v_{PE}) often leads to a good interpletation of data (Pal and Bezdek, 1995). On the other hand, v_{XB} takes into account the amount of separation among the cluster means V_i in addition to the cluster memberships. This additional information is supposed to enhance the quality of cluster validity indices.

In addition, we assign the patterns to the groups in which the probability of membership is larger, either the Mahalanobis distance or the Euclidean distance is used. This membership probability is $\max\left\{\mu_{ik} \middle| 1 \le k \le c\right\}$ being given by Eq.(3.29). The probability of error will be $1 - \max\left\{\mu_{ik} \middle| 1 \le k \le c\right\}$, and then average error will be written as:

$$B_f = E\left[1 - \max\left\{\mu_{ik} \middle| 1 \le k \le c\right\}\right] \tag{3.37}$$

where E is the expected value. This definition is like the definition of the Bayes error (Fukunaga, 1990). The subindex f in Eq.(3.37) indicates that the error is measured using the membership probabilities to the groups in the fuzzy partition. The lower the value of B_f the better the fuzzy partition. We are also going to use B_f to determine the best fuzzy partition executing the FCM algorithm with different group numbers in this research.

As a matter of fact, when we employ fuzzy c-means clustering to classify the unlabelled data, defuzzification procedure is strictly required. That is, we classify these unlabelled data in crisp form. Therefore, we also exploit original correctly classified index v_{DA} which is defined by traditional Discriminant Analysis to express the classification validity in order to explore the best number of clusters.

4. EMPIRICAL STUDY ON EVALUATION OF SUSTAINABLE STRATEGY FOR FISHING INDUSTRY

In this chapter focus on applying fuzzy multi-criteria decision making method as mentioned above to explore the proposed strategy seeking sustainable development. Through this empirical study we successfully demonstrate that these methods of fuzzy measure and non-additive fuzzy integral provide a good evaluation and appear to be more appropriate, especially when the criteria are not independent situations in fuzzy environment. This section is divided into six sections: (1) Problem background and description; (2) Calculating the fuzzy evaluated criteria weights; (3) Obtaining the fuzzy performance matrix, (4) Deriving the non-additive fuzzy synthetic values and determining the preferred order, (5) Fuzzy c-means clustering for solving the optimal strategy combination and discussions.

4.1 Problem Background and Description

Along with technological and economic development, mass production may resulted in increasing waste, including hazardous emissions and toxic waste from manufacturing process. According to the Environmental Protection Agency statistics of the USA in 2000, over 400 million tons of hazardous waste emissions and industrial waste is processed annually worldwide. Furthermore, about 480 million tons of municipal waste is produced in daily life. Preserving the planet on which we live is an urgent challenge for our time.

Green Engineering can be defined as environmentally conscious attitudes, values, and principles, combined with science, technology, and engineering practice, all directed toward improving local and global environmental quality. Green engineering aims to reclaim industrial or municipal waste, and is an increasingly important viewpoint, which also provides the opportunity for sustainable development of enterprise. In 1992, the United Nations Environmental Planning Board (UNEP) presented *Agenda 21* of the Rio Declaration on Environment and Development as a guideline to improve sustainable development. In addition, in 1996 UNEP proposed the structure and approaches of sustainable development index. The United States developed 10 goals and a related sustainable development index for their country in the same year. The United Kingdom declared 120 sustainable development indices for their country in 1992. They then integrated these into 13 major indices to evaluate the performance of economic development, social investment, climate change, environmental quality and ecological conservation for their country in 1996 (Mendoza and Prabhu, 2000). Since the United Nations General Assembly proposed "*Our Common Future*" in 1987, the international social system began to take account of the environmental and sustainable development issues. There have many bilateral, multilateral, regional or global agreements to provide environmental protection, and some of the important regulations are described in Appendix A.

Environmental planning and decision-making in green engineering industries are essentially conflict analysis characterized by sociopolitical, environmental, and economic value judgments. Several alternatives/strategies have to be considered and evaluated in terms of many different criteria resulting in a vast body of data that are often inaccurate or uncertain. Recently, environmental concerns have raised public awareness of environmental issues and are driving forces for regulation. The impact of regulation on the cost of production is expected to become an important determinant for the international competitiveness of industries. In response to cost pressures, industries have launched a number of initiatives aimed at improving efficiency and reducing environmental impact; reclaiming techniques are effective and economic approaches to enable enterprises to achieve goals of sustainable development.

The aquatic products industry is a branch of the food products industry. There are abundant fishery resources in Taiwan because of its geographical features, and aquatic products are an important dietary resource in daily life. However, for example, about 50 percent of harvested fish material is not edible, and how to reclaim this waste is an important challenge. In Japan, special techniques are used to process the waste from aquatic products for extracts such as fish oil, fish meal and fish solution, which are used to make health food, forage additives and so on, in addition to uses in agriculture and medical science.

There are about 600 aquatic products processors in Taiwan based on the Fishery Annual Report in 1998, the majority of which are small-sized enterprises. Only some of them have engaged in reclaiming of the waste from processing of aquatic products as fish, shrimp and shells fish. In this study, we apply fuzzy AHP approach and the non-additive fuzzy integral technique to evaluate the performance of green engineering strategies, reviewing ten companies as samples of aquatic products processors in this island.

As mentioned above, Green Engineering focuses on the design of materials, processes, systems, and devices with the objective of minimizing overall environmental impact (including energy utilization and waste production) throughout the entire life cycle of a product or process, from initial extraction of raw materials used in manufacture to ultimate disposal of materials that cannot be reused or recycled at the end of the useful life of a product. Many evidences have shown that environmental issues may affect business profits. In addition, all enterprises must take responsibility to value our resources by complying with regulations. Reclaiming of resources is an eco-efficient strategy, and a paragon of sustainable development. According to our survey of the literature, several multicriteria analytic methods have been used to deal with environmental problems. The main approaches can be classified based on the type of decision model they used (Lahdelma et al., 2000):

(1) Value or utility function based methods, such as multiattribute utility theory (Keeney and Raiffa, 1976; Teng and Tzeng, 1994; Tzeng et al., 1996), AHP (Saaty, 1980), DEA (Oral et al., 1991), etc.

(2) Outranking methods such as ELECTRE methods (Siskos and Hubert, 1983; Grassin, 1986; Roy and Bouyssou, 1986; Roy, 1991; Hokkanen et al., 1995; Hokkanen and Salminen, 1997), PROMETHEE I and II methods (Brans and Vincke,1984; 1985; Briggs et al., 1990), and GFD method (Caruso et al., 1993).

4.2 Building Hierarchy System for Evaluation

In real MCDM problems, traditional evaluation methods usually take the minimum cost or the maximum benefit as their single index of measurement criteria, although these approaches may not be sufficient for the increasingly complex and diversified decision-making environment. Thus, we utilize a fuzzy hierarchical analytic process to assess the sustainable development strategies for industry.

In this study, we divide the evaluation process into four stages. First, the various stakeholders will be defined after identifying the problem. These stakeholders typically include the decision-makers, various interest groups affected by the decision, experts in the appropriate fields, as well as planners and analysts responsible for the preparations and managing the process. We consider critical criteria from various points of view based on responsibility and effect for sustainable development planning. We also consider available strategies from the life cycles of products to validate the meaning of sustainable development. The hierarchical system for our problem is then set up in this stage.

Secondly, fuzzy set theory is introduced to determine the fuzzy weights of criteria as well as performance values of strategies. Thirdly, because in real world problems independent relationships are not necessary among criteria, we employ factor analysis to extract some independent common factors from criteria that are simultaneously considered, and use the non-additive fuzzy integral to compute the synthetic utility value within each common factor. Because of the independence among common factors, we then aggregate the final utility value of each strategy by additive weighting sum method. Fourth and finally, decision makers decide on the best strategy based on the final utility value.

First of all, we establish a hierarchy system of green engineering industry for analysis and evaluation through scenario writing and brainstorming, as shown in Figure 4.1. Phase 1 includes our overall objectives. Secondly, we consider three aspects for achieving goals in Phase 2, including business activities, government roles and socioeconomic effects.

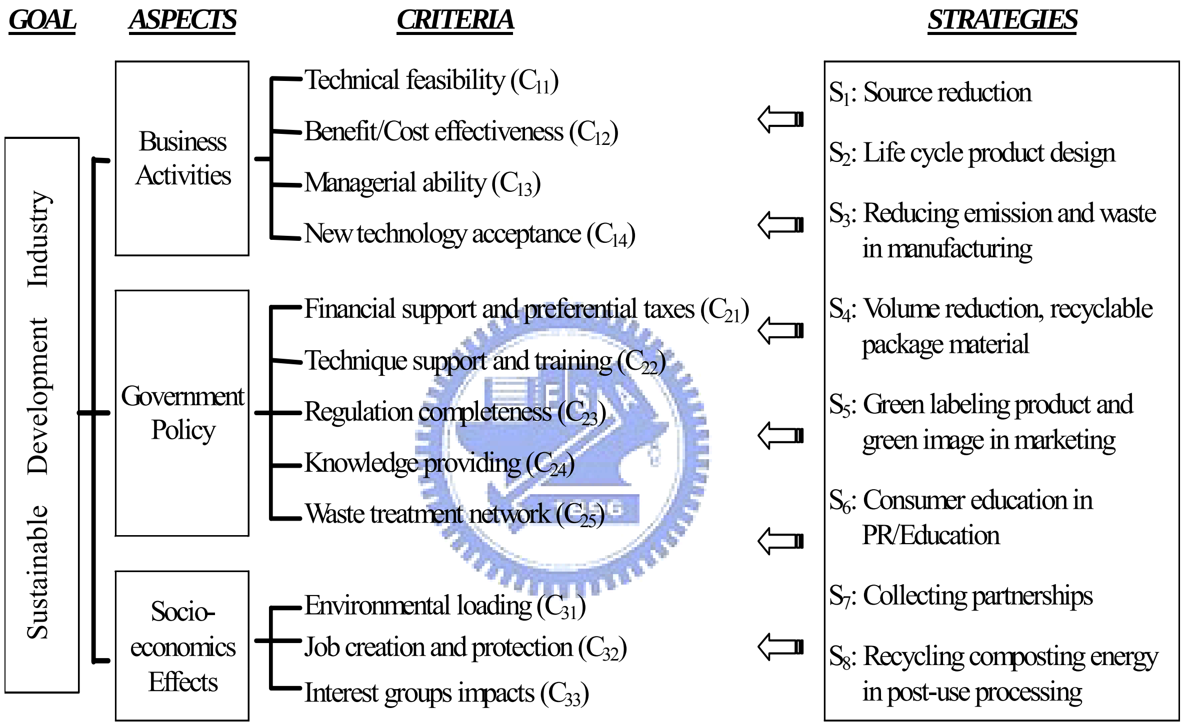


Figure 4.1 Hierarchical System of Green Engineering Industry for Sustainable Development

Thirdly, we consider four criteria in business activities, five criteria in government roles, and three criteria in socioeconomic effects with respect to our consideration aspects that are evaluated and selected outranking listed in Phase 3. All considered criteria measured by evaluators, consisting of individuals with different viewpoints. Finally, the strategies of green engineering to carry on business of participated companies listed in Phase 4. The post-use process of products with eight strategies from source materials is considered to meet green engineering concepts. Each enterprise will choose the strategies based on technical feasibility, financial status, managerial ability, and relevant business situation, etc. In addition, the definitions of relevant criteria and strategies are listed in Table 4.1.

Table 4.1 Definition of Criteria and Strategies in Green Engineering Industry

Criteria	Description
C11. Technical feasibility	To measure the degree of reclaim technique
C12. Benefit/Cost effectiveness	To measure the benefit/cost effectiveness from leading reclaim technique, including the value-increasing of new products and reduction of power expenditure and waste treatment costs, etc.
C13. Managerial ability	To measure whether who possess the managerial ability in technique of waste treatment and reclaim from product processing.
C14. New technology acceptance	To measure the degree of acceptance of all inner members about reclaim technique in waste treatment and recovery that leads to company.
C21. Financial support and preferential taxes	This criterion will encourage business to engage in reclaiming the waste from process or material.
C22. Technique support and training	To measure the degree of government to provide the reclaim technique and knowledge in waste that will enhance business competence.
C23. Regulation completeness	This criterion will indirectly encourage business to develop and lead in the reclaim techniques, it also gives protection to the legitimate companies.
C24. Knowledge providing	To hold periodically or non-periodically technical seminar and publication by government or particular organization to provide the knowledge of reclaim techniques in waste.
C25. Waste treatment network	It will provide the channel of waste treatment that will prevent and reduce environment damage to ensure the sustainable development.
C31. Environmental loading	To measure the degree of loading from enterprise or municipal waste, including water waste, waste liquid, viscera, mud, fishbone, shell, in addition to the offensive smell of fish in aquatic products processing.
C32. Job creation and protection	To measure one of contribution to the community from enterprise.
C33. Interest groups impacts	Including the protest by civil organizations, or residents of the impact area for pollution accident.
Strategies	
S1. Source reduction	Material and source reduction in fore part of product manufacturing.
S2. Life cycle product design	Expanded product lifecycles in design stage.
S3. Reducing emission and waste in manufacturing	Emission and waste reduction in manufacturing process.
S4. Volume reduction, recyclable package material	Volume reduction, using recyclable package material.
S5. Green labeling product and green image in marketing	Produce green labeling product and establish green image exhibiting in marketing will improve consumer to buy and use it.
S6. Consumer education in PR/Education	Green label products will progress consumer to value whole resource on our earth mother
S7. Collecting partnerships	Establish good collecting partnerships and complete recycling network.
S8. Recycling composting energy in post-use processing	Develop new reclaiming technology transfer the waste that from produce and post-used process to new product, it will create new value to originally products and also might bring new niche to industry.

4.3 Determining the Fuzzy Criteria Weights

Because the evaluation of criteria entails diverse and meanings, we cannot assume that each evaluation criterion is of equal importance. There are many methods that can be employed to determine weights (Hwang and Yoon 1981), such as the eigenvector method, weighted least square method, entropy method, AHP, as well as linear programming techniques for multidimension of analysis preference (LINMAP). The selection of method depends on the nature of the problems. Here we utilize the fuzzy geometric mean method to determine the criteria weights in this study.

First, we establish the green engineering decision hierarchy frame shown in Figure 4.1, where the preliminary classification is comprised of aspects involving business, government and socioeconomic dimensions, with twelve criteria selected. Secondly, we have 15 evaluators including staff from government sector who are in charge of sustainable development, academic experts, executives of aquatic products processors, members of environmental interest group and residents. We integrate their subjective judgments to develop the fuzzy criteria weights with respect to aspects by the fuzzy geometric mean method as above Eqs.(3.2). We then derive the final fuzzy weights corresponding to each criterion as shown in Table 4.2, in order to compare the relative importance of evaluated criteria, we transform these fuzzy weights to defuzzified values using by centroid method.

4.4 Obtaining the Fuzzy Performance Score

To determine the performance value of each strategy, the evaluators can define their own individual score range (from 0 to 100 in this study) for the linguistic variables employed in this study according to their subjective judgments within a fuzzy scale. This way of estimating the achievement level of each criterion in each strategy can use the methods of fuzzy theory for treating the fuzzy environment.

Let $\tilde{h}_{ij}^{k}$ represent the fuzzy performance score by the *k*-th evaluator of the *i*-th strategy under the *j*-th criterion. Since the perception of each evaluator varies according to individual experience and knowledge, and the definitions of linguistic variables also vary, we employ the fuzzy geometric mean method to integrate the fuzzy performance score $\tilde{h}_{ij}$ for *m* evaluators, as shown in Table 4.3. That is,

$$\tilde{h}_{ij} = \left(\tilde{h}_{ij}^{1} \otimes \cdots \otimes \tilde{h}_{ij}^{m}\right)^{1/m} \qquad (4.1)$$

Furthermore, in order to make more clearly comprehensive in considered criteria with strategies for readers, we employ the defuzzification procedure to compute the defuzzified values of fuzzy performance score $\tilde{h}_{ij}$, as shown in Table 4.4.

4.5 Deriving the Synthetic Value and Preferred Order

Considering the assessment attributes among criteria that are not quite independent, factor analysis can be introduced to extract common factors such that the factors are mutually independent. Fuzzy integral technique can then be used to calculate the synthetic performance of each factor for which criteria are dependent. Finally a simple additive weighted method is used to aggregate the final synthetic value corresponding to each strategy. The process of assessing the final synthetic values is shown in Figure 4.2.

Factor analysis is a dimension reduction method of multivariate statistics, which explores the latent variables from manifest variables. Two methods for factor analysis are generally in use, principal component analysis and the maximum likelihood method. The main procedure of principal component analysis can be described in the following steps when applying factor analysis:

Table 4.2 Criteria Weights of Green Engineering Strategies

Aspects and Criteria	Local weights	Overall weights	Defuzzified values	
Business activities	*(0.103,0.311,0.917)*			
Technical feasibility	(0.102,0.337,1.178)	(0.011,0.105,1.080)	0.398	(2)*
Benefit/Cost effectiveness	(0.086,0.307,1.032)	(0.009,0.096,0.946)	0.350	(3)
Managerial ability	(0.050,0.185,0.731)	(0.005,0.058,0.670)	0.244	(8)
New technology acceptance	(0.040,0.171,0.653)	(0.004,0.053,0.598)	0.219	*(10)*
Government roles	*(0.128,0.373,1.080)*			
Financial support and preferential taxes	(0.036,0.133,0.444)	(0.005,0.049,0.480)	0.178	(12)
Technique support and training	(0.049,0.169,0.537)	(0.006,0.063,0.580)	0.216	(11)
Regulation completeness	(0.087,0.251,0.738)	(0.011,0.094,0.797)	0.301	(5)
Knowledge providing	(0.066,0.201,0.639)	(0.008,0.075,0.690)	0.258	(7)
Waste treatment network	(0.085,0.246,0.735)	(0.011,0.092,0.793)	0.299	(6)
Social economics effects	*(0.109,0.316,0.945)*			
Environmental loading	(0.162,0.454,1.288)	(0.018,0.143,1.218)	0.460	(1)
Job creation and protection	(0.072,0.206,0.687)	(0.008,0.065,0.649)	0.241	(9)
Interest groups impacts	(0.108,0.340,0.954)	(0.012,0.107,0.902)	0.340	(4)

* Parentheses ( ) denote the order of importance for each criterion

Table 4.3 Fuzzy Performance Score of Green Engineering Strategies

Strategies	Criteria			
	C11	C12	C13	C14
S1. Source reduction	(15.5,26.5,49.1)	(16.3,30.6,53.0)	(28.3,49.1,69.4)	(22.7,44.4,64.9)
S2. Life cycle product design	(28.1,49.9,70.6)	(37.1,59.1,76.7)	(20.3,42.2,62.7)	(29.5,51.6,72.4)
S3. Reducing emission and waste in manufacturing	(23.9,45.9,66.5)	(12.5,23.9,45.9)	(12.5,26.7,48.3)	(12.5,26.7,48.3)
S4. Volume reduction, recyclable package material	(29.5,51.6,72.4)	(22.7,44.4,64.9)	(27.9,50.8,71.8)	(44.4,64.9,83.5)
S5. Green labeling product and green image in marketing	(31.1,53.4,74.2)	(37.8,59.6,78.7)	(21.4,43.6,64.3)	(17.3,34.7,56.2)
S6. Consumer education in PR/Education	(26.7,48.3,68.8)	(33.0,54.4,74.8)	(34.1,55.7,74.8)	(29.8,50.8,71.2)
S7. Collecting partnerships	(26.7,48.3,68.8)	(18.2,40.1,60.7)	(22.5,45.1,66.0)	(19.3,40.8,61.2)
S8. Recycling composting energy in post-use processing	(37.8,59.6,78.7)	(31.3,52.6,73.0)	(33.0,54.4,74.8)	(36.8,57.2,77.4)

Strategies	Criteria			
	C21	C22	C23	C24
S1. Source reduction	(11.2,31.6,51.7)	(33.0,54.4,74.8)	(12.5,26.7,48.3)	(32.4,53.9,73.0)
S2. Life cycle product design	(11.2,20.3,42.2)	(13.9,35.0,55.3)	(19.2,33.3,56.2)	(20.3,42.2,62.7)
S3. Reducing emission and waste in manufacturing	(10.0,19.3,40.8)	(23.9,45.9,66.5)	(34.7,56.2,76.7)	(21.4,43.6,64.3)
S4. Volume reduction, recyclable package material	(13.1,22.1,44.7)	(12.5,23.9,45.9)	(11.2,22.7,44.4)	(36.8,57.2,77.4)
S5. Green labeling product and green image in marketing	(10.0,12.5,33.2)	(28.1,49.9,70.6)	(33.0,54.4,74.8)	(35.9,57.6,76.7)
S6. Consumer education in PR/Education	(14.6,29.0,51.2)	(23.3,41.4,62.7)	(37.8,59.6,78.7)	(36.5,58.1,78.7)
S7. Collecting partnerships	(12.5,23.9,45.9)	(31.1,53.4,74.2)	(40.8,61.2,81.4)	(38.7,59.2,79.4)
S8. Recycling composting energy in post-use processing	(18.2,40.1,60.7)	(44.4,64.9,83.5)	(50.8,71.2,87.8)	(44.4,64.9,83.5)

Strategies	Criteria			
	C25	C31	C32	C33
S1. Source reduction	(33.0,54.4,74.8)	(42.9,63.3,83.5)	(10.0,11.2,31.6)	(10.0,15.5,36.8)
S2. Life cycle product design	(13.9,25.2,47.5)	(29.5,51.6,72.4)	(10.0,15.5,36.8)	(11.2,22.7,44.4)
S3. Reducing emission and waste in manufacturing	(42.2,62.7,81.4)	(43.6,64.3,81.4)	(25.3,46.7,67.1)	(21.4,43.6,64.3)
S4. Volume reduction, recyclable package material	(51.6,72.4,85.6)	(13.9,25.2,47.5)	(18.2,32.2,54.8)	(13.9,31.3,52.6)
S5. Green labeling product and green image in marketing	(39.1,61.1,78.7)	(15.4,30.0,52.5)	(10.0,15.5,36.8)	(21.4,39.1,61.1)
S6. Consumer education in PR/Education	(36.5,58.1,78.7)	(12.5,19.2,41.4)	(10.0,13.9,35.0)	(11.2,14.6,36.2)
S7. Collecting partnerships	(54.4,74.8,87.8)	(40.8,61.2,81.4)	(14.6,29.0,51.2)	(29.5,51.6,72.4)
S8. Recycling composting energy in post-use processing	(31.1,53.4,74.2)	(28.1,49.9,70.6)	(19.2,33.3,56.2)	(17.2,35.3,57.2)

Table 4.4 Defuzzified Values of Fuzzy Performance Score

Strategies	Defuzzified values											
	C11	C12	C13	C14	C21	C22	C23	C24	C25	C31	C32	C33
S1. Source reduction	30.35	33.28	48.94	43.99	31.48	54.06	29.14	53.09	54.06	63.21	17.58	20.77
S2. Life cycle product design	49.53	57.66	41.75	51.18	24.55	34.73	36.20	41.75	28.84	51.18	20.77	26.08
S3. Reducing emission and waste in manufacturing	45.44	27.41	29.14	29.14	23.36	45.44	55.89	43.12	62.10	63.11	46.38	43.12
S4. Volume reduction, recyclable package material	51.18	43.99	50.12	64.24	26.65	27.41	26.08	57.14	69.87	28.84	35.05	32.60
S5. Green labeling product and green image in marketing	52.90	58.70	43.12	36.08	18.56	49.53	54.06	56.76	59.63	32.65	20.77	40.54
S6. Consumer education in PR/Education	47.93	54.06	54.89	50.59	31.62	42.47	58.70	57.79	57.79	24.36	19.62	20.65
S7. Collecting partnerships	47.93	39.65	44.53	40.43	27.41	52.90	61.11	59.09	72.32	61.11	31.62	51.18
S8. Recycling composting energy in post-use processing	58.70	52.29	54.06	57.14	39.65	64.24	69.92	64.24	52.90	49.53	36.20	36.54

Step 1. Find the correlation matrix or variance-covariance matrix for the objects to be assessed;

Step 2. Find the eigenvalues and eigenvectors for assessing the factor loading and the number of factors;

Step 3 Consider the eigenvalue ordering to decide the number of common factors, and pick the number of common factors be extracted by a predetermined criterion.

Step 4. According to Kaiser (1958), use varimax criteria to find the rotated factor loading matrix, which provides additional insights for the rotation of factor-axis;

Step 5. Name the factor referring to the combination of manifest variables.

In order to drive the synthetic utilities while non-independent situation, we first exploit the factor analysis technique to extract the criteria in four common factors (Figure 4.2). The first factor, with 47.98% variance explanation, includes five criteria: technical feasibility (C_{11}), benefit/cost effectiveness (C_{12}), financial support and preferential taxes (C_{21}), technique support and training (C_{22}), and environmental loading (C_{31}). The second factor, with 17.14% variance explanation, includes three criteria: managerial ability (C_{13}), new technology acceptance (C_{14}), and knowledge providing (C_{24}). The third factor, with 14.51% variance explanation, includes three criteria: waste treatment network (C_{25}), job creation and protection (C_{32}), and interest groups impacts (C_{33}). The final factor, with 10.82% variance explanation, includes only one criterion, regulation completeness (C_{23}). The total proportion of variance explanation is 90.34%.

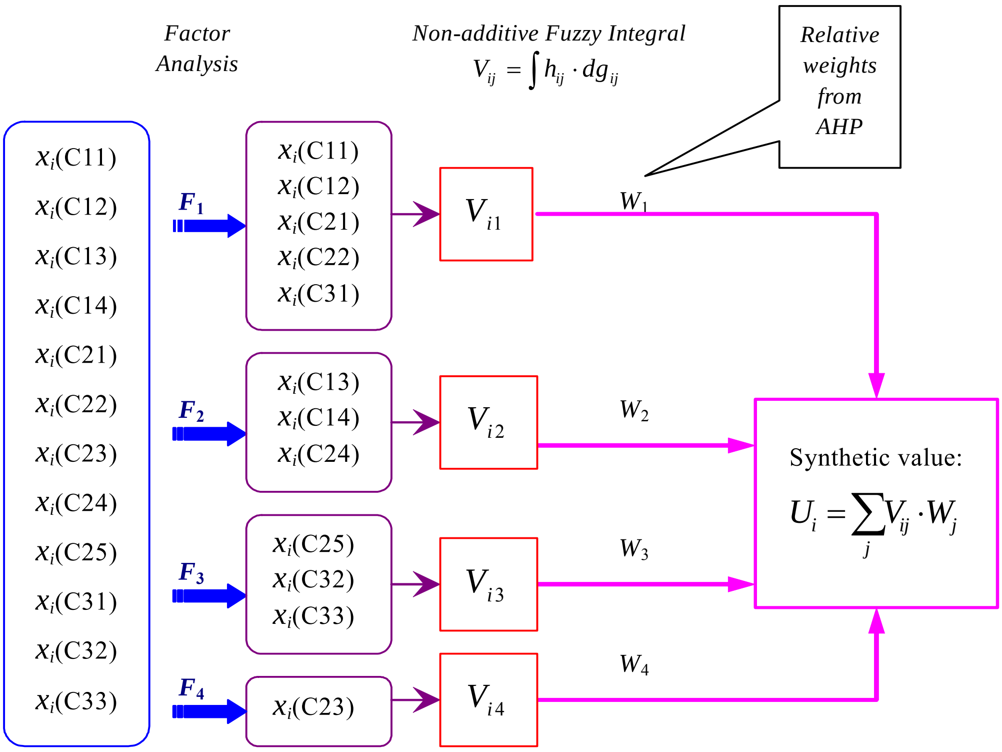


Figure 4.2 Non-additive Synthetic Value Assessing Process

Secondly, because the criteria within the same common factor are dependent, it's a non-additive measurement case, we can utilize fuzzy integral to derive the synthetic value of each common factor. Moreover, there is mutually independent among the common factors, the measurement is an additive case, so we exploit the simple additive weighted method to aggregate the final synthetic value of proposed strategy, individually.

As mentioned above, defuzzification is selection of a specific crisp element based on the output fuzzy set, and it also includes converting fuzzy numbers into crisp scores. In order to determine the preferred order of all proposed strategies based on their final synthetic value, we further use centroid defuzzified method to conduct the nonfuzzified synthetic valuees of each strategy. In addition, the λ fuzzy measure express the relationship of among criteria within common factor, here setting different λ values and observe if the preferred order will vary with λ values, the results as shown in Table 4.5 and Figure 4.3.

In Section 3.4, we introduced the λ value representing the properties of substitution between criteria, where λ values range from –1 to positive infinite value (∞). From Table 4.5, we describe the variation of synthetic values in different λ value as follows.

(1) For each strategy, the synthetic values decreasing with respect to λ increasing.

(2) If $\lambda < 0$, it's a substitutive effect situation. For instance, the nonfuzzy synthetic value

has the following preferred order: $S7 \succ S6 \succ S8 \succ S2 \succ S3 \succ S4 \succ S5 \succ S1$ while $\lambda = -1$.

(3) If $\lambda = 0$, it is an additive effect situation, and the nonfuzzy synthetic value has the following preferred order: $S8 \succ S7 \succ S3 \succ S5 \succ S6 \succ S4 \succ S2 \succ S1$.

(4) If $\lambda > 0$, it's a multiplicative effect situation, For instance, the nonfuzzy synthetic value has the following preferred order: $S8 \succ S7 \succ S5 \succ S3 \succ S6 \succ S4 \succ S1 \succ S2$ while $\lambda = 5$.

Where $A \succ B$ means *A* outranks *B* because *A* has higher synthetic value than *B*.

In addition, if the criteria are independent in a fuzzy environment, conducting the fuzzy synthetic utilities by simple additive weight method is traditionally used. This method is especially appropriate to employ in independent criteria situations.

Table 4.5 Defuzzified Synthetic Values with λ Fuzzy Measure

λ	S1	S2	S3	S4	S5	S6	S7	S8
-1.0	52.629	74.955	71.392	63.973	62.697	76.540	79.191	75.753
-0.5	51.370	53.551	59.832	54.377	59.037	56.730	64.648	68.123
0.0	50.490	51.923	58.530	52.962	58.059	55.159	63.435	67.225
0.5	49.968	50.915	57.764	52.130	57.473	54.240	62.715	66.699
1.0	49.601	50.187	57.227	51.548	57.059	53.599	62.208	66.332
3.0	48.751	48.439	55.994	50.210	56.095	52.127	61.032	65.497
5.0	48.286	47.444	55.326	49.486	55.566	51.331	60.387	65.048
10.0	47.627	46.017	54.400	48.487	54.820	50.230	59.479	64.421
20.0	47.012	44.639	53.553	47.572	54.130	49.218	58.634	63.856
40.0	46.473	43.397	52.830	46.784	53.538	48.343	57.897	63.388
100.0	45.844	41.977	52.033	45.917	52.869	47.376	57.059	62.862
150.0	45.537	41.363	51.670	45.553	52.542	46.960	56.668	62.564
200.0	45.570	41.211	51.691	45.514	52.606	46.907	56.690	62.720

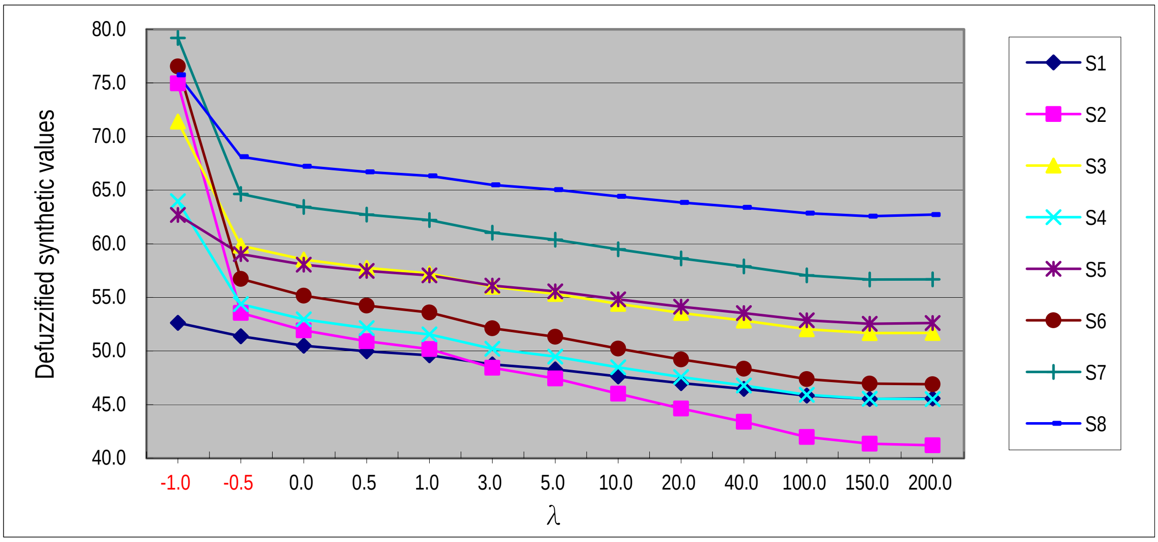


Figure 4.3 Defuzzified Synthetic Values with respect to λ Fuzzy Measure

4.6 Fuzzy C-Means for Solving Optimal Strategic Combination

As mentioned above, cluster analysis is a method for clustering a data set into groups of similar individuals. According to some empirical studies, it indicated that data reduction reduces the computational effort, makes it easier for the analyst to interpret the clustering results and is based on reliable and valid factors. The results also suggested that the solutions based on the factor scores correspond very well with the solutions based on the variable scores. As a result, the rest of this study presents the results based on the factor scores.

Eqs. (3.29) and (3.30) are the necessary conditions for satisfying the minimum object function (Eq. (3.28)). Solution is obtained by iteration through these conditions. An iterative algorithm, also called "alternating optimization", is used to solve these equations and to identify clusters and associated cluster memberships. It starts with an initial solution for U^0 and loops through a cycle of estimates for $U^{q-1} \rightarrow V^q \rightarrow U^q$. The iteration stops when the difference between U^q and U^{q-1} is very small.

For the application presented in this paper, the algorithm was initialized by generating a random matrix of cluster memberships (U^0), as suggested by the literature (Pal and Bezdek, 1995). Similar to many studies in the literature, the algorithm was run multiple times (10 times) with different random starting values. The runs generated similar results all within 150 iterations. There was no limit for the number of iterations. However, the algorithm stopped when the difference between U^q and U^{q-1} was very small, here we define this difference as epsilon (ε) and was set in the program at 10^{-6}.

In addition, the collected information was also subjected to fuzzy c-means clustering to see if there was any heterogeneity among the respondents with regard to their opinions of the service. The results based on different number of clusters all indicated heterogeneity among the respondents. As can be seen from Table 4.6.

A two-cluster solution $(c = 2)$, while $\lambda = -1$ situation, it indicates that all Factors (i.e. Factor 1, Factor 2, Factor 3 and Factor 4) in cluster II attached a greater value; both in $\lambda = 0$ and $\lambda = 5.0$ situations, it also indicates the same distribution as in $\lambda = 0$ situation.

A three-cluster solution $(c = 3)$, while $\lambda = -1$ situation, it indicates that Factor 1 and Factor 3 in cluster I attached a greater value, Factor 2 and Factor 4 in cluster III attached a greater value; while $\lambda = 0$ and $\lambda = 5.0$ situations, both them indicate that Factor 3 in cluster III attached a greater value and other Factors (i.e. Factor 1, Factor 2 and Factor 4) in cluster I attached a greater value.

Table 4.6 Cluster Center in Different Clustering Design

Cluster	$\lambda = -1.0$				$\lambda = 0$				$\lambda = 5.0$			
	F1	F2	F3	F4	F1	F2	F3	F4	F1	F2	F3	F4
C=2												
Cluster I	66.489	55.865	63.366	37.754	55.294	53.965	49.211	36.659	49.821	53.007	46.942	36.412
Cluster II	86.362	62.436	64.450	70.453	60.433	56.705	60.064	71.750	59.378	53.418	57.578	71.701
C=3												
Cluster I	95.419	50.353	67.206	65.520	64.414	65.708	57.400	79.211	64.956	60.517	55.624	78.874
Cluster II	62.801	55.537	63.908	34.343	55.185	54.270	48.474	35.712	49.616	53.776	46.570	35.288
Cluster III	78.633	72.632	60.943	74.360	58.268	49.092	61.320	66.539	54.151	47.592	58.491	66.290
C=4												
Cluster I	60.847	54.928	63.942	33.852	57.997	52.375	42.619	39.116	55.310	49.018	58.621	67.463
Cluster II	100.356	59.879	50.811	43.138	58.481	49.968	61.419	67.311	53.558	49.241	38.807	40.287
Cluster III	78.041	73.893	61.168	76.131	65.819	66.524	57.623	81.135	44.751	55.367	59.509	30.943
Cluster IV	94.549	49.563	70.051	69.475	50.362	56.542	62.375	30.794	65.580	62.494	55.744	81.431
C=5												
Cluster I	64.722	54.202	66.354	64.145	68.360	67.795	58.286	83.987	44.353	55.215	60.761	30.682
Cluster II	100.974	60.025	50.519	42.802	55.276	54.464	47.190	35.475	49.981	57.498	42.731	34.277
Cluster III	60.575	54.869	63.690	32.381	56.182	39.808	62.880	66.338	65.728	63.129	55.828	82.203
Cluster IV	79.301	75.816	61.342	78.453	55.887	64.019	52.176	69.763	55.212	45.406	37.081	43.178
Cluster V	96.618	47.328	69.902	68.923	59.418	53.158	60.220	65.196	55.714	49.654	58.519	67.621
C=6												
Cluster I	79.404	75.983	61.487	78.955	56.258	40.010	62.515	66.535	66.335	53.188	50.669	70.282
Cluster II	101.190	60.038	50.415	42.876	61.692	55.733	67.901	72.541	44.634	55.468	59.608	30.585
Cluster III	64.798	54.194	66.356	64.654	55.914	63.756	52.029	69.904	66.133	65.002	56.071	84.214
Cluster IV	55.364	48.969	57.183	34.001	50.292	56.566	62.469	30.434	55.797	52.782	57.568	66.133
Cluster V	96.858	46.697	69.804	68.769	57.944	52.417	42.515	38.714	49.302	38.034	61.331	66.790
Cluster VI	66.970	62.094	71.648	30.436	68.559	68.115	57.997	84.404	53.826	48.564	38.213	40.429
C=7												
Cluster I	79.349	76.843	61.805	80.522	54.542	56.198	44.158	33.994	49.935	57.626	42.592	33.987
Cluster II	64.496	54.195	66.276	64.563	60.845	49.274	41.110	42.738	55.755	52.445	55.515	64.972
Cluster III	66.928	62.105	71.645	30.374	62.606	57.245	67.742	74.444	44.278	55.334	60.767	30.360
Cluster IV	98.230	41.603	68.956	66.749	56.121	39.200	62.822	66.862	58.035	56.204	65.039	74.375
Cluster V	93.584	58.382	71.582	73.303	59.283	52.922	58.589	64.974	49.233	37.785	61.257	66.837
Cluster VI	101.219	60.062	50.303	42.724	57.100	64.869	52.321	71.820	66.657	54.694	50.919	72.151
Cluster VII	55.328	48.964	57.168	33.967	50.225	56.602	62.738	30.370	55.200	45.436	36.691	42.717

A four-cluster solution $(c=4)$, while $\lambda=-1$ situation, it indicates that Factor 1 in cluster II attached a greater value, Factor 2 and Factor 4 in cluster III attached a greater value, Factor 3 in cluster IV attached a greater value; while $\lambda=0$ situation, it indicates that Factor 1, Factor 2 and Factor 4 in cluster III attached a greater value, Factor 3 in cluster IV attached a greater value; while $\lambda=5.0$ situation, it indicates that Factor 1, Factor 2 and Factor 4 in cluster IV attached a greater value, Factor 3 in cluster III attached a greater value.

A five-cluster solution $(c=5)$, while $\lambda=-1$ situation, it indicates that Factor 1 and Factor 2 in cluster II attached a greater value, Factor 3 in cluster I attached a greater value, Factor 4 in cluster IV attached a greater value; while $\lambda=0$ situation, it indicates that Factor 1, Factor 2 and Factor 4 in cluster I attached a greater value, Factor 3 in cluster III attached a greater value; while $\lambda=5.0$ situation, it indicates that Factor 1, Factor 2 and Factor 4 in cluster III attached a greater value, Factor 3 in cluster I attached a greater value.

A six-cluster solution $(c=6)$, while $\lambda=-1$ situation, it indicates that Factor 1 in cluster II attached a greater value, Factor 2 and Factor 4 in cluster I attached a greater value, Factor 3 in cluster VI attached a greater value; while $\lambda=0$ situation, it indicates that Factor 1, Factor 2 and Factor 4 in cluster IV attached a greater value, Factor 3 in cluster II attached a greater value; while $\lambda=5.0$ situation, it indicates that Factor 1 in cluster I attached a greater value, Factor 2 and Factor 4 in cluster III attached a greater value, Factor 3 in cluster V attached a greater value.

A seven-cluster solution $(c=7)$, while $\lambda=-1$ situation, it indicates that Factor 1 in cluster IV attached a greater value, Factor 2 in cluster I attached a greater value, Factor 3 in cluster III attached a greater value, and Factor 4 in cluster V attached a greater value; while $\lambda=0$ situation, it indicates that Factor 1, Factor 3 and Factor 4 in cluster III attached a greater value, Factor 2 in cluster VI attached a greater value; while $\lambda=5.0$ situation, it indicates that Factor 1, Factor 3 and Factor 4 in cluster IV attached a greater value, Factor 2 in cluster I attached a greater value.

Table 4.7 – Table 4.9 represent the grade of membership in different clustering design, the next step is to employ cluster validity indice for determining the best number of clusters which has described in Section 3.6. Here we select three indice, partition coefficient (v_{PC}), partition entropy (v_{PE}) and Xie–Beni index (v_{XB}). Both v_{PC} and v_{PE} measure the amount of fuzzyness in clustering and when v_{PC} takes its maximum v_{PE} takes its minimum (Pal and Bezdek, 1995). Past research has demonstrated that v_{PC} and v_{PE} can show monotonic

tendencies with the changes in the number of clusters.

Table 4.7 Grade of Membership in Different Clustering Design $(\lambda = -1.0)$

Cluster	Strategy S1	S2	S3	S4	S5	S6	S7	S8
C=2								
Cluster 1	0.9181	0.4579	0.1262	0.9260	0.4504	0.2272	0.0611	0.1470
Cluster 2	0.0819	0.5421	0.8738	0.0740	0.5496	0.7728	0.9389	0.8530
C=3								
Cluster 1	0.0485	0.4860	0.0248	0.0550	0.2850	0.9112	0.7590	0.0886
Cluster 2	0.9038	0.2595	0.0122	0.8922	0.3051	0.0327	0.0433	0.0373
Cluster 3	0.0477	0.2544	0.9630	0.0528	0.4099	0.0561	0.1977	0.8741
C=4								
Cluster 1	0.8884	0.0007	0.0197	0.8177	0.2684	0.0280	0.0272	0.0246
Cluster 2	0.0439	0.9975	0.0266	0.0760	0.1262	0.0614	0.0528	0.0326
Cluster 3	0.0340	0.0007	0.9132	0.0530	0.3415	0.0469	0.1197	0.8780
Cluster 4	0.0336	0.0011	0.0406	0.0533	0.2639	0.8637	0.8003	0.0649
C=5								
Cluster 1	0.0800	0.0001	0.1029	0.0964	0.9987	0.0293	0.0990	0.0344
Cluster 2	0.0382	0.9996	0.0430	0.0676	0.0002	0.0302	0.0672	0.0159
Cluster 3	0.8260	0.0001	0.0310	0.7466	0.0004	0.0136	0.0338	0.0117
Cluster 4	0.0270	0.0001	0.7661	0.0432	0.0004	0.0220	0.1470	0.9103
Cluster 5	0.0288	0.0001	0.0571	0.0461	0.0003	0.9049	0.6530	0.0278
C=6								
Cluster 1	0.0000	0.0000	0.7226	0.0000	0.0004	0.0176	0.1511	0.9146
Cluster 2	0.0000	0.9998	0.0454	0.0000	0.0002	0.0243	0.0695	0.0134
Cluster 3	0.0000	0.0000	0.1105	0.0000	0.9985	0.0238	0.1041	0.0297
Cluster 4	1.0000	0.0000	0.0286	0.0000	0.0003	0.0099	0.0302	0.0089
Cluster 5	0.0000	0.0001	0.0585	0.0000	0.0003	0.9132	0.6063	0.0228
Cluster 6	0.0000	0.0000	0.0344	0.9999	0.0003	0.0113	0.0389	0.0105
C=7								
Cluster 1	0.0000	0.0000	0.5837	0.0000	0.0001	0.0000	0.0002	0.9339
Cluster 2	0.0000	0.0000	0.1227	0.0000	0.9993	0.0000	0.0002	0.0154
Cluster 3	0.0000	0.0000	0.0386	1.0000	0.0001	0.0000	0.0001	0.0055
Cluster 4	0.0000	0.0000	0.0510	0.0000	0.0001	0.9999	0.0004	0.0093
Cluster 5	0.0000	0.0000	0.1213	0.0000	0.0002	0.0000	0.9990	0.0242
Cluster 6	0.0000	1.0000	0.0506	0.0000	0.0001	0.0000	0.0001	0.0070
Cluster 7	1.0000	0.0000	0.0321	0.0000	0.0001	0.0000	0.0000	0.0047

Table 4.8 Grade of Membership in Different Clustering Design ($\lambda = 0$)

Cluster	Strategy S1	S2	S3	S4	S5	S6	S7	S8
C=2								
Cluster 1	0.9780	0.8906	0.1109	0.8771	0.0782	0.2176	0.0440	0.1176
Cluster 2	0.0220	0.1094	0.8891	0.1229	0.9218	0.7824	0.9560	0.8824
C=3								
Cluster 1	0.0105	0.0680	0.5931	0.0759	0.0528	0.0947	0.3638	0.9231
Cluster 2	0.9717	0.8019	0.0860	0.7810	0.0235	0.0654	0.0512	0.0170
Cluster 3	0.0178	0.1301	0.3210	0.1430	0.9237	0.8398	0.5851	0.0599
C=4								
Cluster 1	0.8236	0.9167	0.0994	0.0007	0.0234	0.0735	0.0465	0.0080
Cluster 2	0.0313	0.0292	0.3714	0.0003	0.9193	0.7738	0.6269	0.0286
Cluster 3	0.0174	0.0144	0.4614	0.0001	0.0404	0.0916	0.2824	0.9571
Cluster 4	0.1277	0.0397	0.0678	0.9989	0.0170	0.0611	0.0442	0.0063
C=5								
Cluster 1	0.0048	0.0411	0.0020	0.0533	0.0050	0.0006	0.1694	0.9971
Cluster 2	0.9644	0.6722	0.0006	0.5986	0.0036	0.0006	0.0351	0.0002
Cluster 3	0.0088	0.0862	0.0011	0.1107	0.0183	0.9939	0.1793	0.0004
Cluster 4	0.0104	0.0898	0.9930	0.1019	0.0166	0.0011	0.1752	0.0014
Cluster 5	0.0116	0.1108	0.0033	0.1355	0.9564	0.0038	0.4411	0.0009
C=6								
Cluster 1	0.0247	0.0276	0.0012	0.0001	0.2802	0.9925	0.0043	0.0000
Cluster 2	0.0195	0.0190	0.0022	0.0001	0.3054	0.0033	0.9862	0.0001
Cluster 3	0.0291	0.0286	0.9934	0.0001	0.2472	0.0017	0.0041	0.0001
Cluster 4	0.1124	0.0407	0.0005	0.9996	0.0407	0.0007	0.0008	0.0000
Cluster 5	0.8008	0.8713	0.0007	0.0002	0.0558	0.0009	0.0008	0.0000
Cluster 6	0.0134	0.0128	0.0020	0.0000	0.0705	0.0009	0.0038	0.9999
C=7								
Cluster 1	0.9999	0.0001	0.0032	0.0000	0.0004	0.0000	0.0018	0.0360
Cluster 2	0.0000	0.9999	0.0041	0.0000	0.0006	0.0001	0.0023	0.0454
Cluster 3	0.0000	0.0000	0.0123	0.0000	0.0021	0.0001	0.9519	0.3152
Cluster 4	0.0000	0.0000	0.0060	0.0000	0.0022	0.9993	0.0102	0.0834
Cluster 5	0.0000	0.0000	0.0208	0.0000	0.9925	0.0003	0.0211	0.1581
Cluster 6	0.0000	0.0000	0.9511	0.0000	0.0018	0.0001	0.0107	0.3296
Cluster 7	0.0000	0.0000	0.0026	1.0000	0.0004	0.0000	0.0020	0.0324

Table 4.9 **Grade of Membership in Different Clustering Design** ($\lambda = 5.0$)

Cluster	Strategy S1	S2	S3	S4	S5	S6	S7	S8
C=2								
Cluster 1	0.9743	0.8550	0.0711	0.8807	0.0760	0.2237	0.0437	0.1122
Cluster 2	0.0257	0.1450	0.9289	0.1193	0.9240	0.7763	0.9563	0.8878
C=3								
Cluster 1	0.0130	0.0927	0.5898	0.0715	0.0830	0.1130	0.4139	0.9178
Cluster 2	0.9648	0.7297	0.0621	0.7890	0.0315	0.0735	0.0496	0.0177
Cluster 3	0.0222	0.1776	0.3481	0.1394	0.8855	0.8136	0.5365	0.0645
C=4								
Cluster 1	0.0594	0.0232	0.4512	0.0014	0.8997	0.7184	0.6310	0.0250
Cluster 2	0.6386	0.9357	0.0837	0.0032	0.0291	0.0927	0.0441	0.0064
Cluster 3	0.2694	0.0297	0.0480	0.9947	0.0201	0.0779	0.0416	0.0050
Cluster 4	0.0327	0.0114	0.4171	0.0007	0.0512	0.1110	0.2833	0.9637
C=5								
Cluster 1	0.0004	0.0005	0.0441	0.9993	0.0172	0.0775	0.0387	0.0028
Cluster 2	0.9988	0.0016	0.0583	0.0004	0.0198	0.0705	0.0366	0.0033
Cluster 3	0.0001	0.0002	0.3501	0.0000	0.0416	0.1059	0.2460	0.9746
Cluster 4	0.0006	0.9973	0.0877	0.0002	0.0268	0.1021	0.0421	0.0039
Cluster 5	0.0001	0.0004	0.4598	0.0001	0.8946	0.6441	0.6365	0.0154
C=6								
Cluster 1	0.0517	0.0155	0.9959	0.0007	0.0390	0.0003	0.1816	0.0007
Cluster 2	0.2597	0.0201	0.0002	0.9947	0.0053	0.0001	0.0298	0.0001
Cluster 3	0.0286	0.0068	0.0010	0.0005	0.0103	0.0001	0.1542	0.9986
Cluster 4	0.0657	0.0170	0.0020	0.0011	0.9127	0.0007	0.4607	0.0004
Cluster 5	0.0477	0.0139	0.0006	0.0010	0.0249	0.9986	0.1422	0.0002
Cluster 6	0.5466	0.9267	0.0003	0.0021	0.0077	0.0001	0.0316	0.0001
C=7								
Cluster 1	1.0000	0.0000	0.0036	0.0000	0.0004	0.0000	0.0016	0.0339
Cluster 2	0.0000	0.0000	0.0341	0.0000	0.9932	0.0001	0.0179	0.1574
Cluster 3	0.0000	0.0000	0.0027	1.0000	0.0003	0.0000	0.0017	0.0293
Cluster 4	0.0000	0.0000	0.0187	0.0000	0.0020	0.0001	0.9586	0.3063
Cluster 5	0.0000	0.0000	0.0089	0.0000	0.0015	0.9996	0.0078	0.0746
Cluster 6	0.0000	0.0000	0.9266	0.0000	0.0020	0.0001	0.0107	0.3591
Cluster 7	0.0000	0.9999	0.0053	0.0000	0.0005	0.0000	0.0018	0.0394

On the other hand, as Table 4.10 shows, v_{PC} and v_{PE} are based on the cluster memberships $(\mu_{ik}\text{'s})$ alone, v_{XB} separation among the cluster means $(V_i\text{'s})$ in addition to the cluster memberships. This additional information is supposed to enhance the quality of cluster validity indices.

Table 4.10 Definition of Widely Used Cluster-Validity Indices

Validity Indices	Definition
Partition Coefficient (v_{PC})	$v_{PC} = \left(\sum_{k}^{n} \sum_{i=1}^{c} (\mu_{ik})^2 \right) \Big/ n$
Partition Entropy (v_{PE})	$v_{PE} = -\frac{1}{n} \left(\sum_{k=1}^{n} \sum_{i=1}^{c} \left(\mu_{ik} \cdot \log_a (\mu_{ik}) \right) \right);\ a = (1, \infty)$
Xie-Beni index (v_{XB})	$v_{XB} = \left(\sum_{i=1}^{c} \sum_{k=1}^{n} (\mu_{ik})^2 \left(\lVert x_k - v_i \rVert^2 \right) \right) \Big/ \left(n \cdot \min_{i \neq j} \left(\lVert v_i - v_j \rVert^2 \right) \right)$
Bayes error (B_f)	$B_f = E\left[1 - \max \left\{ \mu_{ik} \middle| 1 \le k \le c \right\} \right]$

Empirical studies suggest that a suitable number of clusters is the one that maximizes v_{PC}, and minimizes v_{PE} and v_{XB}. As summarized in Table 4.11.

In addition, we also summarize the two other classification validity indices, v_{DA} and B_f, to explore the best number of cluster in Table 4.11. Here v_{DA} is express the proportion value of correctly classified defined by traditional Discriminant Analysis, The higher the value of v_{DA} the better the fuzzy partition; B_f represent the expected Bayes error to determine the best fuzzy partition executing the fuzzy c-means algorithm with different group numbers The lower the value of B_f the better the fuzzy partition.

In concludingly, from Table 4.11, if we only take v_{PC} and v_{PE} as validity indice, the best number of clusters is *seven* while in all situations, however, both v_{PC} and v_{PE} only measure the amount of fuzzyness in clustering. On the other hand, if we further takes into account the amount of separation among the cluster means V_i in addition to the cluster memberships, that is, we consider v_{XB} in validating process, the best number of clusters may change while $\lambda = 0$ or $\lambda = 5$. Furthermore, as a result of the crisp data is required in employing Fuzzy C-Means algorithms, we further introduce two other for we classification validity indices, v_{DA} and B_f, we conclude that the best number of cluster is *five or six* in sub-additive effect situation e.g. $\lambda = -1.0$; the best number of cluster is *four* in additive effect situation e.g. $\lambda = 0$; and the best number of cluster is *five* in super-additive effect situation e.g. $\lambda = 5.0$.

Table 4.11 Cluster Validity Indices w.r.t. Different Number of Cluster

	Validity Indice	Cluster 2	3	4	5	6	7
	v_{PC}	0.7230	0.6859	0.7209	0.7479	0.8276	0.9060
	v_{PE}	0.4359	0.5744	0.5756	0.5493	0.3886	0.2166
$\lambda = -1.0$	v_{XB}	0.2117	0.1855	0.0965	0.0621	0.0559	0.0343
	v_{DA} *	0.8750	0.8750	0.6250	0.8750	**1.0000**	
	B_f +	0.0611	0.0370	0.0025	**0.0004**	0.0000	0.0000
	v_{PC}	0.8216	0.7020	0.7200	0.7481	0.8256	0.8800
	v_{PE}	0.3141	0.5419	0.5511	0.5278	0.3851	0.2742
$\lambda = 0$	v_{XB}	0.1164	0.1840	0.0982	0.2339	0.0476	0.0854
	v_{DA} *	1.0000	1.0000	**1.0000**	0.7500	-	
	B_f +	0.0220	0.0283	**0.0011**	0.0029	0.0001	0.0000
	v_{PC}	0.8236	0.6756	0.6883	0.7511	0.7923	0.8777
	v_{PE}	0.3108	0.5799	0.5967	0.5069	0.4493	0.2765
$\lambda = 5.0$	v_{XB}	0.1197	0.2301	0.1233	0.1507	0.2991	0.1999
	v_{DA} *	1.0000	0.7500	0.6250	**1.0000**		
	B_f +	0.0257	0.0352	0.0053	**0.0007**	0.0014	0.0000

* value of original grouped cases correctly classified by Discriminant Analysis.
\+ validity value of Bayes error by Fuzzy C-Means Clustering

4.7 Discussions and Summary

In this Section, we divide two parts for achieveing the purposes of this research through empirical study. The first one is to propose non-additive fuzzy integral with multiple criteria decision analysis for evaluation topics. Here we firstly establish hierarchy system for evaluating the sustainable strategies of green engineering for fishing industry. These proposed strategies surely apply the concepts of sustainable development and green engineering on life cycle of products and services. In order to appropriately interpret the perceptions judgment of participating experts on evaluated targets, criteria weights and performance scores of strategies, we introduce triangular fuzzy number to express the fuzzy linguistic variables in data investigation.

Considering the independence relationship are not necessary conditions among the evaluated criteria. That is, the traditional independence assumption of AHP is not meeting the nature of real problems. In general cases, the evaluated criteria doesn't have mutually independent property. We try to release this assumption and assume that there exist sub-additive effects or super-additive effects among these criteria. We present λ fuzzy measure to express these substitutive effects.

After deriving the criteria weights by fuzzy AHP technique, we then introduce fuzzy multi-criteria decision analysis approach to integrate the criteria weights and performance scores corresponding to criteria with fuzzy computation. In this stage, fuzzy measure can express the relative importance of criteria, fuzzy integral can derive the synthetic value of each aspect in strategy within different substitutive situations, i.e. sub-additive effect, additive (or independent) effect, and super-additive effect. Finally, we utilize simple additive weighting method to aggregate the final synthetic value of strategy, respectively. Furthermore, for determining the preferred order of our proposed strategies with respect to evaluated criteria, centroid defuzzified method was employed to compute the crisp data representing the final synthetic values.

Through this empirical case, we found that there have different ranking order among proposed strategies while different substitutive effects. For instance, in case of $\lambda = -1.0$, we have the preferred order as: $S7 \succ S6 \succ S8 \succ S2 \succ S3 \succ S4 \succ S5 \succ S1$, this is one of sub-additive situations; in case of $\lambda = 0$ (additive situation), we have the preferred order as: $S8 \succ S7 \succ S3 \succ S5 \succ S6 \succ S4 \succ S2 \succ S1$; in case of $\lambda = 5.0$, we have the preferred order as: $S8 \succ S7 \succ S5 \succ S3 \succ S6 \succ S4 \succ S1 \succ S2$, this is one of super-additive situations.

We have successfully demonstrate the non-additive fuzzy integral can appropriate for general evaluation problems. If we employ traditional AHP to determine the criteria weights, and utilize simple additive weighting method to conduct the aggregating values, it would overestimate the synthetic values if there exist sub-additive effects among those criteria, or underestimate the synthetic values if there exist super-additive effects among those criteria.

The second part of research purpose is to propose fuzzy classification for finding the optimal strategy combination. Here we introduce fuccy c-means clustering to explore the strategy combination within different number of cluster. In order to verify the best number of cluster, three widely used validation function were exploited in this segment.

Finally, we can conclude the best number of cluster is *five or six* in sub-additive effect situation e.g. $\lambda = -1.0$, the corresponding strategy combination has shown in Table 4.7; the best number of cluster is *four* in additive effect situation e.g. $\lambda = 0$, the corresponding strategy combination has shown in Table 4.8; and the best number of cluster is *five* in super-additive effect situation e.g. $\lambda = 5.0$, the corresponding strategy combination has shown in Table 4.9.

In summary, for solving the non-independence situations among evaluated criteria, fuzzy integral is a good choice to conduct the synthetic values conforming with the nature of problems; for solving the strategy combination especially in optimal resource allocation policy, fuzzy c-means clustering is a good alternative to support this decision making process.

5. CONCLUSIONS AND RECOMMENDATIONS

After we had devoted so much efforts to the case application of fuzzy multi-criteria decision analysis and fuzzy classification, we now summarize our research findings and concluding remarks and further present recommendations in this Chapter.

5.1 Research Findings and Concluding Remarks

First of all, we had successfully demonstrate the non-additive fuzzy multi-criteria decision analysis for industrial application. We had enriched the concept and methodology of fuzzy multi-criteria decision making through comprehensive survey during this period. We summarize some research findings and concluding remarks as below:

(a) Sustainable development is about ensuring a better quality of life for everyone, now and for generations to come. For freedom of choice effectively to enhance quality of life while protecting the environment and promoting social equity, consumers need information and price signals to make intelligent decisions. Experience shows that consumers may not necessarily choose the ''greenest'' or most socially beneficial option – despite what they indicate on surveys. Consumers want performance, value, safety, and reliability, ahead of environment, social concerns, and aesthetics. The solution is to create the right valueycost ratio, including all information consumers consider relevant to their purchases. Providing all of this information – at the right level of detail – is a challenge, though the Internet and other new communications technologies offer possible ways forward.

(b) There is a growing view in the sustainable development as well as sustainable product development fields that building in sustainability at a strategic level within industry will result in greater improvements in sustainability performance. The requirement to produce sustainable products and/or services as relevant is integrated as one element of the existing corporate strategy. From here it is a core business criterion that can be incorporated into all other business functions for overall sustainability performance improvement.

(c) Sustainable product and service developing should be incorporated within the product development approaches used by the company. Other functions that traditionally feed into product development, e.g. quality, finance, purchasing, etc. will then be incorporated more easily with the sustainability criteria. The optimisation of social, ethical and economic issues is not included in eco-design in its present form. Some empirical study indicate that if sustainability is the aim, just reducing the environmental impact of a product using an eco-design approach is not enough.

(d) The green engineering industry provides environmental planning and decision-making problems that are essentially conflict analyses characterized by sociopolitical, environmental, and economic value judgments. Several strategies have to be considered and evaluated in terms of many different criteria, resulting in a vast body of data that are often inaccurate or uncertain. In this study we introduce fuzzy numbers to express linguistic variables that consider the possible fuzzy subjective judgment of the evaluators. Furthermore, the fuzzy geometric mean technique is an effective method to obtain the fuzzy weights of each criterion.

(e) Through this study we successfully demonstrate the non-additive fuzzy integral technique to deal with the decision-making problem especially the criteria are non-independent situations. Actually, in real MCDM problems, where the criteria are not necessarily mutually independent, if we employ the simple additive aggregate method to derive the final synthetic value, it will overestimate when the criteria have substitutive property, or underestimate when the criteria have multiplicative property.

(f) Fuzzy classification algorithm generated cluster descriptions and the degrees of membership for belonging to the different clusters. Cluster descriptions were in the forms of cluster means for the factors used in the analyses. This paper showed that widely used fuzzy c-means clustering can be used to categorize the development strategy of green engineering industry, this can offer useful information for business. For instance, the manager can maximize the allocation of resources through the optimal strategy combination.

5.2 Recommondations

In this study we applied fuzzy integral to derive the synthetic values of corsidered strategies, this approach mainly relax the independence assumption among criteria. In traditional multi-criteria decision analysis methods set this to be required assumption. However, this assumption doesn't exist in most of real MCDM problems, fuzzy integral and ANP may be more appropriate for conforming the nature of problems.

On the other hand, non-additive or so-called multiplicative evaluating process is more complicate than additive evaluating process. The hierarchy system in real life often more complex and large scale than the case of this study, the first critical task is how to well define considerable indice or criteria, the second important task is how to process the data, may includes quantitative or qualitative or mixed variables. For quantitative data, fuzzy integral is easy to handle, but not suitable for qualitative.

This study can be regarded as a creative approach, it didn't include the whole aspects as mentioned in Section 2.3 to evaluating system. Following the speedy progress in information technology, many heuristic algorithms had been developed for evaluation and/or classification, this will greatly contribute to the accomplishment of our work.

Appendix A. Some Critical International Conventions for Sustainable Development

1. *Basel Convention* -- Including 52 nations, the majority of The Organization of Economic Corporation and Development (OECD) nations, signed in 1989 and taking effect in 1992, to prohibit OECD nations from exporting waste for final disposal or recycling treatment by non-OECD nations.
2. *Rio Declaration* -- The majority of nations who participate in the United Nations Conference on Environment and Development (UNCED) signed in 1992. This declaration clearly expressed the principle of rights and responsibilities for environmental issues.
3. *The Framework Convention on Climate Change* -- The majority of nations who participate the UNCED signed in 1992. This convention includes 5 principles and 10 commitments for waste emission standards that would contribute to the greenhouse effect, such as carbon dioxide CO_2, methane CH_4, chlorofluorocarbons CFC_5, nitrous oxide N_2O, etc.
4. *Convention of Biological Diversity* -- The majority of nations who participate the UNCED signed in 1992 to ensure the sustainable growth of the ecosystem.
5. *Agenda 21* -- The majority of nations who participate the UNCED signed in 1992 to establish the global consensus overcoming the environmental impacts and reaching the overall sustainable development.

Appendix B. Two Numerical Examples of Fuzzy Integral Technique

In this study we utilize non-additive fuzzy integrals to aggregate fuzzy performance scores with weights. How to conduct the final synthetic values is our concerning . Here we summarize the procedure as follows and we give two examples to compare the results with traditional independent assumption among considered criteria..

1. Setting up the hierarchical system including goals, sub-objectives, criteria, alternatives/ strategies.
2. Generating the relative important score of considered criteria and performance score (called h_{ij} with the i-th strategy corresponding to the j-th criterion in this article) of alternatives by subjective judgment of evaluators. Utilizing statistical factor analysis to extract independent common factors from criteria scores, this will help the analyst to verify independent or non-independent relationship among criteria.
3. Establishing pairwise comparison matrix among criteria and then aggregate the relative weights (called w_j for the j-th criterion in this article) using geometric mean or other appropriate method.
4. Using fuzzy integral technique to aggregate performance score with weights in common factors, the evaluation value called u_i corresponding to the i-th strategy in this article. Then employing weighted mean method to gain the final synthetic utilities of each alternative. There exist independent relationships among common factors.
5. Ranking the alternatives based on their final synthetic utilities will provide useful information to decision-maker.

Example 1.

Considering the case of an employer who would like to recruit new staff for the company, the recruiting committee set three criteria, skill (C_1), professional knowledge (C_2) and experience (C_3). Three persons, A, B and C, are interviewed, and the scores from interviewers are summed up as shown in the following table.

Recruiter	Skill (C_1)	Knowledge (C_2)	Experience (C_3)
A	90	80	50
B	50	60	90
C	70	75	70

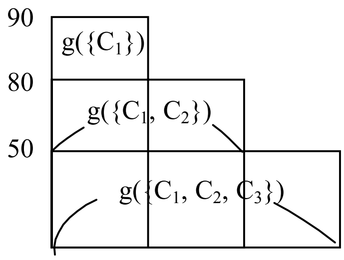
In addition, the committee sets the weights as follows.

$$\mu(\{C_1\})=\mu(\{C_2\})=0.45;\ \mu(\{C_3\})=0.3;\ \mu(\{C_1,C_2\})=0.5;\ \mu(\{C_2,C_3\})=\mu(\{C_1,C_3\})=0.9$$

Applying the fuzzy integral with above fuzzy measure and traditional simple additive weighted (SAW) method leads to following evaluation:

Recruiter	Global evaluation (fuzzy integral)	Global evaluation (SAW method)
A	69.50[a]	76.25[b]
B	68.00	63.75
C	72.25	71.875

(a) Non-independent case among criteria:



(1) Fuzzy measure: g({C_1})=0.45; g({C_1, C_2})=0.50; g({C_1, C_2, C_3})=1.0

(2) Synthetic value = (90-80)*0.45+(80-50)*0.5+50*1.0 = 69.50

where $g(\cdot)$ presents fuzzy measure of criteria, and C_1, C_2, and C_3 are defined as above.

(b) Independent case among criteria:

1. Find the criteria weights through normalization:
   g({C_1})=g({C_2})=0.375; g({C_3})=0.25
2. Synthetic value = 90*0.375+80*0.375+50*0.25 = 76.25

Through the above results, we can see the difference between independent and non-independent cases based on ranking by global evaluation. If the considered criteria have non-independent relationships (either substitutive or multiplicative), fuzzy integrals might be an appropriate method for evaluation.

Example 2.

Considering one decision-making case including three independent criteria C_1, C_2, C_3, and four alternatives A_1, A_2, A_3, A_4, in addition to define h_{ij} represents the performance score with i-th alternative corresponding to j-th criteria, which performance score higher is better, and w_j represents the weight with respective to j-th criteria. If we have ordinary performance matrix H=[h_{ij}], and have driven the ordinary weights $w=\left[w_j\right]^T$ as follows,

$$\mathrm{H} = \begin{bmatrix} 5 & 1 & 9 \\ 7 & 3 & 5 \\ 3 & 7 & 1 \\ 5 & 7 & 9 \end{bmatrix} \qquad w = \begin{bmatrix} \frac{1}{3} & \frac{1}{5} & \frac{7}{15} \end{bmatrix}^T$$

Moreover, we define $u_i = \sum_j h_{ij} \cdot w_j$ as representing the final utility corresponding to i-th alternative. Then we conduct the final utilities as $u = \begin{bmatrix} 6.067 & 5.267 & 2.867 & 7.267 \end{bmatrix}^T$. Finally, the ranking of alternatives based on final utilities as $A_4 \succ A_1 \succ A_2 \succ A_3$, where $A \succ B$ means A is preferential to B.

On the other hand, if we define triangular fuzzy number as Section 3.3. That is,

$\tilde{1} = (1,1,3);\ \tilde{3} = (1,3,5);\ \tilde{5} = (3,5,7);\ \tilde{7} = (5,7,9);\ \tilde{9} = (7,9,9)$

then we can transfer the ordinary performance score matrix and ordinary weighting to fuzzy performance matrix $\tilde{\mathrm{H}} = \left[\tilde{h}_{ij} \right]$ and fuzzy weights $\tilde{w} = \left[\tilde{w}_j \right]^T$ as in the following matrix:

$$\tilde{\mathrm{H}} = \begin{bmatrix} 3 & 5 & 7 & 1 & 1 & 3 & 7 & 9 & 9 \\ 5 & 7 & 9 & 1 & 3 & 5 & 3 & 5 & 7 \\ 1 & 3 & 5 & 5 & 7 & 9 & 1 & 1 & 3 \\ 3 & 5 & 7 & 5 & 7 & 9 & 7 & 9 & 9 \end{bmatrix} \quad \tilde{w} = \begin{bmatrix} \frac{3}{15} & \frac{5}{15} & \frac{7}{15} & \frac{1}{15} & \frac{3}{15} & \frac{5}{15} & \frac{5}{15} & \frac{7}{15} & \frac{9}{15} \end{bmatrix}^T$$

where we define the fuzzy final utility as $\tilde{u}_i = \left(\tilde{h}_{i1} \otimes \tilde{w}_1 \oplus \tilde{h}_{i2} \otimes \tilde{w}_2 \oplus \tilde{h}_{i3} \otimes \tilde{w}_3 \right)$, where $\oplus$ and $\otimes$ are addition and multiplication operators in fuzzy number arithmetic. Then we can intuitively compute the fuzzy final utility $\tilde{u} = \left[\tilde{u}_i \right]$ as follows.

$$\tilde{u} = \begin{pmatrix} 3.000 & 6.067 & 9.667 \\ 2.067 & 5.267 & 10.07 \\ 0.867 & 2.867 & 7.133 \\ 3.267 & 7.267 & 11.67 \end{pmatrix}$$

Furthermore, utilizing the center of area method to conduct the best nonfuzzy performance value of final utility as $\mathrm{u} = \begin{pmatrix} 6.244 & 5.800 & 3.622 & 7.400 \end{pmatrix}^T$, the ranking of alternatives based on final utilities as $A_4 \succ A_1 \succ A_2 \succ A_3$, we have the same ranking result as in the case of crisp ordinary weights. It is important that fuzzy measure and fuzzy synthetic appraisal might be appropriately used to evaluate the subjective semantic judgments or qualitative methods used in evaluating process for social science research such as in public policy, mass transit system, environmental issues.

Appendix C. Generalized Fuzzy Measures in Evidence Theory

According to Shafer (1976), the mathematical theory of evidence is based on the complementary *belief* and *plausibility measures*. This was motivated by previous work on upper and lower probabilities by Dempster (1967).

1. Given a universal set X, assumed here to be finite, a *belief measure* is a function $\mathrm{Bel}: P(X) \to [0,1]$ such that $\mathrm{Bel}(\varnothing) = 0$, $\mathrm{Bel}(X) = 1$, and

$$\mathrm{Bel}(A_1 \cup \cdots \cup A_n) \geq \sum_j \mathrm{Bel}(A_j) - \sum_{j<k} \mathrm{Bel}(A_j \cap A_k) + \cdots + (-1)^{n+1} \mathrm{Bel}(A_1 \cap \cdots \cap A_n) \tag{C.1}$$

2. Given a universal set X, assumed here to be finite, a *plausibility measure* is a function $\mathrm{Pl}: P(X) \to [0,1]$ such that $\mathrm{Pl}(\varnothing) = 0$, $\mathrm{Pl}(X) = 1$, and

$$\mathrm{Pl}(A_1 \cap \cdots \cap A_n) \leq \sum_j \mathrm{Pl}(A_j) - \sum_{j<k} \mathrm{Pl}(A_j \cup A_k) + \cdots + (-1)^{n+1} \mathrm{Pl}(A_1 \cup \cdots \cup A_n) \tag{C.2}$$

3. Let $A_1 = A$ and $A_2 = \bar{A}$ for n=2, where $\bar{A}$ is the complementary set of *A*, then the following properties of *belief measure* and *plausibility measure* are satisfied.

$$\mathrm{Bel}(A) + \mathrm{Bel}(\bar{A}) \leq 1 \tag{C.3}$$

$$\mathrm{Pl}(A) + \mathrm{Pl}(\bar{A}) \geq 1 \tag{C.4}$$

$$\mathrm{Pl}(A) = 1 - \mathrm{Bel}(\bar{A}) \tag{C.5}$$

$$\mathrm{Bel}(A) = 1 - \mathrm{Pl}(\bar{A}) \tag{C.6}$$

4. Belief and plausibility measures can conveniently be characterized by a function $m: P(X) \to [0,1]$ such that $m(\varnothing) = 0$ and $\sum_{A \in P(X)} m(A) = 1$. This function is called a *basic probability assignment*.

5. Let a given finite body of evidence $\langle \Im, m \rangle$ be nested. Then the associated belief and plausibility measures have the following properties for all $A, B \in P(X)$:

$$\mathrm{Bel}(A \cap B) = \min[\mathrm{Bel}(A), \mathrm{Bel}(B)] \tag{C.7}$$

$$\mathrm{Pl}(A \cup B) = \max[\mathrm{Pl}(A), \mathrm{Pl}(B)] \tag{C.8}$$

6. Let *necessity* measures and *possibility measures* be denoted by the symbols $\mathrm{Nec}(\cdot)$ and $\mathrm{Pos}(\cdot)$, respectively. Those measures are a special branch of evidence theory that deals only with bodies of evidence whose focal elements are nested. Therefore, we have following basic equations of possibility theory, which hold for every $A, B \in P(X)$

$$\text{Nec}(A \cap B) = \min[\text{Nec}(A), \text{Nec}(B)] \quad \text{(C.9)}$$

$$\text{Pos}(A \cup B) = \max[\text{Pos}(A), \text{Pos}(B)] \quad \text{(C.10)}$$

7. Since necessity measures are special belief measures and possibility measures are special plausibility measures, hence the following properties hold:

$$\begin{cases} \text{Nec}(A) + \text{Nec}(\bar{A}) \le 1 \\ \text{Pos}(A) + \text{Pos}(\bar{A}) \ge 1 \\ \text{Nec}(A) = 1 - \text{Pos}(\bar{A}) \end{cases} \quad \text{(C.11)}$$

$$\begin{cases} \min[\text{Nec}(A), \text{Nec}(\bar{A})] = 0 \\ \max[\text{Pos}(A), \text{Pos}(\bar{A})] = 1 \end{cases} \quad \text{(C.12)}$$

$$\begin{cases} \text{Nec}(A) > 0 \Rightarrow \text{Pos}(A) = 1 \\ \text{Pos}(A) < 1 \Rightarrow \text{Nec}(A) = 0 \end{cases} \quad \text{(C.13)}$$

On the other hand, the concept of fuzzy measure was introduced by Sugeno (1974). Fuzzy measures are used to assign a value to each crisp subset of the universal set to represent the degree of evidence that a particular element belongs to the set. The fuzzy measure *g* must satisfy three axioms as above Definition 3.1.1 of Section 3.4, that is boundry conditions, monotonicity and continuity.

If a fuzzy measure $g(\cdot)$ satisfies the additive condition $g(A \cup B) = g(A) \cup g(B)$, for $A \cap B = \varnothing$, then $g(\cdot)$ is a *probability measure*. It can be seen that the probability measure is one of fuzzy measures with additivity.

It follows from the above monotonicity that

$$\begin{cases} g(A \cup B) \ge \max\{g(A), g(B)\} \\ g(A \cap B) \le \min\{g(A), g(B)\} \end{cases} \quad \text{(C.14)}$$

In the strict cases, we have

$$\begin{cases} g(A \cup B) = \max\{g(A), g(B)\} \\ g(A \cap B) = \min\{g(A), g(B)\} \end{cases} \quad \text{(C.15)}$$

the former is called the *possibility measures* $\text{Pos}(\cdot)$, and the later is called the *necessity measure* $\text{Nec}(\cdot)$, those have same meaning and properties as above evidence theory.

Furthermore, the relationship among the six types of measures employed can be depicted in Figure C-1.

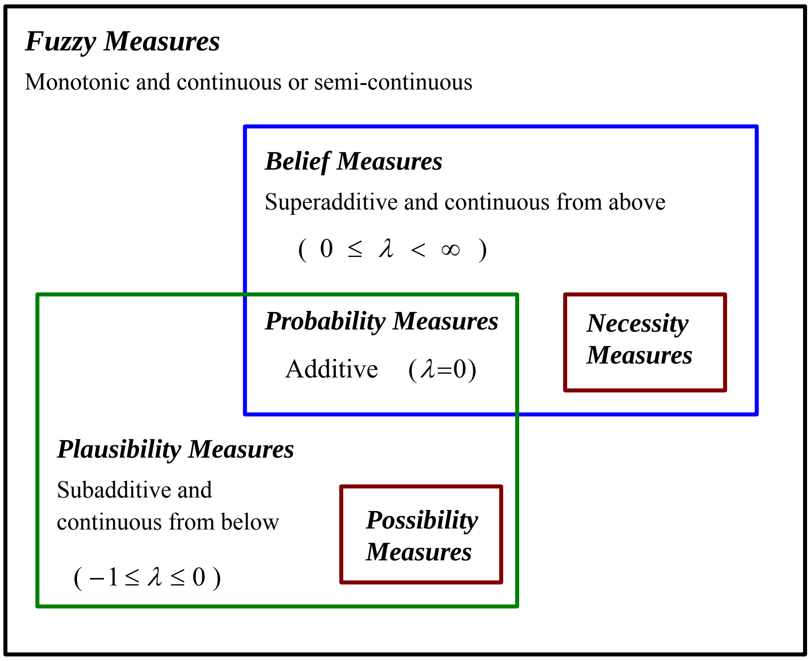


Figure C-1. Generalized Fuzzy Measures in Evidence Theory (Klir & Yuan, 1995)

REFERENCES

[1] Allen, D.T. and Shonnard, D.R. 2002. *Green Engineering: Environmentally Conscious Design of Chemical Processes,* Prentice Hall PTR, Upper Saddle River, New York.

[2] Ball, G. and Hall, D. 1967. A clustering technique for summarizing multivariate data, *Behavior Science* 12(1):153-155.

[3] Bellman, R.E., and L.A. Zadeh, 1970. Decision-making in a fuzzy environment, *Management Science* 17(4),141-164.

[4] Bezdek, J.C. 1973. Fuzzy mathematics in pattern classification, Ph. D. Dissertation, Applied Mathematics, Cornell University, Ithaca, NY.

[5] Bezdek, J.C. 1974. Cluster validity with fuzzy sets, Journal of Cybernetic 3(1):58-72.

[6] Bezdek, J.C. 1975. Mathematical models for systematics and taxonomy, *Proceedings of 8th International Conference on Numerical Taronomy,* Estabrook, G. (Ed.), Freeman, San Franscisco, CA, pp. 143-166.

[7] Bezdek, J.C. 1980. A convergence theorem for the fuzzy ISODATA clustering algorithms, IEEE Transaction on Pattern Analysis and Machine Intelligence. 2(1):1-8.

[8] Bezdek, J.C. 1981. *Panem Recognition with Fuuy Objective Function Algorithms.* New York Plenum.

[9] Bezdek, J.C. and Pal, N.R. 1998. Some new indexes of cluster validity, IEEE Trans. Systems Man Cybernet. 28(3):301–315.

[10] Bossel, H. 1999. Indicators for Sustainable Development: Theory, Method, Applications. International Institute for Sustainable Development, Winnipeg

[11] Brans J.P., Mareschal, B. and Vincke, Ph. 1984. PROMETHEE: A new family of outranking methods in MCDM, *Operational Research*, 477-490.

[12] Brans J.P., and Vincke, Ph. 1985. A preference ranking organization method - The PROMETHEE Method for MCDM, *Management Science*, 31(6), 647-656.

[13] Brezet, H. and van Hemel, C. 1997. Ecodesign, a promising approach to sustainable production and consumption. France: United Nations publication.

[14] Briggs, Th., Kunsch, P.L., and Mareschal, B. 1990. Nuclear waste management: an application of the multicriteria PROMETHEE methods, *European Journal of*

Operational Research, 44(1), 1-10.

[15] Buckley, J.J. 1985a. Ranking alternatives using fuzzy number, *Fuzzy Sets and Systems* 15(1), 21-31.

[16] Buckley, J.J. 1985b. Fuzzy hierarchical analysis, *Fuzzy Sets and Systems* 17(3), 233-247.

[17] Byggeth, S.H. and Broman, G. 2000. Environmental aspects in product development—an investigation among small and medium sized enterprises. In: SPIE International Symposium on Intelligent Systems and Advanced Manufacturing; Environmentally Conscious Manufacturing, Boston, USA, pp.5–8.

[18] Byggeth, S.H., Broman, G., Holmberg, J., Lundqvist, U. and Robert, K.H. 2000. A method for sustainable product development in small and medium sized enterprises. In: TMCE-Tools and Methods of Competitive Engineering, Symposium, Delft, the Netherlands, pp.18–21.

[19] Caruso, C., A. Colorni, and M. Paruccini. 1993. The regional urban solid waste management system: A modeling approach, *European Journal of Operational Research* 70(1):16-30.

[20] Chang, D.Y., 1996, Applications of the extent analysis method on fuzzy AHP, *European Journal of Operation Research* 95(5), 649-655.

[21] Charter, M. and Tischner, U. 2001. Sustainable product design. In: Sustainable Solutions. UK: Greenleaf Publishing Ltd.

[22] Chen, S.J., and Hwang, C.L. (1992). *Fuzzy Multiple Attribute Decision Making: Methods and Applications*, Springer-Verlag, NY.

[23] Chen, T.Y., J.C. Wang, and G.H. Tzeng. 2000. Identification of general fuzzy measures by genetic algorithms based on partial information, *IEEE Transactions on Systems, Man, and Cybernetics Part B: Cybernetics* 30B(4):517-528.

[24] Chen, Y.W., and G.H. Tzeng. 2001. Using fuzzy integral for evaluating subjectively perceived travel costs in a traffic assignment model, *European Journal of Operational Research* 130(3):653-664.

[25] Croner. 2000. Environmental management systems and eco-design. Croner special report. Practical guidance on environmental management. 50(1): 1–8.

[26] Daly,H. and Cobb, J. 1989. For the Common Good. Beacon Press, Boston.

[27] Dubois, D., and H. Prade. 1978. Operations on fuzzy numbers, International Journal of Systems Science 9(3):613-626.

[28] Dubois, D., and H. Prade. 1980. Fuzzy Sets and Systems, Academic Press,New

York.

[29] Dunn, E.G., Keller, J.M., Marks, L.A., Ikerd, J.E., Fader, P.D. and Godsey, L.D. 1995. Extending the application of fuzzy sets to the problem of agricultural sustainability. IEEE Proceedings of ISUMA-NAFIPS '95, IEEE Computer Society Press, Los Alamitos, CA, pp. 497– 502.

[30] Dunn, J.C. 1974. A fuzzy relative of the ISODATA process and its use in detecting compact well-separated clusters, Journal of Cybernetic 3(1): 32-57.

[31] Fukunaga, K. 1990. Introduction to Statistical Pattern Recognition, Academic Press, New York.

[32] Fukuyama, Y. and Sugeno, M. 1989. A new method of choosing the number of clusters for the fuzzy *c*-means method, Proceedings of 5th Fuzzy Systems Symposium, pp. 247-250.

[33] Gabus, A. and Fontela, E. 1972. World problems: an invitation to further thought within the framework of DEMATEL. Geneva: Battelle Geneva Research Centre.

[34] Gabus, A. and Fontela, E. 1973. Perceptions of the world problematique: Communication procedure, communicating with those bearing collective responsibility (DEMATEL No. 1), Geneva: Battelle Geneva Research Centre.

[35] Gath, J. and Geva, A.B. 1989. Unsupervised optimal fuzzy clustering, IEEE Transaction on Pattern Analysis and Machine Intelligence 11(7):773-781.

[36] Gertsakis, J., Lewis, H. and Ryan, C. 1997. A guide to EcoReDesign. Australia: Centre for Design at RMIT.

[37] Ghosh R.N., 1977. Agriculture in economic development New Delhi: VIKAS Publishing.

[38] Ghosh R.N., Gabbay R., Siddique M.A.B., 2000. Growth, development and sustainable development. In: Ghosh R.N., Gabbay R., Siddique M.A.B., editors. Human resource and gender issues in poverty eradication. New Delhi: Atlantic Publishers and Distributors, pp. 1– 11.

[39] Grabisch, M. 1995. Fuzzy integral in multicriteria decision-making, Fuzzy Sets and Systems 69(3):279-298.

[40] Grassin, N. 1986. Constructing population criteria for the comparison of different options for a high voltage line route, *European Journal of Operational Research*, **26**(1), 42-57.

[41] Gunderson, R. 1978. Application of fuzzy ISODATA algorithms to star-tracker pointing systems, Proceedings of 7th Triannual World IFAC Congress, Helsinki, pp.

1319–1323.

[42] Hanley, N., Moffatt, I., Faichney, R. and Wilson, M.D., 1998. Measuring sustainable development: a time series of alternative indicators for Scotland. Ecological Economics 28 (1), 53–73.

[43] Hanssen, O.J. 1997. Sustainable industrial product systems. Norway: Stiftelsen Østfoldforskning.

[44] Hardoy, J.E., Mitlin, D., Satterthwaite, D., 1992. Environmental Problems in Third World Cities. Earthscan Publications, London.

[45] Hardy, A. 1996. On the number of classes, Computation and Statistics Data Analysis 23(1):83–96.

[46] Herkert, J.R., Farrell, A. and Winebrake, J.J., 1996. Technology choice for sustainable development. IEEE Technology on Soc Management,15(2):12– 20.

[47] Hokkanen, J., and Salminen, P. 1997. ELECTRE Ⅲ and Ⅳ decision aids in an environmental problem, *Journal of Multi-Criteria Decision Analysis*, 6(2), 215-226.

[48] Hokkanen, J., Salminen, P., Rossi, E., and Ettala, M. 1995. The choice of a solid waste management system using the ELECTRE Ⅱ decision-aid method, *Waste Management and Research*, 13(2), 175-193.

[49] Hori, S. and Shimizu, Y. 1999. Designing methods of human interface for supervisory control systems, Control Engineering Practice 7 (11) 1413-1419.

[50] Hougaard, J.L., and H. Keiding. 1996. Representation of preferences on fuzzy measures by a fuzzy integral, Mathematical Social Sciences 31(1):1-17.

[51] Hwang, C.L., and K. Yoon. 1981. Multiple Attribute Decision Making, Lecture Notes in Economics and Mathematical Systems, Springer-Verlag, Berlin.

[52] Ishii, K., and Sugeno, M. 1985. A model of human evaluation process using fuzzy measure, *International Journal of Man-Machine Studies*, **22**(1), 19-38.

[53] Kacprzyk, J. 1997. Multistage Fuzzy Control – A Model-Based Approach To Fuzzy Control And Decision Making, John Wiley & Sons, New York.

[54] Kaiser, H.F. 1958. The varimax criterion for analytic rotation in factor analysis, Psychometrika 23(1):187-200.

[55] Karsak, E.E., Sozer, S., Alptekin, S.E., 2002. Product planning in quality function deployment using a combined analytic network process and goal programming approach. Computers and Industrial Engineering, 44 (1), 171–190.

[56] Keeney, R.L. and H. Raiffa. 1976. Decisions with Multiple Objectives: Preferences

and Value Tradeoffs, John Wiley and Sons.

[57] Kelly, K.L., 1998. A systems approach to identifying decisive information for sustainable development. European Journal of Operational Research 109, 452–464.

[58] Kothari, R. and Pitts, D. 1999. On finding the number of classes, Pattern Recognition Lett. 20(3):405–416.

[59] Lahdelma, R., Salminen, P., and Hokkanen, J. 2000. Using multicriteria methods in environmental planning and management, *Environmental Management*, 26(6), 595-605.

[60] Lee, J.W., Kim, S.H., 2000. Using analytic network process and goal programming for interdependent information system project selection. Computers and Operations Research, 27 (4), 367–382.

[61] Lesser J.A. and Zerbe R.O. 1995. What can economic analysis contribute to the sustainability debate? Contemporary Economic Policy 13(3):88 – 99.

[62] Levy, J.K, Hipel, K.W. and Kilgour, D.M., 1995. A holistic approach to sustainable development: the graph model for conflict resolution. Information System Engineering, 1 (3– 4):159– 177.

[63] Maxwell, D. and van der Vorst, R. 2003. Developing sustainable products and services, Journal of Cleaner Production 11(6) 883–895.

[64] McDaniels T.L. 1994. Sustainability, value trade offs, and electric utility planning. Energy Policy, 22(12):1045– 54.

[65] Meade, L.M., Presley, A., 2002. R&D project selection using the analytic network process. IEEE Transaction on Engineering Management, 49 (1), 59–66.

[66] Mebratu, D., 1998. Sustainability and sustainable development: historical and conceptual review. Environment Impact Assessing Review 18(3), 493–520.

[67] Mendoza, G.A., and R. Prabhu. 2000. Development of a methodology for selecting criteria and indicators of sustainable forest management: A case study on participatory assessment, Environmental Management 26(6):659-673.

[68] Milne M.J. 1996. On sustainability: the environment and management accounting. Management Accounting Research, 7(1):135 –161.

[69] Milon, J.W., Shogren, J.F. (Eds.), 1995. Integrating Economic and Ecological Indicators: Practical Methods for Environmental Policy Analysis. Praeger Publishers, Westport, CT.

[70] Minns D.E., 1994. Mathematical modelling as a tool to aid R&D investment decisions in a sustainable development policy climate. Technology Analysis

Strategic Management 6(4):457 –72.

[71] Moffatt, I., 1996. Sustainable Development: Principles Analysis and Policies. Parethenon Press, New York.

[72] Momoh, J.A. and Zhu, J. 2003. Optimal generation scheduling based on AHP/ANP. IEEE Transaction on Systems Man Cybernet.— Part B: Cybernet, 33 (3), 531–535.

[73] Nordhaus, W. and Tobin, T. 1972. Is growth obsolote?. Columbia University Press, New York.

[74] Opricovic, S. and Tzeng, G.H. 2003. Defuzzification for a fuzzy multicriteria decision model, International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems 11(5):635-652.

[75] Oral, M., Kettani, O., and Lang, P. 1991. A methodology for collective evaluation and selection of industrial R&D projects, *Management Science*, 37(7), 871-885.

[76] Pal, N.R. and Bezdek, J.C. 1995. On cluster validity for the fuzzy c-means model, *IEEE Transactions on Fuzzy Systems*. 3(3):370-379.

[77] Pearce, D., Markandya, A., and Barbier, E. 1989. Blueprint for a Green Economy. London: Earthscan.

[78] Pearce, D.W., Turner, R.K., 1990. Economics of Natural Resources and the Environment, Harvester Wheatsheaf, London, UK.

[79] Pedrycz, W. and Gomide, F. 1998. An Introduction to Fuzzy Sets, The MIT Press, Cambridge, Massachusetts, London, England.

[80] Pugh, C. (Ed.), 1996. Sustainability, the Environment and Urbanization, Earthscan, London.

[81] Ralescu, D. A., and G. Adams. 1980. Fuzzy integral, Journal of Mathematical Analysis and Applications 75(2):562-570.

[82] Rauch, W., 1998. Problems of decision making for a sustainable development. Water Science Technology, 38 (11), 31– 39.

[83] Reiskin, E., White, A., Kauffman, J. and Votta, J. 2000. Servicizing the chemical supply chain. Journal of Industrial Ecology 3(1): 2–3.

[84] Roy, B. 1991. The outranking approach and the foundations of ELECTRE methods, *Decision Theory*, 31(1), 49-73.

[85] Roy, B., and Bouyssou, B. 1986. Comparison of two decision-aid models applied to a nuclear power plant sitting example, *European Journal of Operational Research*, 20(2), 200-215.

[86] Saaty, T.L. 1977. A Scaling Method for Priorities in Hierarchical Structures, Journal

of Mathematical Psychology, Vol. 15, No. 3, 234-281.
[87] Saaty, T.L. 1980. The Analytic Hierarchy Process, McGraw-Hill, New York.
[88] Saaty, T.L., 1994, Fundamentals of Decision Making and Priority Theory with the Analytic Hierarchy Process, Pittsburgh PA: RWS Publication.
[89] Saaty, T.L., 1996, Decision Making with Dependence and Feedback: The Analytic Network Process, Pittsburgh PA: RWS Publication.
[90] Saaty, T.L., and Vargas, L. G., 1998, Uncertainty and rank order in the analytic hierarchy process, European Journal of Operational Research 32, 107-117.
[91] Sarkis, J., 2003. A strategic decision framework for green supply chain management. Journal of Cleaner Production, 11 (4), 397–409.
[92] Selman P. 1999. Three decades of environmental planning: what have we learned? In: Kenny M, Meadowcroft J, editors. Planning Sustainability. London: Routledge, pp. 148–74.
[93] Shearman, R., 1990. The meaning and ethics of sustainability. Environmental Management 14 (1), 1–8.
[94] Siddique M.A.B., 1997. Economic development: then and now. The South African Journal of Economics 65(1):7– 27.
[95] Simon, M., Evans, S., McAloone, T., Sweatman, A., Bhramra, T. and Poole, S. 1998. Ecodesign Navigator EPSRC. UK: Deanprint.
[96] Siskos, J., and Hubert, P. 1983. Multicriteria analysis of the impacts of energy alternatives: a survey and a new comparative approach, *European Journal of Operational Research*, 13(2), 278-299.
[97] Slesser M. and Moffit I. 1989. Sustainable development: conceptual issues, an operational model and its implications, Proceedings of the 3rd European Simulation Congress. Ghent, Belgium: SCS Eur, 1989.
[98] Sugeno, M. 1974. Theory of Fuzzy Integrals and its Applications, Doctorial Thesis, Tokyo Institute of Technology, Japan.
[99] Tamura, H., Akazawa, K. and Nagata, H. 2002. Structural modeling of uneasy factors for creating safe, secure and reliable society, SICE System Integration Division Annual Conference 330-340.
[100] Teng, J.Y., and Tzeng, G.H. 1994. Multicriteria evaluation for strategies of improving and controlling air quality in the super city: a case study of Taipei city, Journal Environmental Management 40(2):213-229.
[101] Trauwert, E., Kaufman, L. and Rousseeuw, P. 1991. Fuzzy clustering algorithms

based on the maximum likehood principle, Fuzzy Sets and Systems 42(2): 213–222.

[102] Tsaur, S.H., Tzeng, G.H. and Wang. G.C., 1997. The application of AHP and fuzzy MCDM on the evaluation study of tourist risk, Annals of Tourism Research 24(4):796-812.

[103] van Hemel, C. 1998. Ecodesign empirically explored. In: Design for environment in Dutch SMEs. Amsterdam: Boekhandel Milieu-Boek.

[104] van Weenen, H. 2000. Product design–practical examples of SMEs. In: Proceedings in Sustainable Development, SMEs and New Enterprises, European Foundation, Ireland, pp.12–13.

[105] von Neumann, J., and Morgenstern, O. 1947. *Theory of Games and Economic Behavior*, 2nd ed. Princeton University Press, Princeton, N.J.

[106] Windham, M.P. 1981. Cluster validity for fuzzy clustering algorithms, Fuzzy Sets and Systems 5(2):177–185.

[107] World Commission on Environment and Development (WCED), 1987. Our Common Future. Oxford Univ. Press, Oxford.

[108] World Resources Institute. World resources. New York: Oxford Univ. Press, 1986, 1994,1995,1996,1997.

[109] WRR, 1995. Sustained Risks: A Lasting Phenomenon. Sdu Uitgeverij, The Hague, Reports to the Government 44.

[110] Xerox Corporation. Environment, health and safety report. 2001, UK and USA Xerox Corporation; 2001

[111] Xie, X.L. and Beni, G. 1991. A validity measure for fuzzy clustering, IEEE Transaction on Pattern Analysis and Machine Intelligence 13 (5):841-847.

[112] Yager, R.R. and Filev, D.P. 1993. On the issue of defuzzification and selection based on a fuzzy set, Fuzzy Sets Systems 55(2):255-271.

[113] Yeh, C.H., Deng, H. and Chang, Y.H. 2000. Fuzzy multicriteria analysis for performance evaluation of bus companies, European Journal of Operation Research 126, 459-473.

[114] Zadeh, L.A. 1965. Fuzzy Sets, Information and Control 8(2):338-353.

[115] Zadeh, L.A. 1975. The concept of a linguistic variable and its application to approximate reasoning, Parts 1, 2 & 3. Information Sciences 8(2):199-249; 8(3):301-357; 9(1):43-80.

[116] Zadeh, L.A. 1978. Fuzzy sets as a basis for a theory of possibility, Fuzzy Sets Systems 1(1):3-28.

[117] Zhao, R., and R. Govind. 1991. Algebraic characteristics of extended fuzzy numbers, Information Science 54(1):103-130.

[118] Zimmermann, H.J., (1985) *Fuzzy Set Theory and Its Applications*, Kluwer, Nijhoff Publishing, Boston.

[119] Zimmermann, H.J., (1987) *Fuzzy Set, Decision Making, and Expert System*, Kluwer, Nijhoff Publishing, Boston.

Curriculum Vitae

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Work Experience

- Assistant Engineer, Shipbuilding Factory of Navy (August 1985 – July 1989).
- Officer of Project Management, Headquarter of Navy (August 1991 - June 1995).
- Instructor, Logistic Management, National Defense Management College (August 1995 - September 1996).
- Lecturer, Department of Statistics, National Defense Management College (August 1996 - July 2002).
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Publications

A. Referred Papers

A-1. International Journal

1. Hua-Kai Chiou, Gwo-Hshiung Tzeng and Ding-Chou Cheng. (2005) "Evaluating

Sustainable Fishing Development Strategies Using Fuzzy MCDM Approach", *OMEGA*, Vol.33, No.3, 223-234.**(SCI、SSCI)**.

2. Hua-Kai Chiou and Gwo-Hshiung Tzeng. (2005) "A Novel Compromise Optimization Method for Bidder Selection in the Public Construction Project", *Computer-Aided Civil and Infrastructure Engineering*, **(SCI)**. (Forthcoming)
3. Hua-Kai Chiou, Chin-Huan Liao, Yen-Fang Chu and Gwo-Hshiung Tzeng. (2005) "Applied Hybrid DEA Model to Measure the Performance of Municipal Waste Recycling and Treatment in Taiwan", *Computers and Industrial Engineering*. **(SCI)**. (Revised).
4. Hua-Kai Chiou and Gwo-Hshiung Tzeng. (2003) "An Extended Approach of Multicriteria Optimization for MODM Problems", in T. Tanino, T. Tanaka and M. Inuiguchi (eds.), Multi-Objective Programming and Goal Programming – Theory and Applications, pp.111-116.
5. Hua-Kai Chiou and Gwo-Hshiung Tzeng. (2002) "Fuzzy Multicriteria Decision-Making Approach to Analysis and Evaluation of Green Engineering for Industry", *Environmental Management*, Vol.30, No.6, 816-830. **(SCI)**.
6. Hua-Kai Chiou and Gwo-Hshiung Tzeng. (2001) "Fuzzy Hierarchical Evaluation with Grey Relation Model of Green Engineering for Industry", *International Journal of Fuzzy Systems*, Vol.3, No.3, 466-475.

A-2. Domestic Journal

1. 袁建中、王建彬、曾國雄、邱華凱，「利用模糊集群分析建構台灣機械產業永續發展之最佳策略組合」，淡江大學管理研究學報，2004 年 11 月 (已接受刊登)。

B. Conference Papers

B-1. International Conference

2005

1. Hua-Kai Chiou, Gwo-Hshiung Tzeng and Chia-Chin Wan. "Fuzzy C-Means Clustering for Analyzing the Development Strategy of Nano-Technology Industry in Taiwan", Accepted to present on *The 6th Global Information Technology Management Conference* (**GITMA 2005**, Paper No.: KMDSS01), Anchorage Alaska, USA. June 5-7, 2005.
2. Hua-Kai Chiou and Gwo-Hshiung Tzeng. "Fuzzy Multiple Objective Programming for Evaluating the Performance of Government Funded R&D Projects with Interval Data in Taiwan", Accepted to present on *The 6th Global Information Technology*

Management Conference (**GITMA 2005**, Paper No.: KMDSS02), Anchorage Alaska, USA. June 5-7, 2005.

3. Hua-Kai Chiou Yen-Fang Chu and Gwo-Hshiung Tzeng. "Comparing AHP/GRA with DEA to Evaluate the Performance of Municipal Waste Recycling in Taiwan", Accepted to present on *The 8th International Symposium on AHP* (**ISAHP 2005**), Honolulu, Hawaii, July 8-10, 2005.
4. Hua-Kai Chiou, Chia-Chin Wan and Gwo-Hshiung Tzeng. "Fuzzy AHP with MCDA to Construct the Roadmap of R&D Consortia in Taiwan's M&S Enterprises", Accepted to present on *The 8th International Symposium on AHP* (**ISAHP 2005**), Honolulu, Hawaii, July 8-10, 2005.
5. Hua-Kai Chiou, Gwo-Hshiung Tzeng, Benjamin J.C. Yuan and Chien-Pin Wang. "Fuzzy C-Means Clustering to Explore the Strategy Combination of Fuel Cell Industry in Taiwan", Accepted to present on *The Preeminent International Conference in OR/MS* (**IFORS 2005**), Honolulu, Hawaii, July 11-15, 2005.
6. Chia-Chin Wan, Hua-Kai Chiou and Gwo-Hshiung Tzeng. "Fuzzy AHP with Grey Relation Analysis for Evaluating the Performance of R&D Consortia in Taiwan's M&S Enterprises", Accepted to present on *The Preeminent International Conference in OR/MS* (**IFORS 2005**), Honolulu, Hawaii, July 11-15, 2005.
7. Chia-Chin Wan, Hua-Kai Chiou and Gwo-Hshiung Tzeng. "Fuzzy Multiple Criteria Decision Analysis for Evaluating the Performance of R&D Consortia in Taiwan's M&S Enterprises", Accepted to present on *Portland International Conference on Management of Engineering and Technology* (**PICMET'05**, Paper No.:05A0069), Portland, Oregon, USA. July 31-Aug. 4, 2005.
8. Hua-Kai Chiou, Gwo-Hshiung Tzeng and Chien-Tsung Lee. "Establishing the Key Factors for Industrial Environmental Accounting Implementation from Multivariate Statistical Aspects", Accepted to present on *Portland International Conference on Management of Engineering and Technology* (**PICMET'05**, Paper No.:05A0070), Portland, Oregon, USA. July 31-Aug. 4, 2005.
9. Gwo-Hshiung Tzeng, Hua-Kai Chiou and Chia-Chin Wan. "Multiobjective Compromise Optimization Method for Comparing the R&D Strategies of Small & Medium Enterprises in Taiwan", Accepted to present on *The 35th International Conference on Computers and Industrial Engineering* (**35CIE**), Istanbul, Turkey, June 19-22, 2005.
10. Hua-Kai Chiou, Gwo-Hshiung Tzeng and Chia-Chin Wan. "Fuzzy Classification for

Optimizing the Strategy Combination of Machinery Industry in Taiwan", Accepted to present on *The 7th International Conference on Data Warehousing and Knowledge Discovery* (**DaWaK 2005**), Copenhagen, Denmark, August 22-26, 2005.

11. Hua-Kai Chiou, Gwo-Hshiung Tzeng, Benjamin J.C. Yuan and Chien-Pin Wang. "Solving The Optimal Strategic Action of Fuel Cell Industry Using TOPSIS Method", Accepted to present on *The 7th International Conference on Data Warehousing and Knowledge Discovery* (**DaWaK 2005**), Copenhagen, Denmark, August 22-26, 2005.
12. Hua-Kai Chiou, Yu-Yuan Tsou and Gwo-Hshiung Tzeng. "Fuzzy Multiple Objective Programming for Performance Evaluation of Public Sectors in Taiwan", Accepted to present on *International Conference on Systems, Man and Cybernetics* (**IEEE SMC 2005**), Hawaii, USA, October 10-12, 2005.
13. Hua-Kai Chiou and Gwo-Hshiung Tzeng. "Multiple Objective Compromise Optimization Method to Analyze the Strategies of Nanotechnology in Taiwan", Accepted to present on *International Conference on Systems, Man and Cybernetics* (**IEEE SMC 2005**), Hawaii, USA, October 10-12, 2005.

2004

1. Gwo-Hshiung Tzeng, Hua-Kai Chiou and Yen-Fang Chu. "Imprecise Data Envelopment Analysis for Evaluating the Performance of R&D Project in Taiwan", *Proceedings of The 33rd International Conference on Computers and Industrial Engineering*, Jeju, Korea, March 25-27,2004, CIE773: pp.1-7.
2. Hua-Kai Chiou, Yu-Yuan Tsou and Gwo-Hshiung Tzeng. "Fuzzy Multiple Objective Programming with Bounded Method for Evaluating the Performance of Accounting & Statistics Departments of Taiwan Air Force", *Proceedings of The 6th International Conference on Multiple Objective Programming and Goal Programming*, Hammamet, Tunisia, April 14-16, 2004, F13: pp.1-9.
3. Hua-Kai Chiou, Gwo-Hshiung Tzeng, Gia-Shie Liu and Chih-Kang Cheng. "GM(1,1) Model for Forecasting the Intermittent Demand of Spare Parts in Navy of Taiwan", *Proceedings of The 6th International Conference on Multiple Objective Programming and Goal Programming*, Hammamet, Tunisia, April 14-16, 2004, F34: pp.1-6.
4. Hua-Kai Chiou and Gwo-Hshiung Tzeng. "Evaluating the Performance of R&D Project in Taiwan Using Data Envelopment Analysis with Imprecise Data", *Proceedings of The 6th International Conference on Multiple Objective Programming and Goal Programming*, Hammamet, Tunisia, April 14-16, 2004, B33: pp.1-8.
5. Hua-Kai Chiou, Gwo-Hshiung Tzeng, Chih-Kang Cheng and Gia-Shie Liu. "Grey

Prediction Model for Forecasting the Planning Material of Equipment Spare Parts in Navy of Taiwan", *The 5th World Automation Congress*, Seville, Spain, June 28-July 1, 2004, ISSCI072: pp.1-6.

6. Hua-Kai Chiou, Gwo-Hshiung Tzeng, Benjamin J.C. Yuan and Chien-Pin Wang. "Fuzzy C-Means Clustering for the Optimal Portfolio of Machinery Industrial Sustainable Development Strategies in Taiwan", *The 5th World Automation Congress*, Seville, Spain, June 28-July 1, 2004, ISSCI077: pp.1-6.
7. Hua-Kai Chiou, Gwo-Hshiung Tzeng and Wen-Han Tang. "Imprecise DEA with FMOP method for Evaluating the Performance of R&D Projects in Taiwan", *The 5th World Automation Congress*, Seville, Spain, June 28-July 1, 2004, ISSCI076: pp.1-6.
8. Hua-Kai Chiou, Gwo-Hshiung Tzeng, Gia-Shie Liu and Chih-Kang Cheng. "Gray Prediction Model for Forecasting the Planning Material of Equipment Spare Parts in Navy of Taiwan", *Portland International Conference on Management of Engineering and Technology*, Seoul, Korea, August 1-4, 2004, 04A0054: pp.1-5.
9. Yu-Yuan Tsou, Hua-Kai Chiou and Gwo-Hshiung Tzeng. "IDEA with FMOP Method for Evaluating the Performance of Budget-Accounting & Statistics Departments of ROC Air Force", *Portland International Conference on Management of Engineering and Technology* (*PICMET 2004*), Seoul, Korea, August 1-4, 2004, 04A0089: pp.1-10.
10. Hua-Kai Chiou, Gwo-Hshiung Tzeng and Benjamin J.C. Yuan. "Evaluating the Performance of R&D Project in Taiwan Using Data Envelopment Analysis with Imprecise Data", *Portland International Conference on Management of Engineering and Technology*, Seoul, Korea, August 1-4, 2004, 04R0087: pp.1-10.
11. Yu-Yuan Tsou, Hua-Kai Chiou and Gwo-Hshiung Tzeng. "Performance Evaluation Using by Integrated Model of Imprecise Data Envelopment Analysis with Fuzzy Multiple Objective Programming", *The 17th International Conference on MCDM*, Whistler, B. C. Canada August 6-11, 2004, AP88: pp.1-8.
12. Hua-Kai Chiou, Gwo-Hshiung Tzeng and Chien-Pin Wang. "Fuzzy C-Means Clustering for The Optimal Strategy Combination of Nanotechnology Industry in Taiwan", *The 17th International Conference on MCDM*, Whistler, B. C. Canada August 6-11, 2004, AP89: pp.1-11.
13. Hua-Kai Chiou, Gwo-Hshiung Tzeng and Chih-Kang Cheng. "Grey Prediction GM(1,1) Model for Forecasting Demand of Planned Spare Parts in Navy of Taiwan", *The 17th International Conference on MCDM*, Whistler, B. C. Canada August 6-11, 2004, AP90: pp.1-7.

14. Yu-Yuan Tsou, Hua-Kai Chiou, Gwo-Hshiung Tzeng and Chih-Kang Cheng. "An Empirical Study on Performance Evaluation of ROC Air Force Budget-Accounting & Statistics Departments", *The 34th International Conference on Computers and Industrial Engineering*, San Francisco, USA, November 25-27,2004, pp.341-346.

2003

1. Hua-Kai Chiou and Gwo-Hshiung Tzeng. "Prequalifying the Public Construction Project Using Extended VIKOR with Entropy Measure", *Proceedings of The 32nd International Conference on Computers and Industrial Engineering*, Limerick, Ireland, August 11-13, 2003, pp.170-175.
2. Hua-Kai Chiou, Chin-Huan Liao, Yen-Fang Chu and Gwo-Hshiung Tzeng. "Hybrid DEA with Grey Relation Model to Measure the Performance of Municipal Waste Recycling in Taiwan", *Proceedings of The 32nd International Conference on Computers and Industrial Engineering*, Limerick, Ireland, August 11-13, 2003, pp.584-589.

2002

1. Hua-Kai Chiou and Gwo-Hshiung Tzeng. "Determining the Sustainable Development Strategies for Aquatic Industry Using a Fuzzy MCDM Method", Presented on *The 16th MCDM World Conference*, Semmering, Austria, February 18-22, 2002.
2. Hua-Kai Chiou and Gwo-Hshiung Tzeng. "A New Approach of Multicriteria Optimization and Compromise Solution for MCDM Problems", Presented on *The 5th International Conference on Multiple Objective Programming and Goal Programming*, Nara, Japan, June 4-7, 2002.
3. Yi-Chung Hu, Hua-Kai Chiou, Ruey-Shun Chen and Gwo-Hshiung Tzeng. "Mining of Sequential Patterns Using Concepts of Fuzzy Sets", *Proceedings of The 30th International Conference on Computers and Industrial Engineering*, Tinos Island, Greece, June 29-July 2, 2002, pp.329-334.

B-2. Domestic Conference

1. 邱華凱、鄒予元、鄭志剛，「我國空軍主計部門之績效評量實證研究」，2004 年決策科學研討會，2004 年 6 月 4-5 日，國立東華大學，花蓮。
2. 邱華凱、鄭志剛、鄒予元，「運用灰理論模式預測海軍裝備零附件之計畫備料」，2004 年決策科學研討會，2004 年 6 月 4-5 日，國立東華大學，花蓮。
3. 李建聰、邱華凱，「企業實施環境會計關鍵因素之研究」，2004 年決策科學研討

會，2004 年 6 月 4-5 日，國立東華大學，花蓮。

4. 朱艷芳、邱華凱、徐光展，「ISO-9000 品質管理認證後之服務品質滿意度研究-以海軍修護工廠為例」，2004 年決策科學研討會，2004 年 6 月 4-5 日，國立東華大學，花蓮。
5. 李建聰、邱華凱、「以 AHP 建構企業實施環境會計之績效評量指標」，第 5 屆環境管理研討會，2004 年 5 月 26-27 日，南華大學，嘉義。
6. 邱華凱、鄭志剛，「運用灰理論 GM(1,1)模式預測裝備零附件之計畫備料」，2004 年管理創新與新願景研討會，2004 年 5 月 19 日，真理大學，台北。
7. 邱華凱、鄒予元，「模糊多目標規劃與不確定性資料包絡分析效率評量整合模式之應用」，2004 年管理創新與新願景研討會，2004 年 5 月 19 日，真理大學，台北。
8. 邱華凱、曾國雄，“Fuzzy MCDM Method for Evaluating the Sustainable Strategies of Fishing Industry in Taiwan”，第 10 屆科技管理研討會，2003 年 12 月 11-13 日，國立交通大學，新竹。
9. 廖金環、朱艷芳、邱華凱，「結合灰色關聯與資料包絡法分析台灣省各縣市資源回收作業績效」，2003 年管理思維與實務學術研討會，銘傳大學，2003 年 6 月 10 日，台北。
10. 劉煒仁，邱華凱，朱豔芳，「結合 Kano 二維品質模式與 QFD 之教學品質實證研究」，第五屆科際整合管理國際研討會，東吳大學，2001 年 5 月 25 日，台北，頁 871-890。
11. 劉煒仁、邱華凱、朱艷芳，「應用品質機能展開構建教學品質衡量觀念性模式之探討」，中華民國品質學會第 36 屆年會暨第 6 屆全國品質管理研討會，中華民國品質學會，2000 年 11 月 17 日，台北，頁 183-195。

C. Technique Report and Other Publications

1. 曾國雄、邱華凱，「第十一章：模糊系統決策」，模糊理論及其應用，李允中、王小璠、蘇木春編著，2003 年 5 月，全華科技圖書(股)公司。
2. 劉家熙、邱華凱，從商業競爭觀點探討可損性等候系統之集體汰換模式，國科會專題研究計畫（NSC89-2416-H-123-014），2000/08~2001/07。
3. 黃錫榮、邱華凱等，八十八年航空運輸業狀況調查，民航局專案，2000/04~2000/12。