國立交通大學

科技管理研究所

博士論文

科技政策與計畫之結構評估模式

A Structure Evaluation Model for Technology Policies and Programs

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中華民國九十八年三月

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摘 要

在科技管理領域中，管理者經常在充滿不確定性的決策環境中做決策，尤其在面對如資訊、生物、奈米等新興科技時，決策者常面臨複雜且交錯的決策問題。在解決複雜的問題時，將問題的考量因素及因素間相互的關係予以圖型化，有利於釐清複雜問題中相關的議題及概念。DEMATEL 方法主要的目的即在於研究並解決複雜且決策因子交錯的問題。此方法現在已經廣泛被應用於問題分析或工業規劃等領域之中。應用 DEMATEL 方法時，可以將欲解決的問題予以圖像化，而這圖像亦反應了參與決策的人員對問題的認知情形。但是要得到合適的圖像，門檻值的設定將影響後續對問題的分析或解決方式。在以往，門檻值通常是經由專家們討論之後定案，但在獲得門檻值的共識是一件困難的事，有時候，亦會由研究者自行考量後訂定，而此將導致不同的研究者將得到不同的門檻值。本論文提出最大平均熵差法(Maximum Mean De-Entropy, MMDE)來解決此問題。本論文亦將引用「矽智財交易中心」之政策規劃及「數位學習」之成效評估模式等兩個案例，說明本方法之可行性，並比較本方法與傳統經由專家們決定門檻值間之異同之處。

關鍵字：科技管理、DEMATEL 方法、最大平均熵差法、門檻值

A Structure Evaluation Model for Technology Policies and Programs

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Abstract

Most fields in the management of technology experience uncertainty in the environment of decision-making, especially in emerging technology fields. Information technology, biotechnology and nanotechnology are good examples of sectors with complex coordination problems. To deal with complex problems, structuring them through graphical representations and analyzing causal influences can aid in illuminating complex issues, systems, or concepts. The DEMATEL method is a methodology which can be used for researching and solving complicated and intertwined problem groups. The applicability of the DEMATEL method is widespread, ranging from analyzing world problematique decision making to industrial planning. The end product of the DEMATEL process is a visual representation—the impact-relations map—by which respondents organize their own actions in the world. In order to obtain a suitable impact-relations map, an appropriate threshold value is needed to obtain adequate information for further analysis and decision-making. To obtain the reasonable threshold value, with respect to the difficulty of discussions with experts, the researcher may decide upon the value subjectively themselves. This result may differ among researchers. In this dissertation, we propose a method based on the entropy approach, the Maximum Mean De-Entropy (MMDE) algorithm, to achieve this purpose. Using real cases to find the interrelationships between the criteria for planning SIP Mall policy and evaluating effects in E-learning programs as examples, we will compare the results obtained from the respondents and from our method, and discuss that the different impact-relations maps from these two methods.

Keywords: management of technology, DEMATEL, Maximum Mean De-Entropy (MMDE) algorithm, threshold value

誌　　謝

論文研究與口試期間承蒙交通大學虞孝成教授、洪志洋教授、元智大學曾芳美教授、中原大學胡宜中教授、及致理管理學院張正昌教授撥冗審閱與指正，使本論文疏漏謬誤之處得以匡正，在此致上最深謝意。

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曾國雄講座教授是一位非常令人尊敬的老師，曾老師對於學生的照顧，可說無微不至：小從對身體健康的關懷，大至人生處世態度的分享與生涯規劃的建議，曾老師總是竭盡所能的予以協助；對學生的耐心及追求新知與研究的熱誠，總讓我感到他真是師道的榜樣。我如果未來在學術界中發展，曾老師永遠是我學習的對象，我衷心慶幸能成為他的學生。

我感謝研究所這段期間中，與我共同學習的學長、學姊、學弟、學妹們，無論在學術上的相互砥勵，或是在生活上相互的照應，沒有你們，我應該完成不了學業；和我同時進入本所博士班的同學們，無論是才華、文漢、仁帥、筱琪、雅雯、辭修、鴻裕、華凱，或是半途另謀高就當新娘子的維芯，大家共同生活的記憶，每每想起，總是笑意。國防部的一些好友，在我心情低落的時候，總能給我一些溫暖的鼓勵，元凱、逸舟、坤佑、麗卿、曉雯…，謝謝各位；特別感謝宗耀學長，你的協助與關懷，我點滴心頭。

我的妻子與兒子，一直以來就是我生活的重心與最親愛的人，總是給我過多的包容與體諒，是我一切動力的來源，我能獲得博士學位，這兩位是成就這功名的最大支柱。

我總喜歡陳之藩的一段文句：「因為需要感謝的人太多了，就感謝天罷。無論什麼事，不是需要先人的遺愛與遺產，即是需要眾人的支持與合作，還要等候機會的到來。越是真正做過一點事，越是感覺自己的貢獻之渺小」。一路走來，遇到的貴人太多；我，總顯得渺小。

李宗偉　謹誌

中華民國九十八年三月二十一日

于　新竹交通大學 科技管理研究所

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Chapter 1 Introduction

1.1 Background

Decision-making is the study of identifying and selecting alternatives based upon the values and preferences of the decision-maker. It involves reducing uncertainty and doubt about alternatives to make the most reasonable choice, and therefore stresses information-gathering. Making a decision implies that there are alternative choices to be considered, and in such a case, the decision-maker may want to identify as many of these alternatives as possible, but only choose one. The chosen alternative should have the highest probability of success, effectiveness, or the best fit with the decision-makers goals, desires, and values. Alternatives can be identified (especially in problem evaluation) or developed (created where they did not previously exist, especially in problem planning).

The decision-makers criteria consists of the characteristics or requirements each alternative must possess. Typically, alternatives are rated on how well they possess each criterion. Every decision is made within the decision environment, including the collection of information, alternatives, values, and preferences available at the time of the decision. An ideal decision environment would include the accurate information required for every possible alternative. However, both information and alternatives are constrained, because efforts to gain information or identify alternatives are limited. The effort constraint reflects the limits of manpower, funding, and priorities. Since decisions must be made within this constrained environment, a major challenge of decision-making is to identify the adequate criteria for program planning or problem evaluation.

Information includes knowledge about the decision, the effects of its alternatives, and the probability of each alternative. While a substantial amount of information is desirable, the statement that "the more information, the better" is not true. Too much information can actually reduce the quality of a decision. The fact that decisions must be made within a limiting decision environment means many decision-makers tend to seek more information than required to make a good decision. When too much information is sought and obtained, one or more problems can arise. One of these problems is information overload. In this state, so much information is available that decision-making ability actually declines, because the information in its entirety can no longer be managed or assessed appropriately. Therefore, the selective use of the information will occur. That is, the decision-maker will choose from among all the information available only those facts supporting a preconceived solution or position.

The concepts and techniques in the Management of Technology needed to deal with the complexity of the concepts of technological innovation generate the need for a deeper understanding of organization, systems and strategy. Accordingly, there has evolved a set of core techniques for the Management of Technology, which include: (1) Organizational analysis, (2) Systems analysis, (3) Technology forecasting and planning, (4) Innovation procedures, (5) Technical project management, (6) Marketing experimentation, and (7) Entrepreneurship [1].

Most fields in the Management of Technology experience uncertainty in the environment of decision-making. For example, identifying the emerging issues for innovation in the new product development area [2], managing technology development projects with many unknowns and great technical uncertainties [3], or determining indicators to justify research and development (R&D) programs [4]. Decision-makers usually face the uncertain environment of decision-making. To deal with complex problems, it helps to structure them using graphical representations and analyze causal influences that aid in illuminating complex issues, systems or concepts.

In the social sciences field, casual analysis techniques, such as path analysis and structural equation models, have been applied in a number of areas. These techniques help resolve questions about the possible causes by providing explanations of effects as a result of the previous causes [5-8]. In the multi-criteria decision-making (MCDM) field, the analytic hierarchy process (AHP) and the analytic network process (ANP), are decision analysis methods developed by Saaty [9-11]. These methods consider both qualitative and quantitative information and combine them by decomposing problems into systematic hierarchies to rank alternatives.

Some of the constraints or assumptions of these methodologies make them difficult to use for resolving practical problems. The assumptions of the models [12-14] make these casual analysis techniques inappropriate to use to solve ambiguous problems when it is hard to collect the necessary data. In addition, although path diagrams can be used to represent causal flow in a system of variables, they need not imply such a causal flow; in other words, these models can convey linear relationships and test the correlation between variables, but not the direction of influence of each variable. Although AHP and ANP provide a mechanism for checking the consistency of the evaluation measures, the structure of the problem should be outlined to choosing the most appropriate method.

1.2 Research Purpose

The DEMATEL (Decision-Making Trial and Evaluation Laboratory) method, developed by the Science and Human Affairs Program of the Battelle Memorial Institute of Geneva between 1972 and 1976, was used for researching and solving complicated and intertwined problem groups [15, 16]. DEMATEL was developed with the hope that the pioneering and appropriate use of scientific research methods could improve the understanding of a specific *problematique*, a cluster of intertwined problems, and contribute to the identification of workable solutions by a hierarchical structure. The DEMATEL method is based upon graph theory, enabling the user to plan and solve problems visually, so that they can divide the factors into a cause and effect group, to better understand the causal relationships. The methodology can confirm interdependence among variables and develop a directed graph that reflects the interrelationships between variables.

The applicability of the DEMATEL method is widespread, ranging from analyzing world problematique decision-making to industrial planning [17-20]. The most important property of the DEMATEL method used in the MCDM field is to construct interrelationships between the criteria. After the interrelationships between criteria were determined, the result derived from the DEMATEL method could be used with the fuzzy integral to measure the super-additive effectiveness value, or for the Analytic Network Process method (ANP) [11, 21, 22], to measure dependence and feedback relationships between criteria. When the DEMATEL method is used as a part of a hybrid MCDM model, the result of the DEMATEL will influence the final decision.

The DEMATEL method consists of four steps: Step 1: Calculate the average matrix, Step 2: Calculate the *normalized initial direct-influence matrix*, Step 3: Derive the *total relationship matrix*, and Step 4: Set a threshold value and obtain the *impact-relationship-map* (In Figure 1-1, we divided step 4 into two steps).

In Step 4, an appropriate threshold value is necessary to obtain a suitable impact-relationship-map and adequate information for further analysis and decision-making. The original method for setting a threshold value was determined by discussions with experts. The researcher sets an adequate threshold value and then outlines an impact-relationship-map for discussing whether the map is suitable for the structure of the problematique. If not, the threshold value will be replaced by another value and obtain another impact-relationship-map until a consistent opinion is decided upon. Sometimes, after the researcher obtains the input data for Step 1 from questionnaires, it is not easy to make a consistent threshold value, especially when the number of experts is too many to aggregate at same time. When the factors of the problem are many, the work to obtain a consistent threshold value will become more complex. To obtain the reasonable threshold value, with respect to the difficulty of discussions with experts, the researcher may decide upon the value subjectively themselves. This result may differ among researchers.

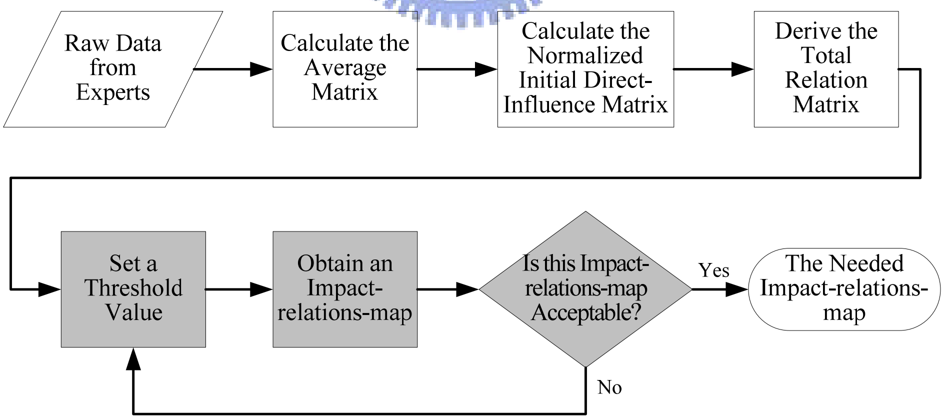


Figure 1-1. The steps of the DEMATEL method.

Different from the traditional method, which confronts the loop from "set a threshold value" to obtain "the needed impact-relationship-map," in this dissertation, we propose the Maximum Mean De-Entropy (MMDE) algorithm to obtain a threshold value for delineating the impact-relationship-map. This algorithm, based on the entropy approach, can be used to derive a set of *dispatch-nodes*, the factors which strongly dispatch influences to others, and a set of *receive-nodes*, which are easily influenced by other factors. According to these two sets, a unique threshold value can be obtained for the impact-relationship-map.

1.3 Framework and Methods

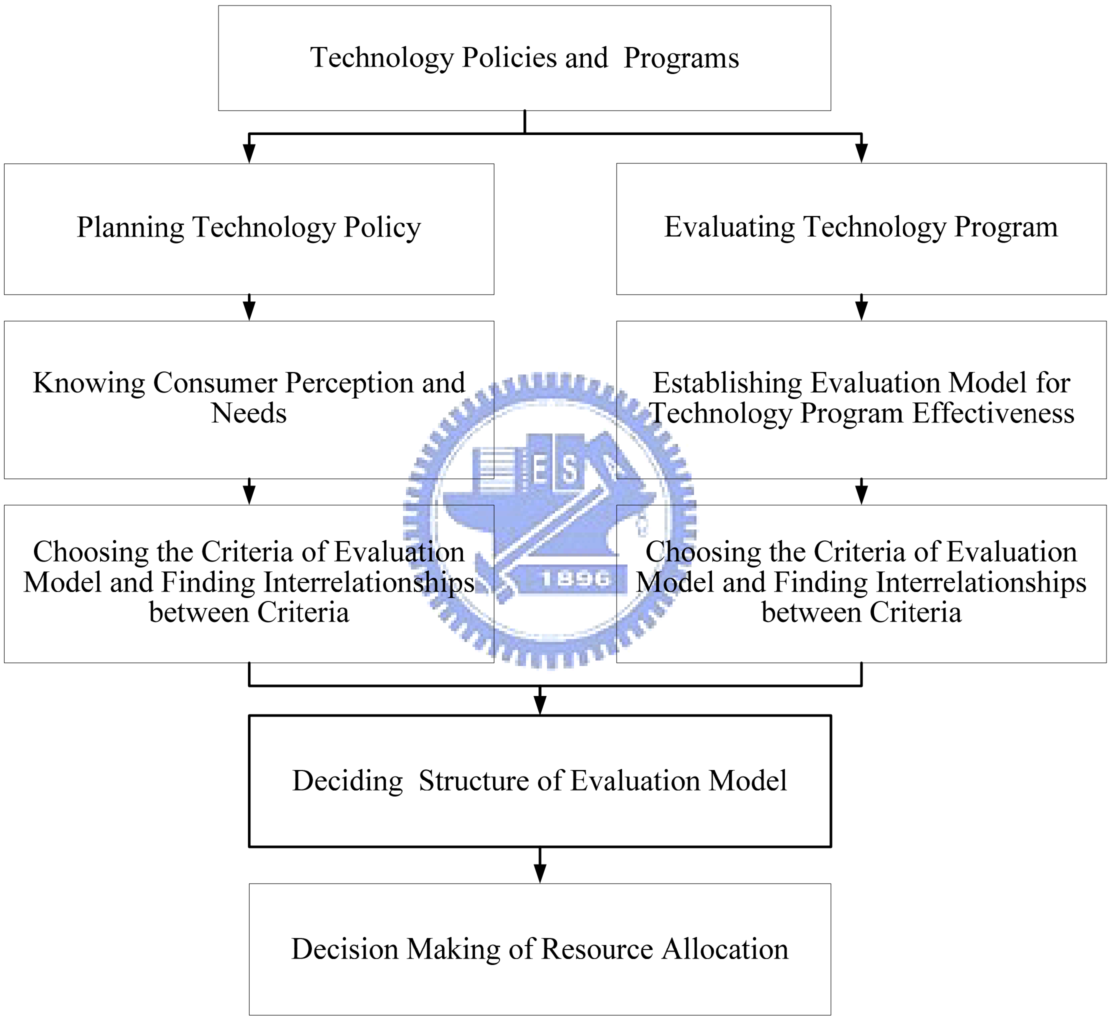


Figure 1-2 Research Framework

The framework in this dissertation is illustrated in Fig 1-2. It will be important to identify the criteria and determine their relationships for the planning or evaluation phases of the technology policy that we will be researching. For a planning problem, knowing customer's needs and perceptions, and determining the key factors for customers is vital for a technology policy. For an evaluating problem, choosing the adequate criteria and delineating the relationships between them is necessary for a structured and effectiveness evaluation model. The method this dissertation proposes can be use to enable the derivation of the interrelated services and the structural interrelationships between them. Using the DEMATEL method and deciding the threshold value by MMDE can effectively be used to describe the structure of a *problematique*.

In the numerical example, two real cases will be evaluated: one for the application in the field of the planning problem and another for the application of a program evaluation. The first case is the Semiconductor Intellectual Property (SIP) Mall case. It is an example of a planning problem required to discover and illustrate the key services needed to attract SIP users and SIP providers to an SIP Mall. By using the proposed the MMDE algorithm to determine the threshold value, we derived the same impact-relationship-maps from traditional methods and the algorithm, although the analytical procedures used were different.

The second case is the E-Learning case, which is an example of the evaluation problem. It is analyzed to establish a new e-learning evaluation model to determine e-learning program effectiveness with consideration to intertwined relationships and synthetic utility between the criteria. In this case, we used the MMDE algorithm to determine the interrelationships between the criteria for evaluating effects in E-learning programs. We aim to demonstrate that MMDE is a suitable method that can be used to determine a threshold value in the first step, or the final step, to discuss the adequacy of the impact-relationship map.

1.4 Assumptions of Dissertation

The assumptions of this study are as follows:

(1) Before using the structural model, or algorithm, this dissertation proposed, the criteria used to plan a policy or evaluate a program must been chosen.

(2) The criteria used to plan a policy, or evaluate a program, must have at least one interrelationship. In other words, the criteria are not independent.

(3) The surveyed population is assumed to be homogenous and have a basic understanding of the questions in the questionnaires.

1.5 Outline of Dissertation

The outline of this dissertation is illustrated in Figure 1-3. The research motivation, background, purpose, framework and methods are described in Chapter 1. Chapter 2 presents the literature review where related studies of structural models for planning problems, evaluation problems, and the DEMATEL method, are reviewed. The steps of the proposed maximum mean de-entropy algorithm will be described, explained, and discussed in Chapter 3. Chapter 4 illustrates the two practical cases. We analyze the results of these two case studies and derive conclusions and recommendations in Chapter 5.

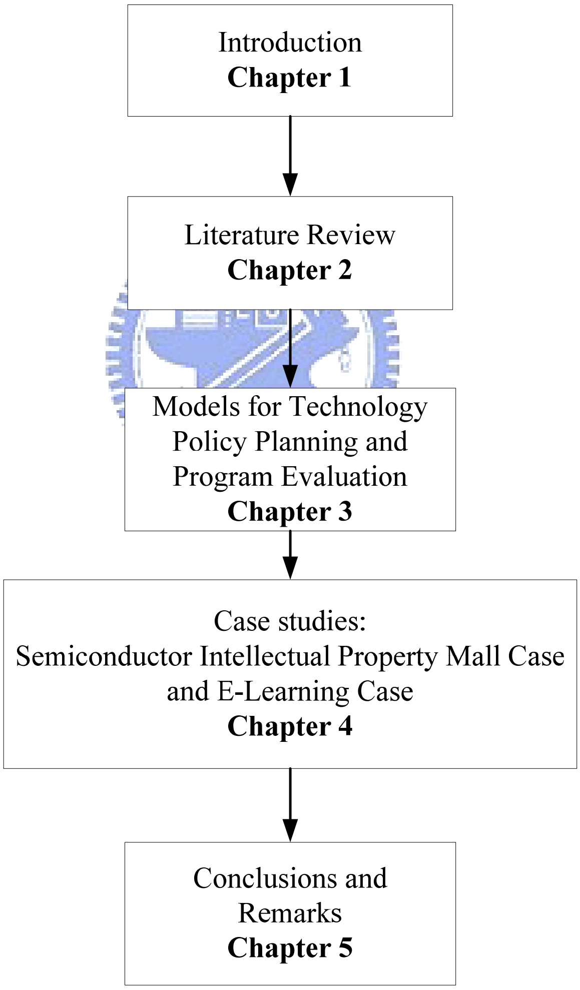


Figure 1-3 Outline of Dissertation

Chapter 2 Literature Review

Technology managers increasingly face problems of scale and complexity in research, development and alliance efforts in emerging technology fields. Information technology, biotechnology and nanotechnology are good examples of sectors with complex coordination problems. Choices which technology managers have to make include the selection of projects, the choice of investment alternatives, and the formation of technology licensing agreements [23, 24].

Methods used for exploring the complexity of societal problems have focused on idea management. In the domain of decision analysis, the decision-makers have to consider the viewpoints of all alternatives to solve the decision problems. With regard to the analysis of decision problems, we should consider the following research directions:

(1) For an accurate analysis, examine and grasp the characteristics of problems. Methodologies in the domain of the data approach of multi-variance statistic analysis should be studied further and developed to find a suitable method to handle such problems;

(2) Methodologies in the domain of Design/Planning should be developed to solve practical multi-aspect problems. The best alternatives can be determined found or programmed;

(3) The last direction is the evaluation of alternatives. The Evaluation/choice multi-attribute evaluation method should be adopted.

MCDM is considered to be a complex and dynamic process in which one managerial level and one engineering level can be distinguished [25]. The managerial level defines the goals and chooses the final "optimal" alternative; the multi-criteria nature of decisions is emphasized at this level, in which public officials, or "decision-makers," have the power to accept or reject the solution proposed by the engineering level. The decision-makers, who provide the preference structure, are "offline" of the optimization procedure completed at the engineering level. In addition the preference structure is often based on political, rather than technical, criteria. In such cases, a system analyst can aid the decision-making process by conducting a comprehensive analysis and by listing the important properties of non-inferior and/or compromising solutions.

Among the numerous approaches available for conflict management, MCDM is one of the most widely used. In this approach, practical problems are often characterized by several non-commensurable and competing (conflicting) criteria, with no solution satisfying all the criteria simultaneously. Thus, a compromising solution for problems with conflicting criteria should be determined to help decision-makers reach a final decision. The MCDM procedure applied in this dissertation consists of the following steps:

(1) Establishing system evaluation criteria (multiple) that relate system capabilities to goals;

(2) Developing (designing) alternative systems for attaining the goals (generating alternatives);

(3) Evaluating alternatives in terms of criteria (the values of the criterion functions);

(4) Applying a normative multi-criteria analysis method (such as compromise ranking) to evaluate alternatives;

(5) Accepting one alternative as ‘‘optimal’’ (preferred); and

(6) If the final solution is not accepted, then gather new information and proceed to the next iteration of multi-criteria optimization.

Steps (1) and (5) are performed at the decision (upper) level, where decision-makers have a central role. Other steps are mostly mechanical tasks. Alternatives can be generated and their feasibility can be tested using mathematical models, physical models, and/or by experiments in the existing system, or other similar systems. Generating alternatives may be a very complex process, there is no general procedure or model for it, and no mathematical procedure could replace human creativity in generating and evaluating alternatives. Constraints are seen as high-priority objectives, and must be considered and satisfied in the alternatives generating process. Assuming that each alternative is evaluated according to each criterion function, the compromised ranking method could be applied to determine a compromised solution, helping the decision-makers to reach a final decision.

The main field of MCDM includes two aspects, multi-objective design/planning and multi-criteria evaluation/choice. Based on these aspects, the systematic research in methodologies and their applications can be put into practice.

2.1 Methods for Technology Policy Planning

Technology policy is defined as government measures or programs to promote the innovation and adoption of new technologies in key industries. Technology policies include government sponsorship of research consortia, support for research and development (R&D), trade measures, and special antitrust exemptions for joint R&D efforts among firms. Planning technology policy is rarely post-modern. Its goal is the improvement of policy and organizations based on an understanding of the underlying scientific and technological constraints and potential.

Policy planning is methodologically diverse using both qualitative and quantitative methods, including case studies, survey research, statistical analysis, and model building among others. One common methodology involves defining the problem and evaluation criteria, identifying all alternatives and evaluating them, and recommending the best policy agenda. Multi-objective decision-making (MODM) methods have became more important for solving practical planning problems.

Methods for solving single objective mathematical programming problems have been studied extensively over the past 40 years. However, single objective decision-making methods reflect an earlier and simpler era. Multiple objective problems have become more important in real-world problems. The concept of Pareto optimization has appeared in classic economics, developing rapidly since Kuhn-Tucker [26] and Koopman introduced vector optimization. The related methods are shown in Figure 2-1 and can be categorized as discussed below.

The trade-off problem is that, since a final optimal solution should generally be given through mathematical programming, multiple objectives must be transformed into a weighted single objective. Therefore, a process of obtaining the trade-off information for the considered objectives should first be identified. Note that if the trade-off information is unavailable, Pareto solutions should be derived. The scaling problem, as the number of dimensions increases beyond capacity, suffers from the problem of the dimensionality curse, i.e., the computational cost increases tremendously. Yu [27] proved the theory of compromise solution, and decision-makers can use this concept to choose the best one from the set of efficient solutions [28]. For the past few decades, a great number of theories and methodologies have been developed based on this concept, and have been applied to various real-world problems such as scheduling, production planning, portfolio selection, capital budgeting, and transportation [28-31].

Charnes, Cooper, and Ferguson introduced data envelopment analysis (DEA) to handle the problem of inconsistent goal units [32]. The DEA approach can combine multiple output and input variables to assess an enterprise's operating performance. One of the goals of the current study is to understand which geographical area exhibits better productivity efficiency. DEA is now one of the most popular approaches for evaluating the performance of non-profit and business units. The inputs and outputs are usually measured by exact values on a ratio scale.

De Novo programming was proposed by Zeleny [33, 34] to redesign or reshape given systems in order to achieve an aspiration/desired level. The original idea was that productive resources should not be engaged individually and separately, because resources are not independent. By releasing various constraints, De Novo programming attempts to break limitations in order to achieve the aspiration/desired solution. This method makes the programmer think in an opposite direction from the traditional methods which fixed constrains.

Instead of building complex utility functions, outranking methods compare the preference relations among alternatives to acquire information on the best alternative. Although outranking methods were proposed to overcome empirical difficulties experienced with the utility function in handling practical problems, the main criticisms of outranking methods are related to the lack of axiomatic foundations. Hwang et al. introduced TOPSIS (technique for order preference by similarity to an ideal solution) method to solve the alternative ranking problems. The TOPSIS method is presented in Chen and Hwang [35], with reference to Hwang and Yoon [36]. The basic principle is that the chosen alternative should have the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution. This method was applied to handle multi-objective programming problems, a process called TOPSIS MODM.

According to the properties of collected data, the fuzzy set, grey, and rough set theories can be used with the MODM models. Fuzzy set theory [37, 38] was originally proposed to deal with problems of subjective uncertainty. Subjective uncertainty results from using linguistic variables to represent the problem or event. A linguistic variable is a variable which is expressed by verbal words or sentences in a natural or artificial language to indicate the membership functions of the expression values. The adoption of linguistic variables is now widespread, and the method is used to assess the linguistic ratings given by evaluators. Furthermore, linguistic variables are employed as a way to measure the achievement of the performance value for each criterion. Fuzzy set theory has been embodied in disciplines such as artificial intelligence, pattern recognition, and information systems in which representation issues are a major concern, forming what can be called information sciences and information engineering [39]. Sakawa [40] combined this concept with Bellman and Zadeh's [41] idea of decision making in a fuzzy environment to develop fuzzy multi-objective programming.

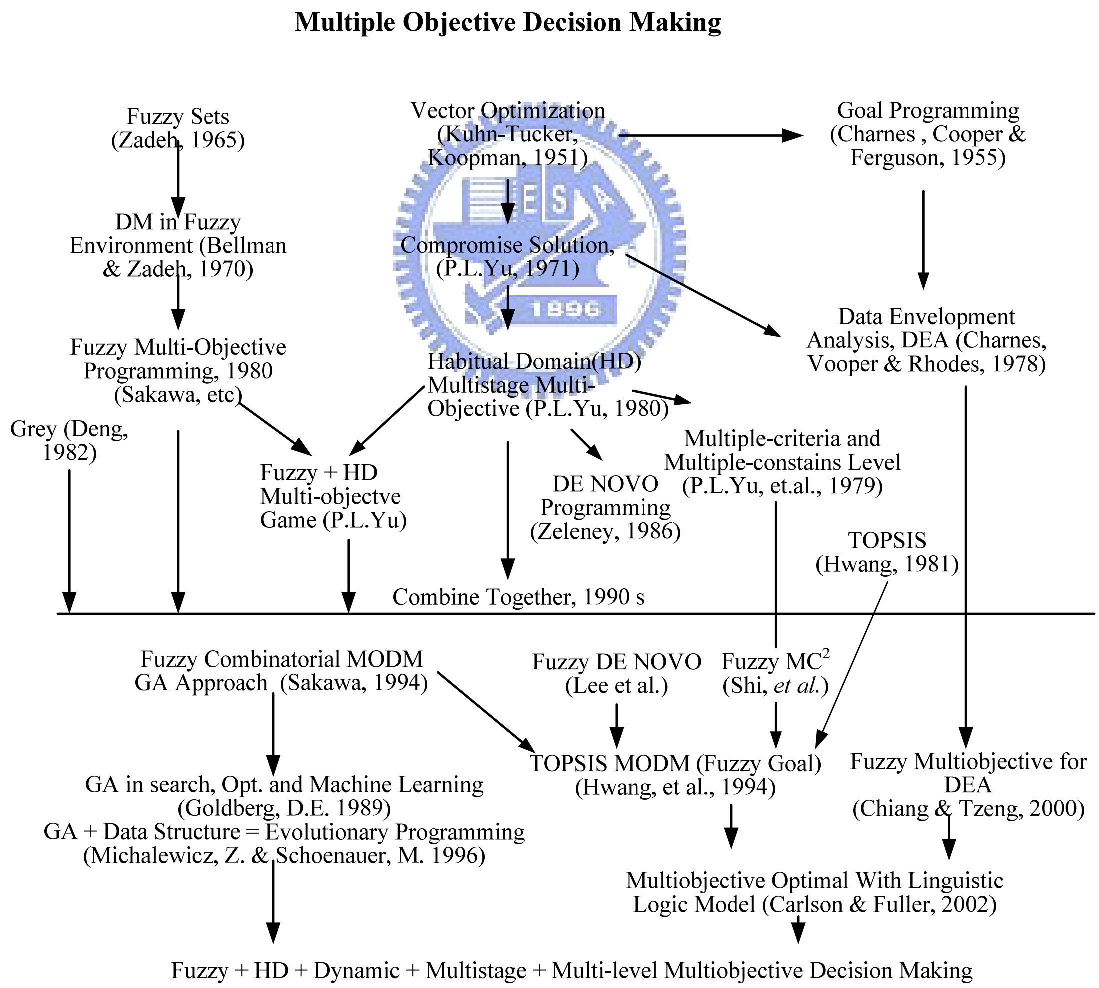
Grey theory, as proposed by Deng [42], can be used to perform grey relation analysis by dealing with finite and incomplete output data[43]. The analysis is used to solve uncertainty problems with discrete data and is basically a robust but simple and straightforward multi-criteria decision-making technique. It is able to handle both incomplete and imprecise information, especially in situations where there is not enough data and the sample distribution pattern is unknown [44].

Rough set theory, originally proposed by Pawlak [45], is a mathematical tool used to deal with vagueness or uncertainty. Compared to fuzzy sets, there are some advantages to rough set theory [46]. One main advantage is that rough sets do not need any pre-assumptions or preliminary information about the data, such as the grade of membership function in fuzzy sets [47]. Rough set theory provides an effective tool for extracting knowledge from data tables and can be applied to solve MCDM problems by Pawlak and Slowinsk [48]. For MODM problems, rough set theory can induce a set of decision rules from exemplary decisions provided by decision makers. The induced decision rules play the role of a comprehensive preference model and can provide recommendations in a new decision-making environment.

A considerable amount of work for solving MODM problems has been done on various applications such as transportation investment and planning, econometric and development planning, financial planning, business planning and investment portfolio selecting, land-use planning, water resource management, public policy and environmental issues, and so on. The work is extended from simple to multilevel and multistage MODM for confronting the more complicated real-world problems.

Recently, many evolution algorithms, such as genetic algorithms [49], genetic programming [50], and evolution strategy [51], have been suggested to solve the various MODM problems.

For MODM problems, structuring complex problems through graphical representations and analyzing causal influences can illuminate complex issues, systems, or concepts. Finding adequate, central criteria to represent the effectiveness of factors/aspects and avoiding "overloading" in regards to planning are important issues. In some cases, delineating the interrelationships between the criteria is the first step in planning a policy. In this dissertation, we use the DEMATEL method to structure the problems of policy planning [52]. The related research on DEMATEL will be reviewed in Section 3.2.



Source: Gwo-Hshiung Tzeng, 2009.

Figure 2-1. Development of Multiple Objective Decision Making

2.2 Methods for Technology Program Evaluation

Program evaluation is a systematic method for collecting, analyzing, and using information to evaluate projects, policies, and programs. In the fields of technology management, program evaluation is usually used for choosing government/firm R&D projects, improving technology policies, or evaluating program effectiveness as related to government/firm investments.

Program evaluations can involve quantitative methods of social research, qualitative methods, or both. The main methods of multi-criteria evaluation/choice problems, also known as multi-attribute decision making (MADM) problems, are shown in Figure 2-2. The concept of the evaluation system begins with the concept of utility introduced by Bernoulli, who argued that humans do not pursue the maximum benefit but maximum utility. "The Theory of Game and Economic Behavior," written by Von Neumann and Morgen [53], is widely considered the groundbreaking text that created the interdisciplinary research field of game theory. In the game of life, the stakes are not necessarily monetary; they may be merely utilities. In discussing utilities, the authors found it advisable to replace the questionable marginal utility theory by a new theory which is more suitable to their analysis and aroused the development of utility theory. Keeney and Raiffa [54] improved the additive multi-attribute utility into a multiplicative measure, and the fuzzy integral brought up by Sugeno [55] changed the concept of additive multi-attribute utility and evaluation.

ELECTRE is a family of multi-criteria decision analysis methods. The ELECTRE method was developed to choose the best action(s) from a given set of actions, but it was soon applied to three main problems: choosing, ranking, and sorting. Roy first introduced ELECTRE in 1967. ELECTRE I was developed in 1971 (the alternatives are divided into good or bad), with ELECTRE II developed in 1976 having the ability to rank the alternatives. The development of fuzzy theory then gradually matured. ELECTRE III and IV, introduced in 1984, contain the concept of fuzzy membership.

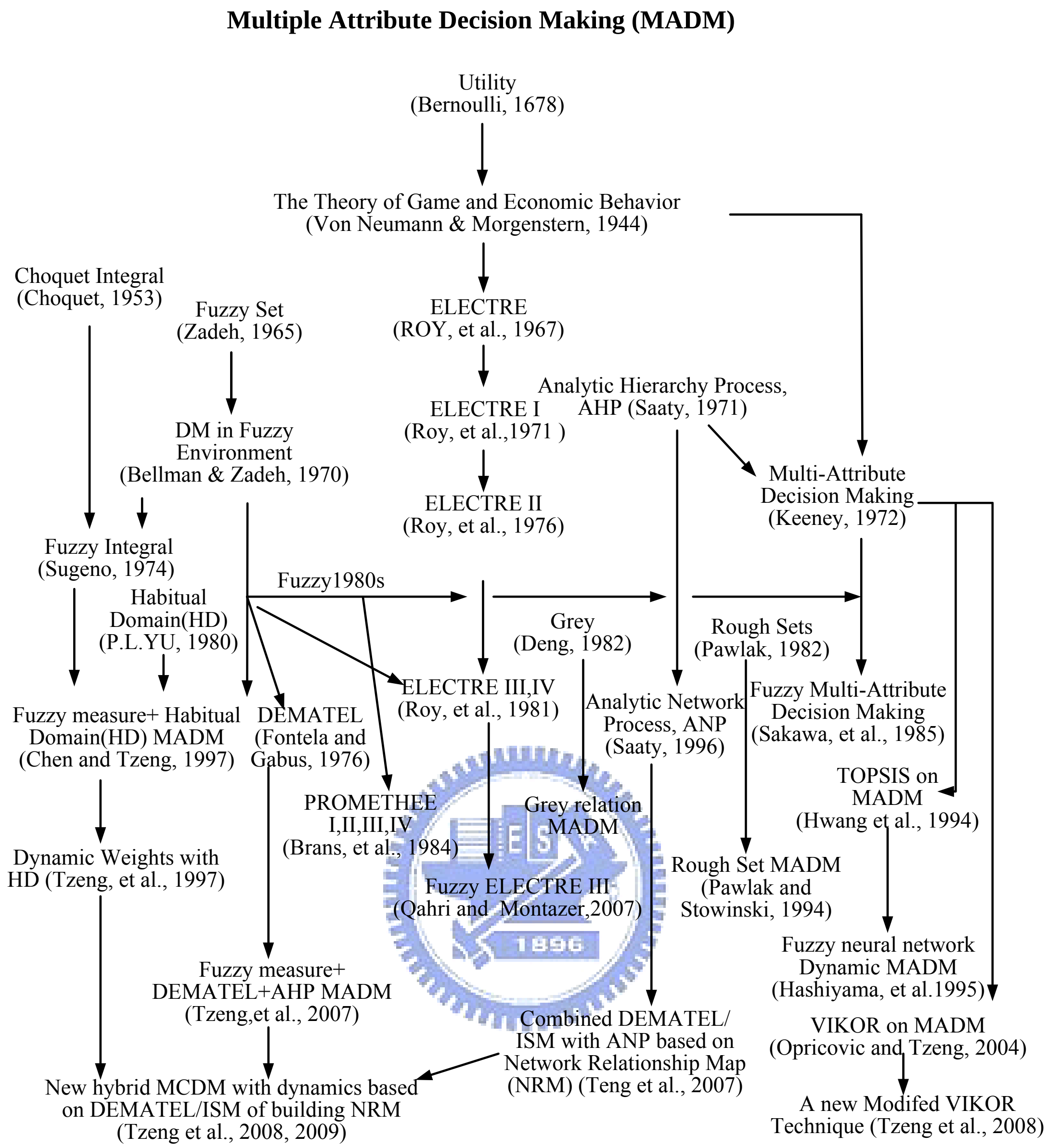
The technique for order preference by similarity to ideal solution (known as TOPSIS) is a modification of compromise programming. This method was developed based on the concept that, using Euclidean distance, the chosen alternative should have the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution [36, 56]. This method has been expanded to fuzzy TOPSIS.

Wolters and Mareschal [57] considered new types of stability analysis for additive MCDM methods, including the additive utility function and outranking methods such as PROMETHEE [58, 59].

The analytic hierarchy process (AHP) was introduced by Saaty in 1971. AHP was originally applied to uncertain decision problems with multiple criteria, and has been widely used for ranking, selection, evaluation, optimization, and prediction decisions. The analytic network process (ANP) was proposed by Saaty [11, 60] to overcome the problem of interdependence and feedback between criteria or alternatives, and is the general form of AHP which has been used in MADM to release the restriction of hierarchical structure. ANP has been applied to project selection [61, 62], product planning, strategic decision [63, 64], optimal scheduling [65], and so on. The procedures of AHP will be discussed in Section 3.4.

The VIKOR method was developed as a MCDM method to solve a discrete decision problem with noncommensurable, conflicting criteria [66]. This method focuses on ranking and selecting from a set of alternatives, and determines compromise solutions for a problem with conflicting criteria, which can help the decision-makers to reach a final decision. Here, the compromise solution is a feasible solution which is the closest to the ideal, and a compromise means an agreement established by mutual concessions.

According to the properties of collected data, the fuzzy set, grey, and rough set theories can also be used with MADM models. With successful applications in the field of automatic control, fuzzy sets have been incorporated into MADM to deal with MADM problems under the situation of subjective uncertainty. Grey relation analysis can be used to evaluate the original data directly and does not need additional interactions during the process. Since its inception, grey relation analysis has been widely used in fields concerning performance evaluation [67]. When rough set theory is applied to MADM, it is crucial to deal with preference-ordered attribute domains and decision classes [68, 69].



Source: Gwo-Hshiung Tzeng, 2009.

Figure 2-2. Development of Multiple Attribute Decision Making

2.3 SIP Mall Policy Planning

The SIP Mall is designed to provide the services needed for SIP providers and SIP users to reduce the time, risk and cost of chip design, and to allow chip design companies to have sufficient and reliable key components for marching into the worldwide chip design market. Although the functions of the SIP Mall are helpful for customers and could accelerate the growth of the SIP market, there are still some obstacles for the development of the SIP Mall. In this section, we will explain the functions and the locus of the SIP Mall, describe the favorable conditions for the development of the SIP Mall, and conclude with a series of issues which issues the SIP Mall confronts and seeks to resolve.

2.3.1 The functions of an SIP Mall

An SIP Mall is a service center to provide customers with a one stop shopping environment for chip design—from mixing-and-matching intellectual properties to manufacturing. As illustrated by the SIP trade flow diagram (see Figure 2-3), an SIP Mall provides services for each step: from SIPs matching to post-sale. The revenue of an SIP Mall comes from the trade commission, service fees as well as a share of the licensing income from co-owner SIPs. Possible benefits of an SIP Mall for customers include enhancing chip design techniques and greater competitiveness in the global market.

Two main roles that an SIP Mall plays in the SIP trade process are the role of an SIP information center and an SIP trade center. As an SIP information center, the main functions of an SIP Mall include SIP collecting, searching, and matching. Most chip design companies are like avant-garde artists that fight alone in a market without adequate information, smooth marketing channels, complete SIP verification, or quality assurance. The numerous types of products, the uncertain development situations of SIPs, and the differing business models, make finding suitable SIPs difficult.

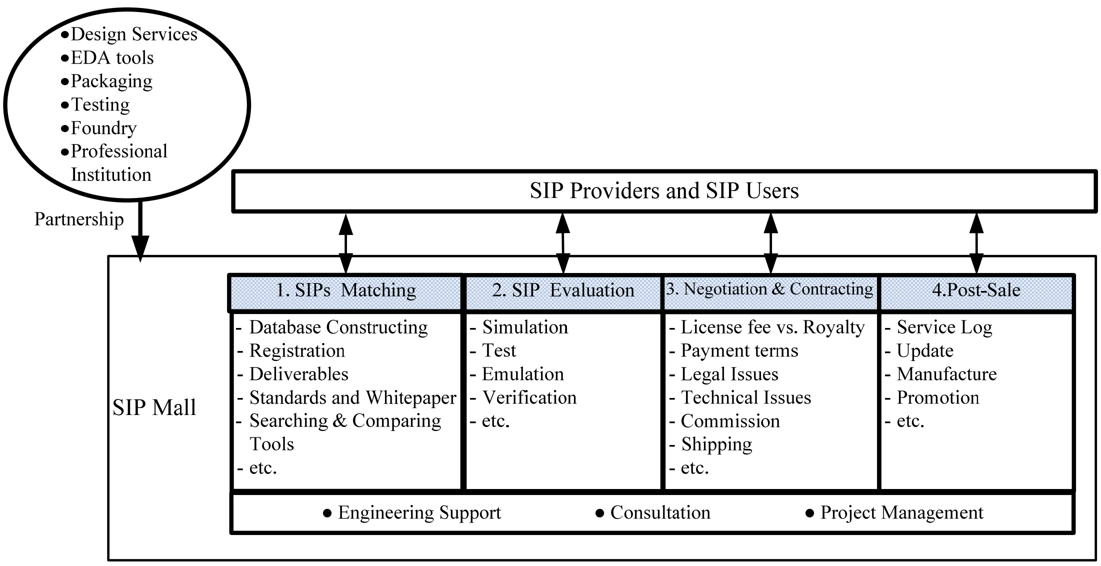


Figure 2-3. Services the SIP Mall provides to facilitate the phases of the SIP trade

Some SIP vendors have set up websites to provide customers with a broad range of SIP information that is needed for chip design*. However, because an SIP Mall also provides expertise in chip design and production, it is not just a searchable SIP database [70]. The websites information, such as the taxonomic schema[71], the SIP providers' credit and the grade of an SIP, is as important as a functional description of SIPs, but is seldom provided by these companies or websites.

The second role of the SIP Mall is of an SIP trading center. As an SIP trading center, the SIP Mall focuses customer's attention on the value added by unique technology, applications expertise, support services, and the ease of evaluating, buying and integrating the product. In addition to the services provided by other SIP vendors, an SIP Mall also provides a complete package of services for producing and marketing chips after they have been designed. This full range of services allows the SIP Mall to cover all phases of SIP trade flow. The value of an SIP product varies on customer utilization [72, 73] and the market share of the SIP product. The SIP Mall can reduce a customer's time to market by allowing them to obtain all these services from a single source.

Beside the roles of information center and trade center, some SIP Malls also act as SIP start-up incubators. Compared with foundries or IDMs, the total assets of most chip design companies are much smaller than other players in the semiconductor industry. In the semiconductor industry, the ability of some firms to capitalize on their ability to learn more rapidly than others may contribute to strong performance in specific areas [74]. Because of the variety of production, multiplicity of technology standards, and the miniaturization of chip design companies, the SIP Mall will expand as new SIP start-ups gain momentum. An SIP Mall, especially one established by a semiconductor foundry or sponsored by a government, not only acts as an SIP vendor, but also plays the role of a venture capitalist. To strengthen customers' attraction and the potential impact on the industry, foundries invest and help design houses by focusing on small and medium chip design companies or start-ups, via an SIP Mall. This kind of SIP Mall can build up a comprehensive portfolio through their R&D efforts and bring together the critical parts of design and manufacturing into streamlined and specially optimized

* The websites of companies such as Virtual Component Exchange (VCX) and Design and Reuse (D&R) provide SIP catalogs, application news, whitepapers and even software for analyzing and finding suitable SIPs.

processes. When this SIP is used in an application and mass produced, the producer, who embeds this SIP in a system, will certainly be a customer of the foundry.

Until now, the main roles of an SIP Mall primarily depended on the intentions of the SIP Mall founder. For example, VCX (http://www.thevcx.com), a company initially funded by the Scottish government but became a private company in 2003, derives revenues from SIP providers and users mainly by licensing software products to allow users to search for SIPs, store information, set requirements, control access to deliverables, control and track requests for information and feed SIP data into internal catalogs. The main role that VCX plays in this instance is an SIP information center. The goals of the Taiwan government are to nurture design houses, most of which are Small to Medium sized Enterprises (SMEs), and to enhance Taiwan's semiconductor industry, from foundry to chip design. The SIP Malls sponsored by the Taiwan government focus on the role of incubator and extend the SIP trade to production as a trading center.

2.3.2 Factors Contributing to the Development of the SIP Mall

Initially, in the SIP industry, only a few companies, such as ARM and MIPS, specifically designed SIPs and licensed them for royalties or a lump sum as their major source of income. Now, the roles of the major players in the SIP industry have been extended to the whole supply chain of the semiconductor industry and successfully pioneered a networked model based on licensing markets. To better support the needs and requirements of customers, SIP companies, such as VCX and Reusable Application-Specific Intellectual Property Developers (RAPID), have created well-established technology alliances with partner companies. These alliances benefit customers by providing access to more complete solutions, accelerating design time, and improving the ease of manufacturing. These platform alliances help to unify a vision for the semiconductor industry and the technical standards required to enable the most critical component of the vision—the mixing and matching of SIPs from multiple sources. The business models of these allied companies familiarize customers with the third-party one-stop service platform the SIP Mall provides.

Some industry consortia, consisting of representatives from the systems, semiconductor, SIP, and Electronic-Design-Automation (EDA) segments of the industry, have also worked for the development of chip design. These consortia are industry bodies focused on the definition and adoption of SIP technical standards and interfaces 1 and educational initiatives for the design community. Companies which utilize SIPs for faster entry into the market, usually license the needed SIP from these individual companies based on the information and standards specified by these consortia. Information about SIP development can be also obtained by monitoring the progress of industry consortia, standard bodies, initiatives and working groups active in SIP issues, such as Hard SIP quality, SIP portability, business models, licensing and other topics for current or future needs [75, 76]. The open standards and specifications created by these consortia also facilitate the integration of SIPs from multiple sources for the SIP Mall and its customers. Additionally, support from the government will also enforce the growth of the SIP market and the services provided by SIP Malls.

Semiconductor manufacturing has become a global enterprise. An SIP Mall would connect SIP designers and users in various locations of the global market and provide them with a chance to enforce the competition of design companies and the semiconductor industry in the country to which they belong. The growing market of the SIP industry attracts the involvement of foundries and governments to look for opportunities to purchase or license SIPs for chip design.11 Many countries, including Japan, South Korea, France, Scotland, and Taiwan, have rolled out SIP Mall programs [19]. The experience and technological capabilities provided by the foundries, and the institutional, technological, and competitive environment of the country, will influence foreign investment decisions [77]. The smaller firms and start-ups have allied to take advantage of perceived opportunities [73] and the government policies can facilitate the initial market entry of SMEs and promote continual upgrades and creation of knowledge [78, 79]. The resources from the government will help the companies which are inclined to join the burgeoning SIP industry to bear more risk in the initial stages of development.

2.3.3. Issues Faced by SIP Malls

In the process of chip design, from clarifying the functional specifications of the requirements to verifying the functions of the chips, it is found to be difficult for designers to incorporate SIPs into a single design because companies have different SIP design specification requirements. Chip design, especially in future SOC design, will contain several reused functional blocks from internal and external sources. SIPs with certain functionalities from different providers are more easily integrated into a product if a standard has been developed.

The Virtual Socket Interface Alliance (VSIA) is the primary organization developing standards to enhance the productivity of chip design. However, VSIA does not develop standards relating to the internal design of SIPs, functional architecture of subsystem components, fabrication processes, and techniques for EDA tools. Most SIP providers license configurable and preconfigured SIP solutions that enable their customers to design products, but lack standards for the processes of testing and verifying components. The SIP provider's licensable technology is usually focused on a specific architecture to dominate the specific application markets. To make an SIP standard architecture, a vast ecosystem of companies must support the SIP provider, but it is difficult for SMEs and new companies entering the market to attract powerful players' support to create a new standard architecture because the players dominate the technology and market.

SIP providers and users also meet with more difficult integration situations in the trading environment. Legal provisions [80, 81], application platform development, SIP development, and other services related to the trading procedure [82] should also be considered before SIP trading. Significant Internet-related obstacles, including SIP ownership conflicts, design support disputes that reflect interdependencies among individual design blocks, and disagreements over pricing and royalties [83] also should be considered. Currently, most contracts are negotiated, signed and completed only between the licensor and the licensee. A design that incorporates multiple SIP products may involve several SIP providers and more than one source of manufacturing. As a result, SIP users have to manage multiple providers in the supply chain, each with different business models and technical capabilities. Even though the SIP business models tend to be more complex, an intermediary, or agent such as the SIP Mall, does not play a major role in the process. The situations make customers consider outsourcing jobs to an agent, but make them doubt that the SIP Mall can resolve these problems.

Although the growing market of the SIP industry attracts the involvement of foundries and governments[†] to search for opportunities to purchase or licence SIPs for chip design, the primary concern for an SIP Mall is how to attract SIP providers and SIP users. While SIP Mall founders must determine which services are most conducive to operating an attractive SIP Mall, these issues have rarely been studied. In this research, we interviewed chief-executive officers, senior technical personnel, and marketing managers from twenty-four SIP licensee and licensor companies to determine which services (customer's needs) were required for establishing a successful SIP Mall. The SIP Mall is designed to provide the services needed for SIP providers and SIP users to reduce the time, risk and cost of chip design, and to allow chip design companies to have sufficient and reliable key components for marching into the worldwide chip design market. Taiwan is the world's largest semiconductor foundry and second largest fabless IC design provider. To maintain the leading position, competitiveness and the value added of Taiwan's foundry, fabless, and thus the IC industry in the SOC era, the Taiwanese government stepped in. The Si-Soft Project [84], launched by the Taiwan government in 2000, was aimed at enhancing Taiwan's capabilities in (1) innovative SOC product designs; (2) silicon SIP development; (3) EDA flow integration; (4) SIP Malls; and (5) SOC design services. Even though the Taiwanese government has exerted considerable effort into developing the SIP and SIP Mall industries over years, Taiwanese SIP Malls are still in their exploratory phase. SIP sources are limited and few SIP transactions are made. As can be seen, users and providers in the SIP industry still experience the difficulties of this maturation. Although the functions of the SIP Mall are helpful for customers and could accelerate the growth of the SIP market, there are still some obstacles for the development of the SIP Mall. An important issue for an SIP Mall is how to attract SIP providers and SIP users to trade it.

[†] Exchange (VCX) Software Ltd. was established and funded by the Scottish government, Unichip, and Faraday Technology and were established by the TSMC (Taiwan Semiconductor Manufacturing Co. Ltd.) and UMC (United Microelectronics Corporation) foundries. The China Software and Integrated Circuit Public Service Platform (CSIP) were set up by the People's Republic of China government (http://www.csip.cn). Chartered, a Singapore foundry, collaborates with the VCX to provide SIP licensing business.

2.4 E-Learning Programs Evaluation

2.4.1 Introduction

Internet has significantly impacted the establishment of Internet-based education, or e-learning. Internet technology evolution and e-business has affected all industrial and commercial activity and accelerated e-learning industry growth. It has also fostered the collaboration of education and Internet technology by increasing the volume and speed of information transfer and simplifying knowledge management and exchange tasks. E-learning could become an alternative way to deliver on-the-job training for many companies, saving money, employee transportation time, and other expenditures. An e-learning platform is an emerging tool for corporate training, with many companies developing their own e-learning courses for employee on-the-job training. Employees can acquire competences and problem solving abilities via Internet learning for benefits among business enterprises, employees, and societies while at work.

Although e-learning has been developing for several years, evaluating e-learning effectiveness is critical as to whether companies will adopt e-learning systems. A considerable number of studies have been conducted emphasizing the factors to be considered for effectiveness evaluation. Several evaluation models are considered with specific aspects. The criteria used for e-learning effectiveness evaluation are numerous and influence one another.

The evaluation models however, are deficient and do not have an evaluation guideline. Effectiveness evaluation criteria must integrate learning theories, relative web site design, course design, and learning satisfaction theories to form an integrated evaluation model [6, 85-87]. Since e-learning can be evaluated according to different aspects and criteria, the MCDM approach is suitable for e-learning evaluation.

E-learning combines education functions into electronic form and provides instruction courses via information technology and Internet in e-Era. The most popular definition of e-learning as defined by the American Society for Training and Development (ASTD) is a wide set of applications and processes, such as Web-based learning, computer-based learning, virtual classrooms, and digital collaboration. E-learning is not an innovative education idea, since Computer-Aided Training (CAT), Computer-Based Training (CBT), and distance learning have been used as elements of e-learning for more than ten years. Research shows that students can be effective learners over the Web, and learn as much, if not more, than in traditional courses.

E-learning is currently a burgeoning educational and training tool because of its cost saving advantages, institution reusability, and learner flexibility. World governments emphasize e-learning for social and public education, and want to enlarge it as a branch of education. The European Union in 2000, proposed the e-Europe project, promoting an information society for all. Moreover, the Japanese government has proposed the e-Japan project, making e-learning one of seven main application development items. E-learning has also been used with university and enterprise education. Enterprises can introduce e-learning courses and systems into the firm, which can then be used by the human resources or research development department to do on-the-job training. When companies induce e-learning courses into their organization, they can save money otherwise used for guest lecturers, and employees can learn on demand.

Each e-learning procedure, from course design to learner response or behaviour measurement, will affect course performance. According to previous research, instructional system design process models are process-oriented rather than product-oriented and include built-in evaluation and revision systems [88]. Systematic instructional system designs follow five learner need stages: (1) analysis, (2) design, (3) development, (4) implementation, and (5) evaluation, or the ADDIE acronym model [89]. The ADDIE is usually used in mentoring as an intervention that can be linked to three primary functions: (1) organization, (2) training and development, and (3) career development [90].

The basic reason for e-learning evaluation is to find out the effectiveness, efficiency, or appropriateness of a particular course of action. E-learning effectiveness evaluation intends to highlight good or bad practice, detect error and correct mistakes, assess risk, enable optimum investment to be achieved, and allow individuals and organizations to learn [91]. Evaluation can be most effective when it informs future decisions [92]and is better used to understand events and processes for future actions, whereas accountability looks back and properly assigns praise or blame.

Over the past few years, considerable studies have been undertaken primarily to find the dimensions or factors to be considered in evaluation effectiveness, however, with a specific perspective. Kirkpatrick proposed four levels of training evaluation criteria: (1) reactions, (2) learning, (3) behaviour, and (4) results [93, 94]. Garavaglia [95] proposed five dimensions to evaluate e-learner change: (1) supervisory report, (2) on- the-job peer surveys, (3) action plan reports, (4) observation, and (5) self-report. Among these five methods, the observation method can avoid the possible bias a supervisor may have when reporting on a subordinate. The self-report method involves either interviews or surveys distributed or conducted two to three months after the learning session. Phillips [96] formed a logical framework to view ROI (Return on Investment) both from a human performance and business performance perspective. Urdan [97] proposed four measure indicators, learner focused measures, performance focused measures, culture focused measures, and cost-return measures, to evaluate corporate e-learning effectiveness. Since web-based instruction has become the most engaging type for learning, four factors that affect the e-learning environment should also be identified: (1) efficacy studies, (2) technological advances, (3) pressures of competition and cost containment, and (4) professional responses to market influences [98].

2.4.2 Methods for Evaluating E-Learning Course Effectiveness

Formative evaluation and summative evaluation are two common methods for evaluating e-learning course effectiveness in recent decades. Formative evaluation is used at the onset of new instructional program implementation to assess the needs and learning goals of an organization, or for program evaluation following training to revise existing programs. Several familiar formative evaluation models prescribe a four-part evaluation procedure employing expert reviews, one-to-one evaluations, small group evaluation, and field trials [99]. Formative evaluation is typically categorized according to different processes such as design-based, expert-based, and learner-based for assessment, although.

Summative evaluation, one of the most popular methods focused on outcomes and used in classroom education. For example, the CIRO (Contents/Contexts, Inputs, Reactions and Outcomes) model which measures learning/training effectiveness by CIRO elements, both before and after training, is currently widely used in business

[100]. The strength of the CIRO model is consideration of objectives (contexts) and training equipment (inputs). The main emphasis of CIRO is measuring managerial training program effectiveness, but it does not indicate how measurement takes place. Adopting measures during training provides the training provider with important information regarding the current training situation, leading to improvements [101]. Summative evaluation models lack consideration of other factors, such as individual characteristics, e-learning interface design, instructional system design, and course design, which may influence e-learning effectiveness.

Most evaluation models however, do not measure e-learning effectiveness from an overall perspective and ignore the interrelation among criteria. Most evaluation models concentrate on finding factors, aspects, or casual relationships between them. Quantitative study models mainly use traditional statistic methods or linear models (e.g. ANOVA, factor analysis and structural equation model) to find learner satisfaction or dissatisfaction via questionnaires or facial communications [102-106]. Typically, e-learning program effectiveness is evaluated by multiple intertwined and inter-affected criteria, and the perceptions of utility for learners are not monotonic. Establishing a model to evaluate all available criteria and to determine central criteria, learner utility perception about these criteria, and the future improvement direction for the programs is necessary.

Chapter 3 Models for Technology Policy Planning and Programs Evaluation

This chapter presents the models, which used for policy planning and policy evaluating, include factor analysis, DEMATEL method, fuzzy measure and fuzzy integral, and the analytical hierarchy procedure. These models are used to explore the structure of criteria for planning problem and to establish a hybrid model for policy evaluation. Five methods are illustrated from Section 3.1 to 3.4, respectively. Then, the MMDE algorithm is described in Section 3.5.

3.1 The Factor Analysis

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:

(1) Find the correlation matrix $(\boldsymbol{R})$ or variance-covariance matrix for the objects to be assessed;

(2) Find the eigenvalues $(\lambda_k,\ \ k=1,2,...,m)$ and eigenvectors $(\boldsymbol{\beta}_k=[\beta_{1k},...,\beta_{ik},...,\beta_{pk}])$ for assessing the factor loading $(a_{ik}=\sqrt{\lambda_k}\beta_{ik})$ and the number of factors (m);

(3) Consider the eigenvalue ordering $(\lambda_1>...>\lambda_k>...>\lambda_m;\lambda_m>1)$ to decide the number of common factors, and pick the number of common factors to be extracted by a predetermined criterion;

(4) According to Kaiser [107], use varimax criteria to find the rotated factor loading matrix, which provides additional insights for the rotation of factor-axis;

(5) Name the factor referring to the combination of manifest variables.

When a large set of variables are factored, the method first extracts the combinations of variables, explaining the greatest amount of variance, and then proceeds to combinations that account for progressively smaller amounts of variance. Two kinds of criteria are used for selecting the number of factors: latent root criterion and percentage of variance criterion. The former criterion is that any individual factor should account for the variance ($Var(Y_k) = \lambda_k$) of at least a single variable if it is to be retained for interpretation. In this criterion only the factors having eigenvalues greater than 1 (i.e. $\lambda_k \geq 1, \quad k = 1, 2, ..., m$) are considered significant. The latter criterion is based on achieving a specified cumulative percentage of total variance extracted by successive factors. Its purpose is to ensure the extracted factors can explain at least a specified amount of variance. Practically, to be satisfactory the total amount of variance explained by factors should be at least ninety-five per cent in the natural sciences, and sixty per cent in the social sciences. However, no absolute threshold has been adopted for all applications [108].

3.2 The DEMATEL Method

The DEMATEL method is based on graph theory, enabling us to plan and solve problems visually, so that we may divide the relevant factors into cause and effect groups in order to better understand causal relationships. The methodology can confirm interdependence among variables and aid in the development of a directed graph to reflect the interrelationships between variables.

The end product of the DEMATEL process—the impact-relations map—is a visual representation of the mind by which the respondent organizes his or her own action in the world. This organizational process must occur for the respondent to keep internally coherent and to reach his or her personal goals. The steps of the DEMATEL method [20] are described as follows:

(1) Find the average matrix

Suppose there are h experts available to solve a complex problem and there are n factors to be considered. The scores given by each expert give us a $n \times n$ non-negative answer matrix $\boldsymbol{X}^k$, with $1 \leq k \leq h$. Thus $\boldsymbol{X}^1$, $\boldsymbol{X}^2$,…, $\boldsymbol{X}^h$ are the answer matrices for each of the h experts, and each element of $\boldsymbol{X}^k$ is an integer denoted by x_{ij}^k. The diagonal elements of each answer matrix $\boldsymbol{X}^k$ are all set to zero. We can then compute the $n \times n$ average matrix $\boldsymbol{A}$ by averaging the h experts' score matrices. The (i, j) element of matrix $\boldsymbol{A}$ is denoted by a_{ij} ,

$$a_{ij} = \frac{1}{h}\sum_{k=1}^{h} x_{ij}^k . \tag{3-1}$$

In application, respondents were asked to indicate the direct influence that they believe each factor exerts on each of the others according to an integer scale ranging from 0 to 4. A high score from a respondent indicates a belief that greater improvement in i is required to improve j. From any group of direct matrices of respondents, it is possible to derive an average matrix $\boldsymbol{A}$.

(2) Calculate the normalized initial direct-relation matrix

We then create a matrix $\boldsymbol{D}$ by using a simple matrix operation on $\boldsymbol{A}$. Suppose we create matrix $\boldsymbol{D}$ and $\boldsymbol{D} = s \cdot \boldsymbol{A}$ where

$$s = Min\left[\frac{1}{\max\limits_{1\le i\le n}\sum_{j=1}^{n}\left|a_{ij}\right|}, \frac{1}{\max\limits_{1\le j\le n}\sum_{i=1}^{n}\left|a_{ij}\right|}\right]. \tag{3-2}$$

Matrix $\boldsymbol{D}$ is called the *normalized initial direct-relation matrix*. The (i, j) element d_{ij} denotes the direct influence from factor x_i to factor x_j. Suppose $d_{i\bullet}$ denotes the row sum of the i-th row of matrix $\boldsymbol{D}$.

$$d_{i\bullet} = \sum_{j=1}^{n} d_{ij} \tag{3-3}$$

The $d_{i\bullet}$ shows the sum of influence directly exerted from factor x_i to the other factors. Suppose $d_{\bullet j}$ denotes the column sum of the j-th column of matrix $\boldsymbol{D}$.

$$d_{\bullet j} = \sum_{i=1}^{n} d_{ij} \tag{3-4}$$

Then $d_{\bullet j}$ shows the sum of influence that factor x_j received from the other factors. We can normalize $d_{i\bullet}$ and $d_{\bullet j}$ as

$$w_i(d) = \frac{d_{i\bullet}}{\sum_{i=1}^{n} d_{i\bullet}} \tag{3-5}$$

$$v_j(d) = \frac{d_{\bullet j}}{\sum_{j=1}^{n} d_{\bullet j}} \tag{3-6}$$

(3) Derive the total relation matrix

Matrix $\boldsymbol{D}$ shows the initial influence which a factor exerts and receives from another. Each element of matrix $\boldsymbol{D}$ portrays a contextual relationship among the elements of the system and can be converted into a visible structural model — an *impact-relations map* — of the system with respect to that relationship. For example, as shown in Figure 3-1, the respondents are requested to indicate only direct links. In the directed graph represented in Figure 3-1, factor *i* directly affects only factors *j* and *k*; while indirectly, it also affects first *l*, *m,* and *n* and, secondly, *o* and *q*. The digraph map helps to explain the structure of the factors.

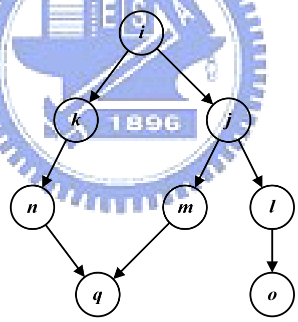


Figure 3-1. Example of a direct graph.

A continuous decrease of the indirect effects of problems along the powers of matrix $\boldsymbol{D}$, e.g. $\boldsymbol{D}^2$, $\boldsymbol{D}^3$,…, $\boldsymbol{D}^{\infty}$, guarantees convergent solutions to the matrix inversion, similar to an absorbing Markov chain matrix. Note that $\lim_{m\to\infty} \boldsymbol{D}^m = [0]_{n\times n}$, where $[0]_{n\times n}$ is the $n \times n$ null matrix. The total relation matrix $\boldsymbol{T}$ is an $n \times n$ matrix and is defined as follows:

$$\begin{aligned}\sum_{m=1}^{\infty} \boldsymbol{D}^i &= \boldsymbol{D} + \boldsymbol{D}^2 + \boldsymbol{D}^3 + \ldots + \boldsymbol{D}^m = \boldsymbol{D}\,(\boldsymbol{I} + \boldsymbol{D} + \boldsymbol{D}^2 + \boldsymbol{D}^3 + \ldots + \boldsymbol{D}^{m-1}) \\ &= \boldsymbol{D}\,(\boldsymbol{I} - \boldsymbol{D})^{-1}\left(\boldsymbol{I} - \boldsymbol{D}\right)(\boldsymbol{I} + \boldsymbol{D} + \boldsymbol{D}^2 + \boldsymbol{D}^3 + \ldots + \boldsymbol{D}^{m-1}) \\ &= \boldsymbol{D}\,(\boldsymbol{I} - \boldsymbol{D})^{-1}(\boldsymbol{I} - \boldsymbol{D}^m) \\ &= \boldsymbol{D}\,(\boldsymbol{I} - \boldsymbol{D})^{-1},\end{aligned} \tag{3-7}$$

where $\boldsymbol{I}$ is the identity matrix and $\boldsymbol{T}$ is called the *total relation matrix*. The (i, j) element of the matrix $\boldsymbol{T}$, t_{ij}, denotes the full direct and indirect influence exerted from factor x_i to factor x_j. Like the formula (3-3) — (3-6), we can obtain $t_{i\bullet}$, $t_{\bullet j}$, $w_i(t)$, and $v_j(t)$.

(4) Set a threshold value and obtain the impact-relations map

In order to explain the structural relationship among the factors while keeping the complexity of the system to a manageable level, it is necessary to set a threshold value p to filter out the negligible effects in matrix $\boldsymbol{T}$. Using the values of $w_i(t)$ and $v_i(t)$ from the matrix of full direct/indirect influence relations, the level of dispatching and receiving of the influence of factor i can be defined. The inter-relationship of each factor can be visualized as the oriented graphs on a two-dimensional plane after a certain threshold is set. Only those factors that have an effect in matrix $\boldsymbol{T}$ greater than the threshold value should be chosen and shown in an impact-relations map.

3.3 Fuzzy Measure and Fuzzy Integral

The concept of Fuzzy measure and fuzzy integral was introduced by Sugeno. Fuzzy measure is a measure for representing the membership degree of an object to candidate sets [55, 109]. A fuzzy measure is defined as follows:

Let X be a universal set and $P(X)$ be the power set of X.

A fuzzy measure, g, is a function, which assigns each crisp subset of X a number in the unit interval [0, 1] with three properties:

(1) g: $\mathrm{P}(X) \rightarrow [0,1]$;

(2) $g(\varnothing) = 0$, $g(X) = 1$ (boundary conditions);

(3) $A \subset B \in X$ implies $g(A) \leq g(B)$ (monotonicity).

Sugeno proposed the so-called λ-fuzzy measure or Sugeno measure satisfying the following additional two properties:

(1) $\forall A, B \in P(X)$, $A \cap B = \phi$;

(2) $g_\lambda(A \cup B) = g_\lambda(A) + g_\lambda(B) + \lambda g_\lambda(A) g_\lambda(B)$, where $\lambda \in (-1, \infty)$.

For two criteria *A* and *B*, if $\lambda > 0$, i.e. $g_\lambda(A \cup B) > g_\lambda(A) + g_\lambda(B)$ implies *A*, *B* have multiplicative effect; $\lambda = 0$ implies *A* and *B* have additive effect; and $\lambda < 0$ imply *A*, *B* have substitutive effect. Since λ value is in the interval (-1, ∞), researcher usually choose λ value as -0.99 and 1 to represent the different types of effect and to discuss the results.

General fuzzy measures and fuzzy integrals, which require only boundary conditions and monotonicity, are suitable for real life. Fuzzy measures and fuzzy integrals can analyze the human evaluation process and specify decision-makers' preference structures. Following the results of Section 3.2, the impact-digraph-map and the interrelation between components of each factor are illustrated. Criteria effectiveness is affected directly/indirectly by other criteria, and can be calculated as follows:

(1) Calculate affected element weights using fuzzy measure

Let *X* be a finite criterion set, $X = \{x_1, x_2, \cdots, x_n\}$, and *P*(*X*) be a class of all the subsets of *X*. It can be noted as $g_i = g_\lambda(x_i)$. Based on the properties of Sugeno measure, the fuzzy measure $g_\lambda(X) = g_\lambda(\{x_1, x_2, \cdots, x_n\})$ can be formulated as Eq. (3-8)-(3-9) (Leszcynski *et al.*, 1985).

$$g_\lambda(\{x_1, x_2, \cdots, x_n\}) = \sum_{i=1}^{n} g_i + \lambda \sum_{i1=1}^{n-1} \sum_{i2=i1+1}^{n} g_{i1} g_{i2} + \cdots + \lambda_{n-1} g_{i1} g_{i2} \cdots g_{in}$$
$$= \frac{1}{\lambda} \left| \prod_{i=1}^{n} (1 + \lambda g_i) - 1 \right|, \quad for -1 < \lambda < \infty \tag{3-8}$$

$$\lambda + 1 = \prod_{i=1}^{n} (1 + \lambda g_i) \tag{3-9}$$

(2) Calculate the effectiveness of final affected elements using fuzzy integral

The fuzzy integral is often used with fuzzy measure for the purpose of congregating information evaluation. The Choquet integral of fuzzy measure is the most frequently used calculation method. This research adopts this method to calculate the effectiveness scores of final affected elements (criteria) of a factor. The basic concept of traditional integral and fuzzy integral can be illustrated in **Figure** 3-2.

Let *h* is a measurable set function defined on the 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 Eq. (3-10) [55, 110-112] ($(c)\int h \cdot dg$ means the Choquet integral). 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. The basic concept of traditional integral and fuzzy integral can be illustrated in **Figure** 3-2.

$$
\begin{aligned}
(c)\int h \cdot dg &= h(x_n)\cdot g(H_n) + \left[h(x_{n-1}) - h(x_n)\right]\cdot g(H_{n-1}) + \cdots + \left[h(x_1) - h(x_2)\right]\cdot g(H_1) \\
&= h(x_n)\cdot\left[g(H_n) - g(H_{n-1})\right] + h(x_{n-1})\cdot\left[g(H_{n-1}) - g(H_{n-2})\right] + \cdots + h(x_1)\cdot g(H_1)
\end{aligned}
$$

where $H_1 = \{x_1\}, H_2 = \{x_1, x_2\}, \cdots, H_n = \{x_1, x_2, \cdots, x_n\} = X$ (3-10)

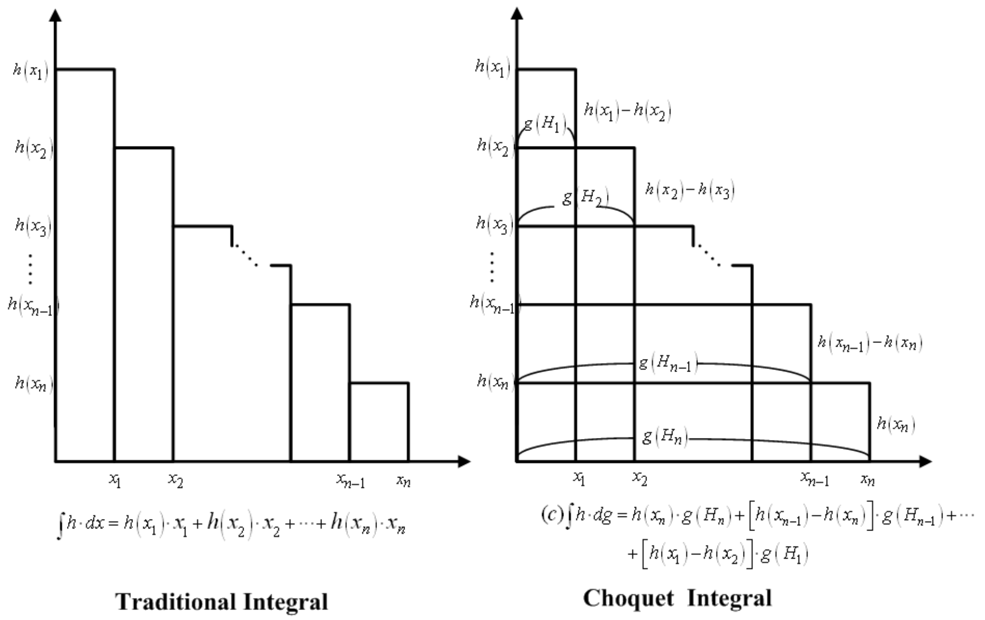


Figure 3-2. Diagrams of traditional Riemann integral and non-additive fuzzy integral (Choquet integral)

3.4 Analytical Hierarchy Procedure (AHP)

The AHP is proposed by Saaty [10]. AHP was originally applied to uncertain decision problems with multiple criteria, and has been widely used in solving problems of ranking, selection, evaluation, optimization, and prediction decisions [113]. Harker and Vargas [114] stated that “AHP is a comprehensive framework designed to cope with the intuitive, rational, and the irrational when we make multi-objective, multi-criteria, and multifactor decisions with and without certainty for any number of alternatives." The AHP method is expressed by a unidirectional hierarchical relationship among decision levels. The top element of the hierarchy is the overall goal for the decision model. The hierarchy decomposes to a more specific criteria until a level of manageable decision criteria is met [115]. Under each criterion, sub-criteria elements relative to the criterion can be constructed. The AHP separates complex decision problems into elements within a simplified hierarchical system [116].

AHP procedures to gain the weights are described as follows:

(1) Structuring the hierarchy for evaluation

The AHP method is used to make the decomposition (or structuring) of the problem as a hierarchy. In general, the AHP method divides the problem into three levels: (a) the goal for resolving the problem; (b) the objectives for achieving the goal; and (c) the evaluation criteria for each objective.

(2) Pairwise-comparing for the relative importance of factors and obtaining a $n \times n$ pairwise comparison matrix

The n means the number of criteria. After structuring a hierarchy, the pairwise comparison matrix for each level is constructed. During the pairwise comparison, the nominal scale is used for evaluation. The scale of relative importance is presented in Table 3-1.

(3) Check the logical judgment consistency using the Consistency Index (*C.I.*) and Consistency Ratio (*C.R.*)

The *C.I.* value is defined as $C.I. = (\lambda_{\max} - n)/(n-1)$, and the $\lambda_{\max}$ is the largest eigenvalue of the pairwise comparison matrix. The *C.R.* value is defined as *C.R.* = *C.I.*/*R.I.* (*R.I.*: Random Index. The *R.I.* value is decided by the value of *n*. The *R.I.* values from $n=1$ to $n=10$ be 0, 0, 0.58, 0.9, 1.12, 1.24, 1.32, 1.41, 1.45 and 1.49). In general, the values of *C.I.* and *C.R.* should be less than 0.1 or reasonably consistent.

(4) Use the normalized eigenvector of the largest eigenvalue ($\lambda_{\max}$) as the factor weights

Table 3-1 Scale of relative importance

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Intermediate between equal and weak	
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
4	Intermediate between weak and strong	
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
6	Intermediate between strong and demonstrated	
7	Demonstrated importance	An activity is strongly favored and its dominance is demonstrated in practice
8	Intermediate between demonstrated and absolute	
9	Absolute or extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above non-zero numbers	If activity i has one of the above non- zero numbers assigned to it when compared with activity j; then j has the reciprocal value when compared with i.	Reasonable assumption

3.5 Maximum Mean De-Entropy Algorithm (MMDE)

As this dissertation described in Chapter 1 and Section 3.2, there are four steps in the DEMATEL method: (1) calculate the average matrix, (2) calculate the *normalized initial direct-influence matrix*, (3) derive the *total relation matrix*, and (4) set a threshold value and obtain the *impact-relations map*. In Step 4, an appropriate threshold value is necessary to obtain a suitable impact-relations map as well as adequate information for further analysis and decision-making. The threshold value can be chosen by the decision maker or through discussions with experts. If the threshold value is too low, the map will be too complex to show the necessary information for decision-making. If the threshold value is too high, many factors will be presented as independent factors, without showing the relationships with other factors. Each time the threshold value increases, some factors or relationships will be removed from the map (an example based on a total relation matrix $\boldsymbol{T}^{\text{example}}$ is shown as Formula 3-11 and in Figure 3-3). An appropriate threshold value is necessary to obtain a suitable impact-relations map as well as adequate information for further analysis and decision-making.

$$
\boldsymbol{T}^{\text{example}} = \begin{bmatrix} 0.0093 & 0.0126 & 0.0538 & 0.0523 & 0.0759 \\ 0.0284 & 0.0077 & 0.0292 & 0.0284 & 0.0517 \\ 0.0509 & 0.0729 & 0.0087 & 0.0299 & 0.0341 \\ 0.0313 & 0.0340 & 0.0531 & 0.0086 & 0.0752 \\ 0.0532 & 0.0758 & 0.0547 & 0.0532 & 0.0150 \end{bmatrix} \tag{3-11}
$$

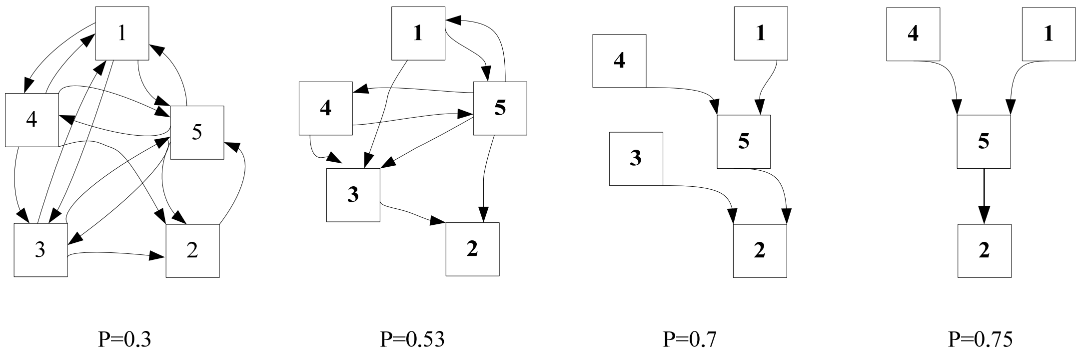


Figure 3-3. Impact-relations maps based on the same total relation matrix but different threshold values.

As we mentioned above, the threshold value is determined by asking experts or by the researcher (as a decision maker). Choosing a consistent threshold value is time-consuming if the impact-relations maps are similar when threshold values are changed slightly. If we consider the total-relation matrix as a partially ordered set, the order relation is decided by the influence value. The question about deciding a threshold value is equal to a real point set divided into two subsets: one subset provides information on the obvious inter-dependent relationships of factors but the relationships are considered not so obvious in another subset. The proposed algorithm is a way to choose the "cut point".

We propose the Maximum Mean De-Entropy (MMDE) algorithm to find a threshold value for delineating the impact-relations map. In this algorithm, we use the approach of entropy, which has been widely applied in information science, but define another two information measures: *de-entropy* and *mean de-entropy*. In addition, the proposed algorithm mainly serves to search for the threshold value by nodes (or vertices). This algorithm differs from the traditional methods through which the threshold value is decided by searching a suitable impact-relations map.

In contrast to the traditional method, which confronts the loop from a "set a threshold value" to obtain "the needed impact-relations-map", as shown in Figure1-1, the MMDE algorithm is used to obtain a threshold value for delineating the impact-relations map. This algorithm based on the entropy approach can be used to derive a set of dispatch-nodes, the factors which strongly dispatch influences to others, and a set of receive-nodes, which are easily influenced by another factor. According to these two sets, a unique threshold value can be obtained for the impact-relations map.

In this section, we use the symbol ■ as the end of a definition or a step in the proposed algorithm.

3.5.1 Information Entropy

Entropy is a physical measurement of thermal-dynamics and has become an important concept in the social sciences [29, 117]. In information theory, entropy is used to measure the expected information content of certain messages, and is a criterion for measuring the amount of "uncertainty" represented by a discrete probability distribution.

Definition 3-1: Let a random variable with n elements be denoted as $X = \{x_1, x_2, ..., x_n\}$, with a corresponding probability $P = \{p_1, p_2, ..., p_n\}$, then we define the entropy, H, of X as follows:

$$H(p_1, p_2, \cdots, p_n) = -\sum p_i \lg p_i$$

subject to constraints (3-12) and (3-13):

$$\sum_{i=1}^{n} p_i = 1 \quad (3\text{-}12)$$

$$p_i \lg p_i = 0 \quad \text{if} \quad p_i = 0 \quad (3\text{-}13)$$

■

By Definition 3-1, the function "lg" means the logarithms which are taken to an arbitrary but fixed base. The value of $H(p_1, p_2, \cdots, p_n)$ is the largest when $p_1 = p_2 = \cdots = p_n$ and we denote this largest entropy value as $H\left(\frac{1}{n}, \frac{1}{n}, \cdots, \frac{1}{n}\right)$. Now we will define another measure for the decreased level of entropy: *de-entropy*.

Notation: In this dissertation, the function "lg" means the logarithms to base exponential e.

Definition 3-2: For a given finite discrete scheme of X**,** the *de-entropy* of X is denoted as H_n^D and defined as:

$$H_n^D = H\left(\tfrac{1}{n}, \tfrac{1}{n}, \cdots, \tfrac{1}{n}\right) - H\left(p_1, p_2, \cdots, p_n\right)$$

■

By Definition 3-2, the value of H^D is equal to or larger than 0. Unlike entropy, which is used for the measure of uncertainty, the H_n^D can explain the amount of useful information derived from a specific dataset, which reduces the "uncertainty" of information. We define the de-entropy for searching the threshold value in order to assess the effect of information content when adding a new node to an existing impact-relations map. By Definition 3-1, Formula (3-14) can be proven (the proof can be found in (Khinchin, 1957)):

$$H_n = H\left(\tfrac{1}{n}, \tfrac{1}{n}, \cdots, \tfrac{1}{n}\right) \leq H\left(\tfrac{1}{n+1}, \tfrac{1}{n+1}, \cdots, \tfrac{1}{n+1}\right) = H_{n+1} \qquad (3\text{-}14)$$

Formula (3-14) explains that when adding a new variable to a system where all variables in the system have the same probability, the entropy of the system will increase.

To delineate an impact-relations map, if adding a new factor to the impact-relations map can make the system less uncertain, or lead to more de-entropy, then the new factor provides worthwhile information for a decision maker. In other words, in an existing information system whose variables and corresponding probabilities have been fixed, adding a new variable to the system will change the probability distribution; if $H_{n+1}^D > H_n^D$ exists, then this new variable provides useful information to avoid uncertainty for the decision maker.

3.5.2 The Dispatch- and Receive-Nodes

In the DEMATEL method, the total-relation matrix is the matrix used to delineate the final output of the DEMATEL method, the impact-relations map, after the threshold value is determined. As in the notation in Section 2, an $n \times n$ total relation matrix is denoted as $\boldsymbol{T}$. The (i, j) element of the matrix $\boldsymbol{T}$, $t_{ij,}$ refers to the full direct and indirect influence exerted from factor x_i to factor x_j. Like the "vertices" and "edges" in graph theory [118], x_i and x_j are vertices in the directed graph impact-relations map, and t_{ij} can be considered as a directed edge which connects factors x_i and x_j with an influence value. In an impact-relations map, every factor may influence, or be influenced by, another factor, or both.

Definition 3-3: The (i, j) element of the matrix $\boldsymbol{T}$ is denoted as t_{ij} and refers to a directed influence relations from factor x_i to factor x_j. For each t_{ij}, the factor x_i is defined as a *dispatch-node* and factor x_j is defined as a *receive-node* with respect to t_{ij}.

■

By Definition 3-3, an $n \times n$ total relation matrix $\boldsymbol{T}$ can be considered as a set (set T) with n^2 pair-ordered elements. Every subset of set T can be divided into two sets: an ordered dispatch-node set and an ordered receive-node set. For an ordered dispatch-node set (or an ordered receive-node set), we can count the frequency of the different elements of the set. If the finite cardinality of an order dispatch-node set (or an ordered receive-node set) is m and the frequency of element x_i is k, we assign the corresponding probability of x_i as $p_i = \frac{k}{m}$. In this way, for an ordered set, we can assign each different element a probability and follow Definition 1 for $\sum_{i=1}^{n} p_i = 1$.

Notation: In this dissertation, $C(X)$ denotes the cardinal number of an ordered set X and $N(X)$ denotes the cardinal number of different elements in set X. For example, if $X = \{1, 2, 2, 3, 1\}$, $C(X) = 5$ and $N(X) = 3$.

3.5.3 Maximum Mean De-Entropy (MMDE) Algorithm

Based on a calculated total relation matrix $\boldsymbol{T}$, the steps of the proposed Maximum Mean De-Entropy algorithm for determining a threshold value are described as follows:

Step 1: Transforming the total relation matrix into an ordered triplets set.

Transforming the n x n total relation matrix $\boldsymbol{T}$ into an ordered set T, $\{t_{11}, t_{12}, \ldots,$

t_{21}, t_{22}, …, t_{nn}} , rearranging the element order in set T from large to small, and transforming to a corresponding ordered triplets (t_{ij}, x_i, x_j) set denotes T^*. ■

Every element of set T, t_{ij}, can also be considered as an ordered triplet (t_{ij}, x_i, x_j) as (influence value, dispatch-node, receive-node). As the matrix $\boldsymbol{T}^{\text{example}}$ of the example mentioned above, the transformed and rearranged set, T^{example}, is {0.0759, 0.0758, 0.0752, ..., 0.0077}. The ordered triplets set is {(0.0759, 1, 5), (0.0758, 5, 2), (0.0752, 4, 5), …, (0.0077, 2, 2)} and the cardinal number of $T^{*\text{example}}$, $C(T^{*\text{example}})$, is 25.

Step 2: Taking the second element from the ordered triplets set to establish a dispatch-node set

Taking the second element, the dispatch-node, from the ordered triplets of the set T^* and then obtaining a new ordered dispatch-node set, T^{Di}. ■

According to the set T^*, we can derive the corresponding ordered dispatch-node set. As the set $T^{*\text{example}}$ of the example in Step 1, the ordered dispatch-node set T^{Di} is {1,5, 4, ..., 2} and $C(T^{Di})$ is also 25.

Step 3: Calculating the mean de-entropy of dispatch-node set

Taking the first t elements of T^{Di} as a new set T_t^{Di}, assign the probability of different elements, and then H^D of the set T_t^{Di}, H_t^{Di}. We can calculate the *mean de-entropy* by $MDE_t^{Di} = \dfrac{H_t^{Di}}{N(T_t^{Di})}$. At first, the t is set as 1, then of value of t is determined by raising the value from 1 to $C(T^{Di})$ in increments of 1. ■

Why we use $\dfrac{H_t^{Di}}{N(T_t^{Di})}$ as "mean de-entropy" rather than $\dfrac{H_t^{Di}}{C(T_t^{Di})}$ must be clarified. Regardless of how many times a dispatch-node repeats in a set T_t^{Di}, this dispatch-node will show in the impact-relations map only once if we use this T_t^{Di} to draw the impact-relations map. The H_t^{Di} is the de-entropy of $N(T_t^{Di})$ dispatch-nodes in the impact-relations map, not $C(T_t^{Di})$

dispatch-nodes. In this step, we can obtain $C(T^{Di})$ mean de-entropy values. As the set $T^{*example}$, we will obtain 25 mean de-entropy values.

Step 4: Finding the maximum mean de-entropy

In $C(T^{Di})$ mean de-entropy values, select the *maximum mean de-entropy* and its corresponding T_t^{Di}. This dispatch-node set, with the maximum mean de-entropy, is denoted as $T_{\max}^{Di}$.

■

Step 5: Similar to Steps 2 to 4, an ordered receive-node set T^{Re} and a maximum mean de-entropy receive-node set $T_{\max}^{Re}$ can be derived.

■

Step 6: Finding the threshold value

Taking the first u elements in T^* as the subset, T^{Th}, which includes all elements of $T_{\max}^{Di}$ in the dispatch-node and all elements of $T_{\max}^{Re}$ in the receive-node, the minimum influence value in T^{Th} is the threshold value, and Formula (3-15) holds.

$$1 < C(T^{Th}) < C(T^*) \tag{3-15}$$

■

In Step 6, the elements of $T_{\max}^{Di}$ are the "more important" factors which provide more information about influence dispatching for a decision maker than other factors. The elements of $T_{\max}^{Re}$ provide information on which are easily influenced. If we use the ordered triplets T^{Th}, $T_{\max}^{Di}$, and $T_{\max}^{Re}$ in the structured directed graphs $G(T^{Th})$, $G(T_{\max}^{Di})$ and $G(T_{\max}^{Re})$, Formula (3-16) holds.

$$G(T^{Th}) = G(T_{\max}^{Di}) \cup G(T_{\max}^{Re}) \tag{3-16}$$

with the property of

$$G(T_{\max}^{Di}) = G(T_{\max}^{Re}) \quad \text{or} \quad G(T_{\max}^{Di}) \subseteq G(T_{\max}^{Re}) \quad \text{or} \quad G(T_{\max}^{Di}) \supseteq G(T_{\max}^{Re}) .$$

If $G(T^{Di}_{max}) = G(T^{Re}_{max})$, then $G(T^{Th})$ is the perfect directed graph for the impact-relations map with both the maximum mean de-entropy dispatch-node set and receive-node set. If $G(T^{Di}_{max}) \subseteq G(T^{Re}_{max})$ or $G(T^{Di}_{max}) \supseteq G(T^{Re}_{max})$, then the structured $G(\mathrm{T}^{Th})$ is the minimum impact-relations map which includes the necessary maximum mean de-entropy dispatch- and receive-node sets. Based on $\boldsymbol{T}^{\text{example}}$, the results from Steps 1 to 6 are shown in Table 3-2.

Table 3-2: The results from Step 1 to Step 6

Item	Data
Step 1: The ordered triplets set $T^{*\text{example}}$	{ (0.0759, 1, 5), (0.0758, 5, 2), (0.0752, 4, 5), (0.0729, 3, 2), (0.0547, 5, 3), (0.0538, 1, 3), (0.0532, 5, 1), (0.0532, 5, 4), (0.0531, 4, 3), (0.0523, 1, 4), (0.0517, 2, 5), (0.0509, 3, 1), (0.0341, 3, 5), (0.0340, 4, 2), (0.0313, 4, 1), (0.0299, 3, 4), (0.0292, 2, 3), (0.0284, 2, 1), (0.0284, 2, 4), (0.0150, 5, 5), (0.0126, 1, 2), (0.0093, 1, 1), (0.0087, 3, 3), (0.0086, 4, 4), (0.0077, 2, 2) }
Step 2: Dispatch-Node set, T^{Di}	{1, 5, 4, 3, 5, 1, 5, 5, 4, 1, 2, 3, 3, 4, 4, 3, 2, 2, 2, 5, 1, 1, 3, 4, 2}
Step 3.1: T_t^{Di} sets and MDE_t^{Di} values	T_1^{Di}={1}, MDE_1^{Di}=0; T_2^{Di}={1, 5}, MDE_2^{Di}=0; T_3^{Di}={1, 5, 4}, MDE_3^{Di}=0; T_4^{Di}={1, 5, 4, 3}, MDE_4^{Di}=0; T_5^{Di}={1,5, 4, 3, 5}, MDE_5^{Di}=0.0135; ..., T_{25}^{Di}={1, 5, 4, 3, 5, 1, 5, 5, 4, 1, 2, 3, 3, 4, 4, 3, 2, 2, 2, 5, 1, 1, 3, 4, 2}, MDE_{25}^{Di}=0;
Step 3.2: Set of 25 MDE_t^{Di} values	{0, 0, 0, 0, 0.0135, 0.0142, 0.0273, 0.0433, 0.0283, 0.0266, 0.0283, 0.0185, 0.0169, 0.0145, 0.0160, 0.0165, 0.0060, 0.0019, 0.0012, 0.0025, 0.0009, 0.0012, 0.0012, 0.0007, 0}
Step 4.1: Maximum MDE_t^{Di}	0.0433
Step 4.2: Dispatch- Node set of maximum MDE_t^{Di}	{1, 5, 4, 3, 5, 1, 5, 5}={1, 3, 4, 5}
Step 5.1: Receive-Node set, T^{Re}	{5, 2, 5, 2, 3, 3, 1, 4, 3, 4, 5, 1, 5, 2, 1, 4, 3, 1, 4, 5, 2, 1, 3, 4, 2}
Step 5.2: Set of 25 MDE_t^{Re} values	{0, 0, 0.0283, 0, 0.0146, 0, 0.0086, 0.0099, 0.0173, 0.0105, 0.0126, 0.0041, 0.0089, 0.0071, 0.0045,0.0015, 0.0020, 0.0019,0.0012, 0.0025, 0.0009,0.0012, 0.0012, 0.0007, 0}
Step 5.3: Maximum MDE_t^{Re}	0.0283
Step 5.4: Receive-Node set of the maximum MDE_t^{Re}	{5, 2, 5}= {2,5}
Step 6.1: T^{Di}_{max}	{(0.0759, 1, 5), (0.0758, 5, 2), (0.0752, 4, 5), (0.0729, 3, 2)} (The nodes in shaded box is the needed dispatch-nodes shown at first time in the ordered set)
Step 6.2: T^{Re}_{max}	{ (0.0759, 1, 5), (0.0758, 5, 2)} (The nodes in shaded box is the needed receive-nodes shown at first time in the ordered set)
Step 6.3: T^{Th}	{ (0.0759, 1, 5), (0.0758, 5, 2), (0.0752, 4, 5), (0.0729, 3, 2) }
Step 6.4: Threshold Value	0.0729

The proposed MMDE algorithm has some properties that differ from the traditional method to make the threshold value, as discussed below.

1. *The MMDE mainly serves to decide the "node" rather than the "map".*

In traditional methods, the researcher set a subject adequate threshold to draw the impact-relations map and discussed it with experts to obtain a consistent opinion. If experts are not in agreement on the results, the researcher increases or decreases the threshold value to create another impact-relations map and again discusses it with experts until a consistent impact-relations map is accepted by experts and the final threshold value is set. In the proposed MMDE, the main issue is about whether it is suitable to add a new "node". If we add a new node, the "mean de-entropy" can be improved, then adding it can be helpful to understand a problematique by decreasing the uncertainty of information.

2. *The MMDE considers the properties of both the dispatch and receive influences of a factor*

In the DEMATEL method, after a suitable map is obtained, the focus of the problem can be shown by analyzing the values w_i and v_i, as Formulas (3-5)—(3-6), of the factors in the map. Using the proposed MMDE, we search the **nodes**, including dispatch- and receive-nodes, simultaneously. The MMDE not only considers the factors which strongly influence others, but also the factors which are easily influenced by other factors.

3. *The MMDE can obtain a unique threshold value*

To create a total relation matrix, the threshold value is determined through discussions with respondents or subjectively by the researcher, so the threshold value may differ if the experts or the researcher change. In the traditional method, the researcher may determine the threshold value by decreasing the value (this will change the impact-relations map from simple to complex) or by increasing the value (this will change the impact-relations map from complex to simple), so the results of these two methods may different. If too many factors are included, the problematique becomes too complex. Using the MMDE, a researcher can obtain a unique threshold value, which is helpful to solve the problem a researcher confronts in regards to selecting a consistent threshold value.

Chapter 4 Applications of MMDE Algorithm in Technology Management

In chapter 3, we explained that the end product of the DEMATEL process is a visual representation—the impact-relations map—by which respondents organize their own aspect of the problem and an appropriate threshold value is an important issue to obtain a suitable impact-relations map. The proposed MMDE algorithm can achieve the purpose to obtain a unique threshold value for the DEMATEL. In this chapter, two cases will be used to show the application of DEMATEL with the MMDE algorithm. In these two cases, we use the SIP Mall case to explain how to find the interrelationships between the criteria for a policy planning problem and use E-learning as an example of programs' effects evaluating problem.

4.1 Policy Planning of the SIP Mall

The SIP Mall is a transaction platform for gathering SIPs and promoting SIP trade services. However, SIP users and SIP providers face many obstacles in the process of purchasing SIPs. Due to the increased use of commercial SIPs from multiple sources, the process of finding and evaluating SIPs has become time consuming and more complex. The primary concern for an SIP Mall is how to attract SIP providers and SIP users. While SIP Mall founders must determine which services are most conducive to operating an attractive SIP Mall, these issues have rarely been studied.

An important issue for an SIP Mall is how to attract SIP providers and SIP users to trade it. In addition to feasibility and efficiency, the founders of SIP Malls have to know the perceptions, relationships and needs of both SIP providers and SIP users [12-14] and differentiate their services from the consortium and other SIP vendors. To address this issue, it is necessary to answer the following questions: What critical services should an SIP Mall provide? Do these services all have the same priorities? Is there any interrelation between them? How should an SIP Mall perform these services? To truly benefit its customers, an SIP Mall must understand the needs and expectations of all parties related to the SIP Mall. Answering these questions is also critical to the SIP industry to clarify the role of the SIP agent. In the next section, we will describe the DEMATEL method, explain how to construct the research data set of this study, and illustrate the analysis results.

In this research, we interviewed chief-executive officers, senior technical personnel, and marketing managers to determine which services (customer's needs) were required for establishing a successful SIP Mall. Our hypothesis was analyzed by using the DEMATEL method [7]. Unlike a Structural Equation Model (SEM), which has been applied in a number of economic arenas to determine the structure of correlations between variables, the DEMATEL method illustrates the structure and interrelationships of the services and induces a few key services to improve its effectiveness. The DEMATEL method determines eighteen influential services and their interrelationships.

4.1.1. DEMATEL Method and Interrelated Factors

The DEMATEL method is based upon graph theory, enabling us to plan and solve problems visually, so that we may divide the factors into a cause and effect group, in order to better understand causal relationships. The purpose of the DEMATEL enquiry in this research, with experts' knowledge for contributing to a deeper comprehension of the component services, is the analysis of the structure and interrelationships of the services, and the identification of the key services which will influence the satisfaction of customers for an SIP Mall.

4.1.2.1 Data set

To conduct our research, a services list and questionnaire were created by consulting with academics and practitioners that focus on the SIP trading and licensing process. The services list and questionnaire take into account several dimensions of services, of which SIP providers and users need to be aware, such as technology, cost, strategy, and legal issues [22-27].

Second, based on listings in the "2003 Semiconductor Industry Yearbook" [28], companies were surveyed via phone and e-mail about their willingness to participate and their level of experience in the SIP trading and licensing process. There were twenty-four companies that agreed to answer the questionnaire and discuss their responses. These twenty-four companies were experienced as licensees and licensors in the SIP business and had extensive knowledge about SIP trading and licensing. After we discussed and revised the questionnaire with their chief executive officers, senior technical personnel, and marketing managers, eighteen interrelated services (presented in **Appendix A**) were included to use in the final questionnaire.

In our questionnaire, experts were to be asked to use the DEMATEL approach to measure the influence of each service on the others. The relationships among the eighteen services were measured using a scale from 0 to 9 (where 0 is “no influence” and 9 is “the most influence”). Experts evaluated the relationship between sets of paired services in terms of degree of influence and direction of mutual movements. In total, twenty-four questionnaires were sent to exporters, nineteen questionnaires were responded. Because of missing data, the final sample size for this study became seventeen, constituting an effective response rate of 71 percent. The response data, an 18 ×18 scoring matrix, for each company, was used for the DEMATEL analysis. Then, a Total Relation Matrix was obtained from the seventeen 18 ×18 weighted matrices. Finally, based on the Total Relation Matrix and experts’ advice, a threshold value was determined and a graphical presentation, referred to as an impact-relations-map, of the interrelationships among the services was created and discussed.

4.1.2 Results and Implications

4.1.3.1 The normalized initial direct-influence matrix

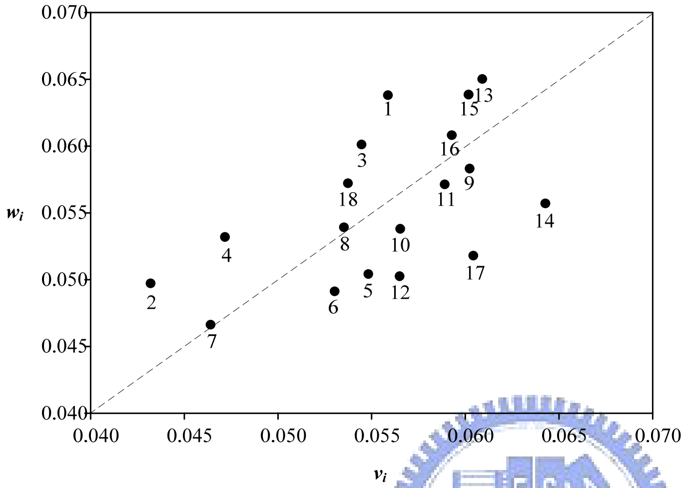
After receiving the seventeen questionnaire responses, an average matrix $\boldsymbol{A}$ (an 18 ×18 matrix) was calculated and a Normalized Initial Direct-Influence Matrix $\boldsymbol{D}$, shown in Figure 4-1, was derived.

$$\boldsymbol{T} = \begin{bmatrix}
0.3416 & 0.2946 & 0.3938 & 0.3161 & 0.3927 & 0.3936 & 0.3230 & 0.3736 & 0.4252 & 0.3969 & 0.4188 & 0.3984 & 0.4357 & 0.4587 & 0.4328 & 0.4192 & 0.4185 & 0.3791 \\
0.2903 & 0.2051 & 0.2991 & 0.2688 & 0.3025 & 0.2889 & 0.2546 & 0.2929 & 0.3411 & 0.3124 & 0.3223 & 0.3175 & 0.3369 & 0.3644 & 0.3169 & 0.3211 & 0.3342 & 0.2947 \\
0.3741 & 0.2745 & 0.3136 & 0.3129 & 0.3604 & 0.3454 & 0.3103 & 0.3714 & 0.4148 & 0.3708 & 0.3990 & 0.3735 & 0.4201 & 0.4162 & 0.4056 & 0.3809 & 0.3941 & 0.3690 \\
0.3153 & 0.2693 & 0.3099 & 0.2399 & 0.3263 & 0.3067 & 0.2781 & 0.3164 & 0.3556 & 0.3362 & 0.3645 & 0.3401 & 0.3579 & 0.3846 & 0.3447 & 0.3338 & 0.3602 & 0.3058 \\
0.3167 & 0.2488 & 0.2980 & 0.2663 & 0.2637 & 0.2932 & 0.2558 & 0.2965 & 0.3411 & 0.3132 & 0.3346 & 0.3192 & 0.3363 & 0.3535 & 0.3389 & 0.3213 & 0.3422 & 0.3011 \\
0.3221 & 0.2331 & 0.2879 & 0.2567 & 0.2863 & 0.2491 & 0.2570 & 0.2869 & 0.3210 & 0.3105 & 0.3190 & 0.3153 & 0.3338 & 0.3477 & 0.3278 & 0.3259 & 0.3266 & 0.2911 \\
0.2748 & 0.2178 & 0.2815 & 0.2428 & 0.2709 & 0.2754 & 0.2069 & 0.2743 & 0.3107 & 0.2981 & 0.3206 & 0.2879 & 0.3139 & 0.3333 & 0.3122 & 0.3191 & 0.3111 & 0.2728 \\
0.3195 & 0.2547 & 0.3392 & 0.2739 & 0.3172 & 0.3035 & 0.2629 & 0.2760 & 0.3732 & 0.3335 & 0.3511 & 0.3392 & 0.3736 & 0.3865 & 0.3650 & 0.3643 & 0.3619 & 0.3308 \\
0.3562 & 0.2713 & 0.3646 & 0.3039 & 0.3585 & 0.3294 & 0.2889 & 0.3460 & 0.3349 & 0.3683 & 0.3883 & 0.3700 & 0.4029 & 0.4222 & 0.3909 & 0.3777 & 0.3892 & 0.3454 \\
0.3336 & 0.2561 & 0.3102 & 0.2779 & 0.3311 & 0.3204 & 0.2813 & 0.3138 & 0.3511 & 0.2900 & 0.3501 & 0.3361 & 0.3594 & 0.3823 & 0.3678 & 0.3636 & 0.3651 & 0.3227 \\
0.3609 & 0.2765 & 0.3496 & 0.3203 & 0.3348 & 0.3456 & 0.2960 & 0.3346 & 0.3776 & 0.3509 & 0.3209 & 0.3493 & 0.3876 & 0.4092 & 0.3764 & 0.3767 & 0.3717 & 0.3396 \\
0.3177 & 0.2517 & 0.3022 & 0.2636 & 0.3077 & 0.2953 & 0.2513 & 0.2993 & 0.3280 & 0.3120 & 0.3194 & 0.2705 & 0.3434 & 0.3535 & 0.3350 & 0.3286 & 0.3414 & 0.3014 \\
0.4116 & 0.3088 & 0.4023 & 0.3420 & 0.3997 & 0.3820 & 0.3356 & 0.3816 & 0.4312 & 0.4067 & 0.4263 & 0.4029 & 0.3774 & 0.4612 & 0.4313 & 0.4265 & 0.4355 & 0.3826 \\
0.3395 & 0.2762 & 0.3231 & 0.2984 & 0.3443 & 0.3293 & 0.2807 & 0.3319 & 0.3754 & 0.3548 & 0.3565 & 0.3511 & 0.3639 & 0.3410 & 0.3641 & 0.3797 & 0.3831 & 0.3287 \\
0.4075 & 0.2951 & 0.3902 & 0.3194 & 0.3890 & 0.3746 & 0.3340 & 0.3824 & 0.4213 & 0.4022 & 0.4060 & 0.3932 & 0.4304 & 0.4490 & 0.3672 & 0.4266 & 0.4329 & 0.3964 \\
0.3815 & 0.2979 & 0.3648 & 0.3174 & 0.3685 & 0.3688 & 0.3373 & 0.3664 & 0.3950 & 0.3807 & 0.3856 & 0.3700 & 0.3971 & 0.4351 & 0.4116 & 0.3440 & 0.4061 & 0.3553 \\
0.3205 & 0.2582 & 0.3098 & 0.2774 & 0.3208 & 0.2995 & 0.2600 & 0.3072 & 0.3434 & 0.3305 & 0.3298 & 0.3268 & 0.3449 & 0.3702 & 0.3483 & 0.3423 & 0.2985 & 0.3037 \\
0.3656 & 0.2653 & 0.3539 & 0.2946 & 0.3595 & 0.3346 & 0.2944 & 0.3392 & 0.3867 & 0.3535 & 0.3683 & 0.3550 & 0.3869 & 0.4028 & 0.3851 & 0.3723 & 0.3766 & 0.2936
\end{bmatrix}$$

Figure 4-1. The total relation matrix of the SIP mall case.

4.1.3.2 The total relation matrix

After deriving the Total Relation Matrix ***T***, based on the Normalized Initial Direct-Influence Matrix ***D***, the values w_i and v_i of each service can be mapped to a coordinate plane, as shown in Figure 4-2. The points above the diagonal, $w_i > v_i$, indicate that the services exerted more influence than they received, and vice versa.



	v_i	w_i	Capability/Service
x_1	**0.0559**	**0.0638**	Verification
x_2	**0.0432**	**0.0497**	Financial Assistance
x_3	**0.0545**	**0.0601**	Research Institutions Questing
x_4	**0.0472**	**0.0531**	Credit Investigation
x_5	**0.0549**	**0.0504**	Business Process Streamlining
x_6	**0.0531**	**0.0491**	SIP Support and Maintenance
x_7	**0.0464**	**0.0466**	Increasing Company Awareness
x_8	**0.0536**	**0.0539**	Patent Analysis
x_9	**0.0603**	**0.0583**	Technology Valuation
x_{10}	**0.0566**	**0.0538**	Establishing Strategic Partnership
x_{11}	**0.0589**	**0.0571**	Licensing Support
x_{12}	**0.0565**	**0.0502**	Project Assessment
x_{13}	**0.0609**	**0.0650**	SIP Grading
x_{14}	**0.0643**	**0.0557**	Better Price Negotiation
x_{15}	**0.0602**	**0.0638**	Technical Standard Specifying
x_{16}	**0.0593**	**0.0608**	Market Share Improving
x_{17}	**0.0605**	**0.0518**	Overhead Cost Saving
x_{18}	**0.0538**	**0.0572**	Documentation

Figure 4-2. The values w_i and v_i of each service (the points above the diagonal indicate services which exerted more influence than they received ($w_i > v_i$)).

Ten services which exerted more influence than they received are located above the diagonal and the "SIP Grading (x_{13})" service and have the highest w_i values (0.065). This provides a clue for the following analysis that the services which affect service "SIP Grading" may play central roles in the problem. Eight services are under the diagonal, and the service "Better Price Negotiation (x_{14})" has the highest v_i value (0.0643). This provides a clue that the "Better Price Negotiation" service might be on the lowest level of the structured map, if the "Better Price Negotiation" service is included in the map.

4.1.3.3 Threshold values and the impact-relations-map

Based on the matrix ***T***, the maximum threshold value that allowed all services to be displayed on the impact-relations-map was 0.36. When the threshold value increased to 0.45, only two direct relationships existed: service "Verification" directly affected service "Better Price Negotiation" (0.4587) and service "SIP Grading" directly affected service “Better Price Negotiation” (0.4612). After raising the threshold value from 0.36 to 0.45 in increments of 0.01 and conferring with experts to determine the optimal value to sufficiently display the interrelationships among these services, the threshold value was decided to be 0.42. Thus, the structured impact-relations-map was also decided as shown in Figure 4-3. There were nine services whose values of exerted or received influence were higher than 0.42. Figure 4-3 illustrates the relationships among these nine services: “Verification”, “Research Institutions Questing”, “Technology Valuation”, “Licensing Support”, “SIP Grading”, “Better Price Negotiation”, “Technical Standard Specifying”, “Market Share Improving” and “Overhead Cost Saving”. Figure 4-3 also shows that, because of their obvious interrelationships, these nine services are related to establishing or operating an attractive SIP Mall.

4.1.3.4. The ($w_i + v_i$) and ($w_i - v_i$) values of services

Based on Step 4 in Section 3, we obtained the values of ($w_i + v_i$) and ($w_i - v_i$) and their coordinate plane (see Figure 4-4). Of the nine services shown in Figure 4-3, the “SIP Grading (x_{13})” service had the highest ($w_i + v_i$) value (0.1259) in Figure 4-4. The ($w_i + v_i$) value is an index for the DEMATEL method. The analysis of the impact-relations-map was started from service whose ($w_i + v_i$) is the highest, “SIP Grading (x_{13})”.

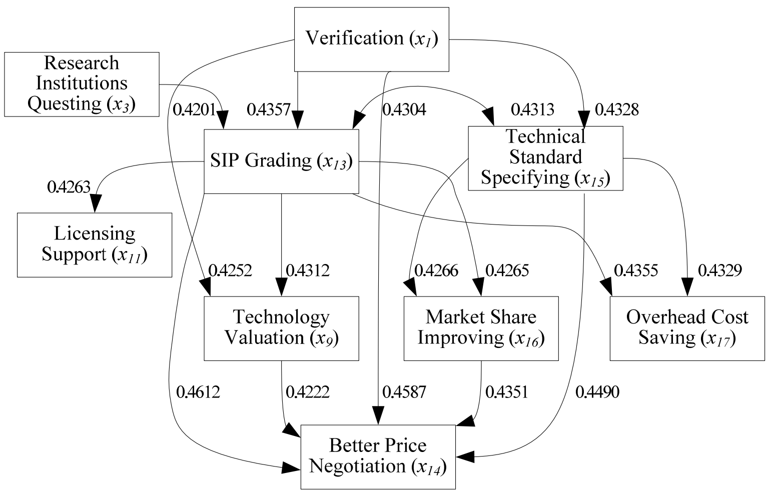
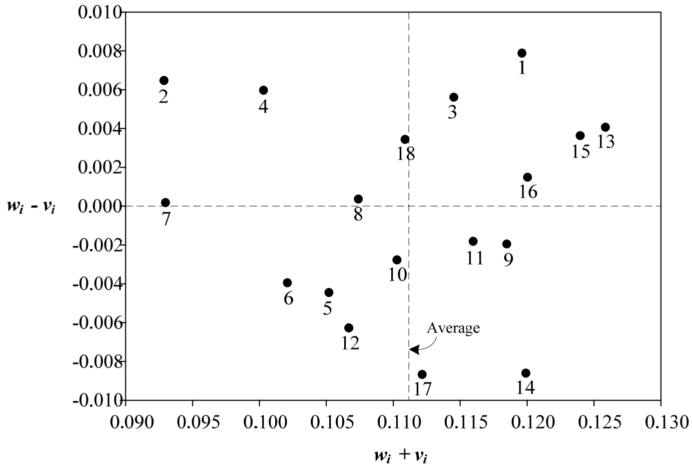


Figure 4-3. Impact-relations-map based on the threshold value $p = 0.42$



	$w_i + v_i$	$w_i - v_i$	Capability/Service
x_1	**0.1197**	**0.0078**	Verification
x_2	**0.0929**	**0.0064**	Financial Assistance
x_3	**0.1146**	**0.0056**	Research Institutions Questing
x_4	**0.1004**	**0.0059**	Credit Investigation
x_5	**0.1052**	**- 0.0045**	Business Process Streamlining
x_6	**0.1021**	**- 0.0040**	SIP Support and Maintenance
x_7	**0.0930**	**0.0001**	Increasing Company Awareness
x_8	**0.1074**	**0.0003**	Patent Analysis
x_9	**0.1185**	**- 0.0020**	Technology Valuation
x_{10}	**0.1103**	**- 0.0028**	Establishing Strategic Partnership
x_{11}	**0.1160**	**- 0.0018**	Licensing Support
x_{12}	**0.1067**	**- 0.0063**	Project Assessment
x_{13}	**0.1259**	**0.0040**	SIP Grading
x_{14}	**0.1200**	**- 0.0086**	Better Price Negotiation
x_{15}	**0.1240**	**0.0036**	Technical Standard Specifying
x_{16}	**0.1201**	**0.0015**	Market Share Improving
x_{17}	**0.1122**	**- 0.0087**	Overhead Cost Saving
x_{18}	**0.1109**	**0.0034**	Documentation

Figure 4-4. Values $(w_i + v_i)$ and $(w_i - v_i)$ of the eighteen services (the average of $(w_i + v_i)$ is 0.1111 and the average of $(w_i - v_i)$ is 0).

The "Verification", "Research Institutions Questing", "SIP Grading" and "Technical Standard Specifying" services are the most important services for an SIP Mall. They exerted complete direct/indirect influence to five other services — "Technology Valuation", "Licensing Support", "Better Price Negotiation", "Market Share Improving" and "Overhead Cost Saving". If an SIP Mall wants to provide the "Technology Valuation", "Licensing Support", "Better Price Negotiation", "Market Share Improving" and "Overhead Cost Saving" services, it must first demonstrate to consumers the capabilities of "Verification", "SIP Grading" and "Technical Standard Specifying". The "Research Institutions Questing" capability is also needed to support the "SIP Grading" and "Technical Standard Specifying" capabilities.

4.1.3.5. The remaining services

Excluding the nine services displayed in Figure 4-3, the remaining services were considered to be independent services for an SIP Mall. Although the "Project Assessment", "Better Price Negotiation" and "Overhead Cost Saving" services, with negative $(w_i - v_i)$ values, were easily affected by other services, the effects were not obvious when the threshold value equaled 0.42. It is apparent that the other services, which have neither a $(w_i + v_i)$ value higher than the average of all $(w_i + v_i)$, nor a negative $(w_i - v_i)$ value, can be provided independently.

4.1.3. Discussions

4.1.4.1 DEMATEL method to derive interrelated key factors

In a totally interdependent system, all of its elements are mutually related, directly or indirectly; thus, any interference with one of the elements affects all the others, making it difficult to find priorities for action. The decision-maker who wants to obtain a specific objective is at a loss if he wants to avoid disturbing the rest of the system while attaining his objective. While the vision of a totally interdependent system leads to passive positions, the vision of a clearer hierarchical structure leads to a linear activism. This neglects feed-back and may engineer many new problems in the process of solving others. DEMATEL was developed in the hope that pioneering and appropriate use of scientific research methods could improve the understanding of a specific *problematique*, a cluster of intertwined problems, and contribute to identification of workable solutions by a hierarchical structure.

By using the DEMATEL method, we not only know the structure and interrelationships of eighteen services, but we can also identify four key services that influence the satisfaction of customers using an SIP Mall. In this research, we have shown that the DEMATEL method is an appropriative method to delineate the structure of a totally interdependent problem and find the foci for solving the problem. We used the DEMATEL method to divide the needed services into a cause and effect group to better understand the causal relationships. By identifying the structure and interrelationships, we were able to derive the key services that influence the satisfaction of customers using an SIP Mall. These results can be helpful for a decision-maker to allocate resources effectively.

4.1.4.2. The focus for an attractive SIP Mall

According to the results, it is essential for an SIP Mall to provide “Verification”, “Research Institute Questing”, “SIP Grading” and “Technical Standard Specifying” services concurrently, in order to operate an attractive SIP Mall. Based on our research, a reliable “Verification” service is the most important service of a successful SIP Mall. The “Verification” service has the highest (w_i - v_i) value, 0.0078, and affects seven services directly or indirectly. This result reveals that the verification of an SIP is the most important index for SIP users, when they think an SIP Mall could be relied on to collaborate in their chip design project. The "Research Institutions Questing" service is a latent factor for an SIP Mall to attract consumer trade. As shown in Figure 4-3, the "Verification (x_1)", "SIP Grading (x_{13})" and "Technical Standard Specifying (x_{15})" services directly affect four services, but the "Research Institutions Questing (x_3)" service affected another six services indirectly via the influence of the "SIP Grading (x_{13})" service. It is necessary for the SIP Mall to search for an institution with the breadth and depth of technical expertise, not only to troubleshoot, but also to add value. Reliable "SIP Grading" and "Technical Standard Specifying" services are also attractive to customers.

Our research revealed eight services whose (w_i - v_i) values are negative. This indicates that these services receive more influence from other services than the influences they exert. This means that these services could be improved by resolving the services that connect and affect these negative (w_i - v_i) value services. As shown in Figure 4-3**,** the "Business Process Streamlining (x_5)", "SIP Support and Maintenance (x_6)", "Technology Valuation (x_9)", "Establishing Strategic Partnership (x_{10})", "Licensing Support (x_{11})", "Project Assessment (x_{12})", "Better Price Negotiation (x_{14})", and "Overhead Cost Saving (x_{17})" services, (w_i - v_i) values are negative. Among them, the "Technology Valuation", "Licensing Support", "Better Price Negotiation" and "Overhead Cost Saving" services have a higher than average ($w_i + v_i$) value with at least one w_i or v_i value higher than the threshold value. These four services are affected by other services. If an SIP Mall wants to provide any of these four services, it should first identify the services which directly affect what they want to provide. The "Business Process Streamlining", "SIP Support and Maintenance", "Establishing Strategic Partnership" and "Project Assessment" services, that do not have a w_i or v_i value higher than the threshold value, can be considered independent services. An SIP Mall can provide these services and ignore the influence of the other services.

The "Financial assistance (x_2)", "Credit Investigation (x_4)", "Increasing Company Awareness (x_7)", "Patent Analysis (x_8)" and "Documentation (x_{18})" services have positive (w_i - v_i) values, but do not have w_i or v_i values higher than the threshold value. These services are neither easily affected by other services, nor play central roles when the threshold value is 0.42. Because the connection with other services is not obvious, an SIP Mall can establish these services independently. Of course, the decision maker(s) could find that these services exert and receive influence by lowering the threshold value of the full direct/indirect matrix. The designers who acquire SIPs for products are much more concerned about the technological benefits of the SIP Mall than the business model and strategic benefits. These services could be provided after an SIP Mall has been operating steadily or at a customer's request.

4.2 The Usage of MMDE Algorithm in SIP Mall Case

In the SIP Mall, the original threshold value was determined through discussions with experts. As a total relation matrix was obtained from the nineteen 18 ×18 weighted matrices, shown in Figure 4-1. Based on the matrix ***T***, as same as we derived in Section 4.1, the maximum threshold value that allowed all services to be displayed on the impact-relations map was 0.36. When the threshold value increased to 0.45, only two direct relationships existed. The threshold value was determined by raising the threshold value from 0.36 to 0.45 in increments of 0.01 and conferring with experts in order to determine the optimal value to sufficiently display the interrelationships among these services. The threshold value then set at 0.42, and the structured impact-relations map is shown in Figure 4-3.

By using the MMDE algorithm and following the steps in Section 3.3, we obtained the results shown below:

Step 1: After transforming the total relation matrix ***T***, shown in Figure4-1, the ordered triplets set T^* was obtained as {(0.4612, 13, 14), (0.4587, 1, 14), (0.4489, 15, 14), (0.4357,1, 13), (0.4355,13, 17), …, (0.2051, 2, 2)}.

Step 2: According to the results of Step 1, the ordered dispatch-node set T^{Di} can be derived as {13, 1, 15, 1, 13, 16, …, 7, 4, 6, 7, 7, 2}.

Step 3: Based on the set T^{Di}, a collection of sets T_t^{Di}, in which t is from 1 to 324, can be obtained. After we calculate all of the H^D values of the sets T_t^{Di}, we can obtain a set with 324 mean de-entropy values, {0, 0, 0, 0.0196, 0.0146, 0.0142, …, 0, 0, 0}, shown in Figure 4-5.

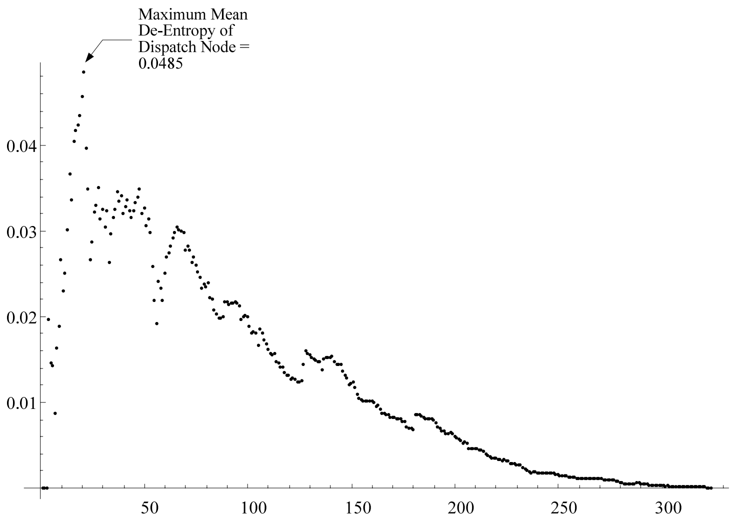


Figure 4-5. 324 mean de-entropy values with a MMDE value of 0.0485.

Step 4: Within the set obtained in Step 3, the maximum mean de-entropy value is 0.0485 and the corresponding dispatch-node set is {13, 1, 15, 1, 13, 16, 15, 1, 13, 13, 15, 15, 13, 13, 1, 9, 15, 3, 1, 1, 1}.

Step 5: Similar to Steps 2 to 4, the ordered receive-node set T^{Re}, the de-entropy value set of T^{Re}, a maximum-mean-de-entropy value, and corresponding receive-node set $T^{Re}_{\max}$ are shown in Figure4-6 and Table 4-1.

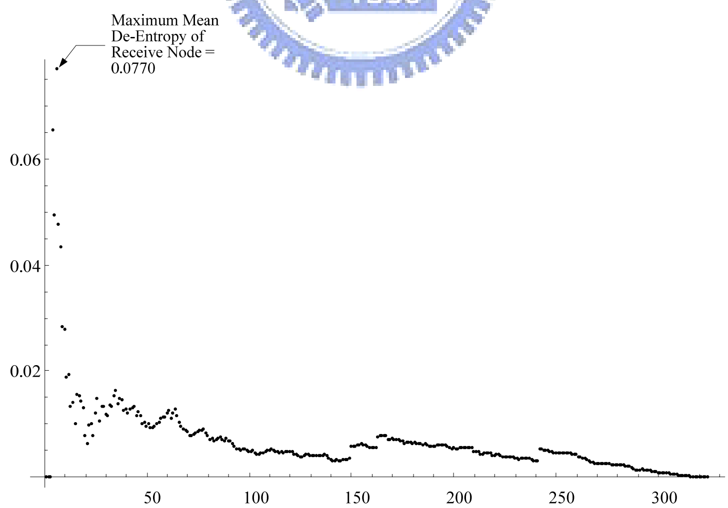


Figure 4-6. 324 mean de-entropy values of receive-nodes set with a MMDE value of 0.0770.

Step 6: According to the results of Steps 4 and 5, the elements {1, 3, 9, 13, 15, 16} must be the dispatch-nodes and the elements {13, 14, 17} must be the receive-nodes in the impact-relations map. Based on these two constraints, the needed subset, T^{Th}, of the ordered set $T^{*}$is { (0.4612, 13, 14), (0.4587, 1, 14), (0.4490, 15, 14), (0.4357, 1, 13), (0.4355, 13, 17), (0.4351, 16, 14), (0.4329, 15, 17), (0.4328, 1, 15), (0.4313, 13, 15), (0.4312, 13, 9), (0.4304, 15, 13), (0.4266, 15, 16), (0.4265, 13, 16), (0.4263, 13, 11), (0.4252, 1, 9), (0.4222, 9, 14), (0.4213, 15, 9), (0.4201, 3, 13) }. In above set T^{Th}, the nodes in the shaded box are the needed dispatch-nodes shown the first time in the ordered set T^{Th}, the nodes in the non-shaded box are the needed dispatch-nodes shown the first time in the ordered set T^{Th} , and the minimum influence value in T^{Th} is the threshold value, 0.4201.

Based on the subset obtained in Step 6, the threshold value could be determined as 0.4201 and then the impact-relations map can be structured. In this case, the impact-relations map derived from the MMDE algorithm is same as that shown in Figure 4-3.

Table 4-1: The results derived from Steps 2 to 6 using the MMDE algorithm.

Item	Data
Receive-node set, T^{Re}	{14, 14, 14, 13, 17, 14, 17, 15, 15, 9, 13, 16, 16, 11, 9, 14, 9, 13, 16, 11,17, 14, 9, 1, 15, 14, 1, 10, 17, 15, 11, 13, 3, 12, 14, 10, 5, 11, 12, 18, 10, 13, 9, 6, 3, 17, 5, 12, 15, 3, 17, 5, 11, 13, 9, 13, 14, 15, 11, 14, 17, 8, 18, 14, 6, 1, 8, 10, 16, 16, 18, 9, 16, 16, 17, 15, 9, 6, 13, 1, 13, 9, 12, 8, 16, 8, 17, 10, 14, 12, 12, 18, 6, 5, 10, 15, 11, 8, 1, 11, 17, 15, 3, 14, 3, 16, 15, 16, 15, 13, 17, 1, 17, 5, 5, 13, 5, 13, 11, 1, 9, 10, 18, 12, 3, 14, 10, 14, 12, 11, 9, 10, 11, 3, 12, 15, 14, 6, 8, 18, 6, 13, 5, 15, 13, 9, 17, 16, 4, 17, 9, 16, 9, 12, 3, 18, 12, 8, 1, 15, 1, 7, 14, 13, 10, 13, 12, 7, 15, 11, 6, 8, 7, 17, 5, 13, 1, 14, 10, 16, 9, 8, 5, 18, 10, 11, 6, 6, 18, 16, 15, 9, 12, 5, 17, 16, 1, 18, 7, 3, 11, 11, 4, 5, 16, 16, 9, 6, 1, 16, 12, 11, 11, 1, 4, 11, 1, 12, 4, 1, 5, 8, 15, 12, 4, 1, 13, 8, 10, 4, 10, 15, 10, 3, 17, 9, 10, 7, 3, 3, 3, 2, 5, 8, 6, 18, 4, 18, 6, 5, 3, 18, 18, 8, 6, 3, 4, 10, 2, 3, 8, 17, 7, 6, 2, 18, 7, 4, 2, 6, 8, 18, 18, 1, 6, 7, 12, 10, 3, 8, 5, 7, 3, 7, 7, 4, 4, 2, 2, 6, 8, 1, 2, 8, 4, 18, 2, 5, 2, 4, 12, 4, 2, 4, 7, 5, 7, 2, 7, 4, 2, 7, 7, 2, 2, 7, 2, 6, 4, 4, 2, 2, 7, 2}
Mean de-entropy value set of T^{Re}	{0, 0, 0, 0.0654, 0.0494, 0.0770, 0.0476, 0.0433, 0.0283, 0.0277, 0.0187, 0.0193, 0.0133, 0.0141, 0.0099, 0.0156, 0.0152, 0.0143, 0.0130, 0.0078, 0.0063, 0.0098, 0.0099, 0.0077, 0.0119, 0.0149, 0.0106, 0.0133, 0.0132, 0.0117, 0.0114, 0.0135, 0.0133, 0.0153, 0.0163, 0.0139, 0.0147, 0.0145, 0.0125, 0.0128, 0.0119, 0.0128, 0.0130, 0.0133, 0.0115, 0.0123, 0.0116, 0.0101, 0.0102, 0.0095, 0.0099, 0.0092, 0.0093, 0.0096, 0.0101, 0.0103, 0.0111, 0.0112, 0.0114, 0.0121, 0.0124, 0.0110, 0.0120, 0.0128, 0.0115, 0.0102, 0.0095, 0.0091, 0.0087, 0.0085, 0.0078, 0.0079, 0.0080, 0.0083, 0.0084, 0.0087, 0.0088, 0.0090, 0.0082, 0.0078, 0.0070, 0.0073, 0.0069, 0.0071, 0.0072, 0.0075, 0.0070, 0.0067, 0.0072, 0.0069, 0.0067, 0.0062, 0.0058, 0.0053, 0.0051, 0.0051, 0.0051, 0.0053, 0.0050, 0.0047, 0.0048, 0.0050, 0.0045, 0.0042, 0.0042, 0.0045, 0.0046, 0.0048, 0.0049, 0.0050, 0.0052, 0.0050, 0.0046, 0.0048, 0.0046, 0.0047, 0.0046, 0.0048, 0.0048, 0.0046, 0.0047, 0.0043, 0.0042, 0.0040, 0.0037, 0.0037, 0.0039, 0.0041, 0.0041, 0.0040, 0.0041, 0.0041, 0.0041, 0.0039, 0.0039, 0.0040, 0.0042, 0.0039, 0.0035, 0.0033, 0.0030, 0.0031, 0.0032, 0.0031, 0.0031, 0.0032, 0.0033, 0.0033, 0.0034, 0.0058, 0.0057, 0.0058, 0.0059, 0.0060, 0.0062, 0.0061, 0.0059, 0.0058, 0.0056, 0.0055, 0.0054, 0.0055, 0.0075, 0.0076, 0.0078, 0.0077, 0.0077, 0.0070, 0.0071, 0.0072, 0.0071, 0.0071, 0.0069, 0.0067, 0.0068, 0.0063, 0.0064, 0.0064, 0.0064, 0.0063, 0.0065, 0.0064, 0.0063, 0.0061, 0.0061, 0.0061, 0.0060, 0.0059, 0.0058, 0.0058, 0.0058, 0.0059, 0.0059, 0.0060, 0.0059, 0.0060, 0.0058, 0.0055, 0.0054, 0.0054, 0.0053, 0.0054, 0.0054, 0.0055, 0.0055, 0.0055, 0.0055, 0.0055, 0.0054, 0.0048, 0.0047, 0.0048, 0.0043, 0.0043, 0.0044, 0.0045, 0.0045, 0.0045, 0.0041, 0.0041, 0.0041, 0.0041, 0.0040, 0.0037, 0.0038, 0.0038, 0.0038, 0.0038, 0.0037, 0.0036, 0.0034, 0.0034, 0.0034, 0.0034, 0.0034, 0.0035, 0.0035, 0.0032, 0.0031, 0.0030, 0.0030, 0.0052, 0.0051, 0.0051, 0.0050, 0.0049, 0.0047, 0.0047, 0.0046, 0.0046, 0.0046, 0.0045, 0.0045, 0.0045, 0.0044, 0.0044, 0.0044, 0.0043, 0.0043, 0.0043, 0.0038, 0.0038, 0.0035, 0.0035, 0.0031, 0.0031, 0.0028, 0.0027, 0.0025, 0.0025, 0.0025, 0.0025, 0.0025, 0.0025, 0.0025, 0.0025, 0.0023, 0.0023, 0.0023, 0.0023, 0.0023, 0.0023, 0.0022, 0.0021, 0.0020, 0.0019, 0.0018, 0.0016, 0.0014, 0.0014, 0.0014, 0.0014, 0.0012, 0.0012, 0.0011, 0.0011, 0.0010, 0.0010, 0.0010, 0.0009, 0.0008, 0.0008, 0.0007, 0.0007, 0.0006, 0.0006, 0.0005, 0.0004, 0.0004, 0.0003, 0.0003, 0.0002, 0.0002, 0.0002, 0.0001, 0, 0, 0, 0, 0, 0, 0, 0}
Maximum mean de-entropy value	0.0770
The receive-node set of the maximum mean de-entropy value	{14, 14, 14, 13, 17, 14}

4.3 Evaluation of the E-learning Program

The purpose of this research is to establish a new e-learning evaluation model for e-learning program effectiveness with consideration of intertwined relations and synthetic utility between criteria. Based on several evaluation criteria considered for e-learning effectiveness, this research used several methods to establish the evaluation model. Factor analysis figures the main aspects of e-learning evaluation and generates independent factors/aspects for further evaluation using the AHP method. Criteria interrelations and components of independent factors are usually intertwined and inter-affected. Applying the DEMATEL method illustrates the interrelations among criteria, finds the central criteria to represent the effectiveness of factors/aspects, and avoids the "overfitting" for evaluation. Thus, non-additive methods, fuzzy measure, and fuzzy integral, are used to calculate the dependent criteria weights and the satisfaction value of each factor/aspect for fitting with the patterns of human perception. Finally, the Analytic Hierarchy Process (AHP) method is employed to find out the weights of factors/aspects and obtain each e-learning program score.

The empirical experiments of this research are demonstrated with two e-learning company-training programs. The proposed model could be used to evaluate effectiveness by considering the fuzziness of subjective perception, finding the central criteria for evaluating, illustrating criteria interrelations, and finding elements to improve the effectiveness of e-learning programs. Moreover, the results show that the effectiveness calculated by the proposed model is consistent with that from traditional additive methods.

4.3.1 A Hybrid MCDM Model for Program Evaluation

In this section, the concepts of establishing the evaluation structure model, combined factor analysis, and the DEMATEL method for determining the criteria weights, are introduced. In real evaluation problems, it is difficult to quantify a precise value in a complex evaluation system. However, the complex evaluation environment can be divided into many criteria or subsystems to more easily judge differences or measure scores of the divided criteria groups or subsystems. The Factor Analysis method is commonly used to divide criteria into groups. Although it seems logical to sum the scores of these criteria for calculating factor effectiveness, the weights between the criteria may differ and the criteria may have interdependent relationships. Assuming that criteria weights are equal may distort the results. In the proposed model, DEMATEL, Fuzzy Measure, and Fuzzy Integral are used to overcome these problems. DEMATEL is used to construct the interrelations between criteria, while Fuzzy Measure and Fuzzy Integral are used to calculate the weights and synthetic utility of the criteria. Factor weights can then be obtained via processing individual or group subjective perception by the AHP method. Then, the final effectiveness value can be obtained.

The Hybrid MCDM Model procedures are shown briefly in **Figure4-7**. Factor Analysis, the DEMATEL method, Fuzzy Measure, Fuzzy Integral, AHP method, and the goals for combining these methods to evaluate e-learning effectiveness will be explained as follows:

Based on various points of view or the suitable measuring method, the criteria can be categorized into distinct aspects. In real program problem assessment based on a general problem statement, various opinions from participants and the evaluation criteria will be setup. When the evaluation criteria in real complex problems are too large to determine the dependent or independent relation with others, using factor analysis can verify independent factors. Another reason for using factor analysis in this research is the conventional AHP method, which performs the final evaluation in an additive type, based on the assumption of independence among criteria within the evaluating structure systems.

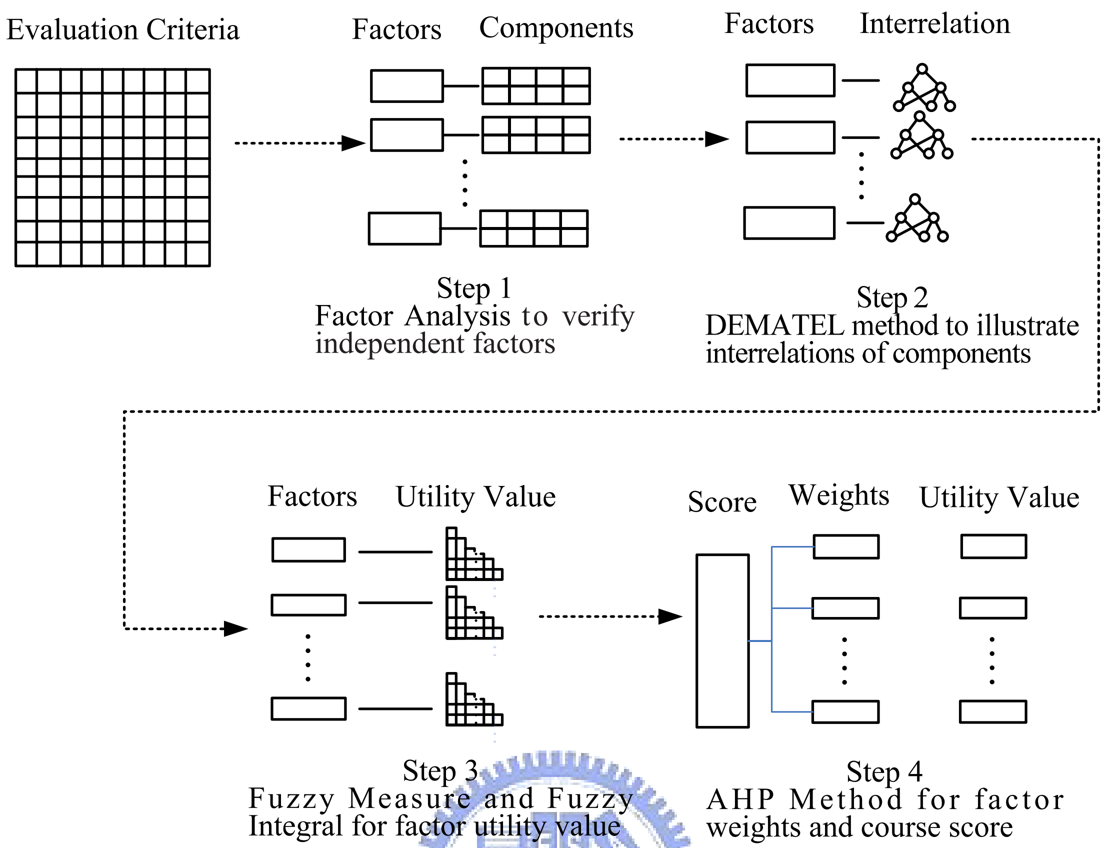


Figure 4-7 Hybrid MCDM Model procedures

In a totally interdependent system, all criteria of the systems are mutually related, directly or indirectly; thus, any interference with one of the criteria affects all the others, so it is difficult to find priorities for action. The decision-maker who wants to obtain a specific objective/aspect is at a loss if the decision-maker wants to avoid disturbing the rest of the system while attaining the decision-maker's objective/aspect. While the vision of a totally interdependent system leads to passive positions, the vision of a clearer hierarchical structure leads to a linear activism which neglects feed-back and may engineer many new problems in the process of solving the others.

The reason for applying fuzzy measure and fuzzy integral is based on the assumption that the synthetic effects of human perception exist between dependent criteria (shown as **Figure4-8**). Traditionally, researchers use additive techniques to evaluate the utilities of each criterion to meet the assumption of independent relationship among considered criteria. In the proposed model, the non-additive methods, or the sum between the measure of a set and the measure of its complement is not equal to the measure of space, are used to evaluate e-learning program effectiveness. Unlike the traditional definition of a measure based on the additive property, the non-additive MCDM methods, fuzzy measure and fuzzy integral, have been applied to evaluate the dependent multi-criteria problem.

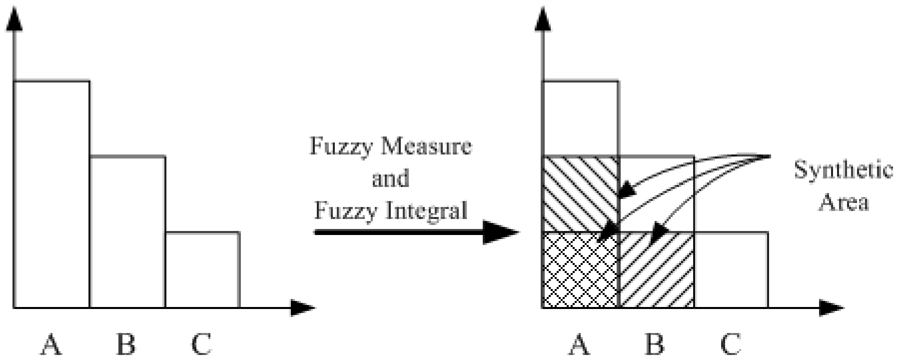


Figure 4-8 Non-additive methods for finding the synthetic effect

The fuzzy measure was used to determine weights of dependent criteria from subjective judgment and the fuzzy integral was used to evaluate the effectiveness of the final affected elements in an e-learning program. Since Zadeh put forward the fuzzy set theory [37], and Bellman and Zadeh described the decision-making methods in fuzzy environments [41], an increasing number of studies have dealt with uncertain fuzzy problems by applying fuzzy measure and fuzzy integral [111, 116, 119, 120].

Factor effectiveness can be obtained based on the effectiveness of the final affected elements and other independent elements using the AHP method to be described in Section 3.4.

The purpose of the AHP enquiry in this research is to construct a hierarchical evaluation system. Based on the independent factors obtained in Section 2.1 and the reduced criteria derived from Section 3.2, the AHP method could gain factor weights and criteria, and then obtain the final effectiveness of the e-learning program.

4.3.2 Empirical Experiment of the Hybrid MCDM Model

The empirical experiment in this dissertation was a collaborative research with MasterLink Securities Corporation, Taiwan. The empirical examples are two e-learning training programs. Program 1, a novice-training program designed to acquaint new employees with the regulations, occupational activities, and visions of a corporation, was established by Masterlink Securities. Program 2, designed by the Taiwan Academy of Banking and Finance, is a professional administration skills training program. Based on the approach constructed in this section, these two programs are used to explain the feasibility and features of the proposed evaluation model.

MasterLink Securities, founded in 1989, developed its core business to including brokerage, asset management, and investment banking in Taiwan, China, and Hong Kong. In Taiwan, Masterlink Securities Corporation with its forty-four branches, has used e-learning as a training tool since 2003. Except for courses developed by Masterlink Securities Corporation or purchased from the Taiwan Academy of Banking and Finance, some courses are outsourcing to consulting firms. An effective e-learning evaluation model is necessary for a company designed training programs and budget allowance.

Based on the criteria and approaches from the ADDIE model, Kirkpatrick theories, CIRO model, and other theories [121-126], fifty-eight criteria related to e-learning evaluation were chosen (shown in **Appendix B**) and used to design Questionnaire 1. Employees in Questionnaire 1 were asked to score the importance of each element for effectiveness evaluation; then, the experiment was executed according to four stages as follows:

Stage 1: The Factor Analysis to obtain independent criteria Groups

One hundred copies of Questionnaire 1 were distributed to employees of Masterlink Securities Corporation, with sixty-five responses. Respondents included experts and professionals, familiar and experienced with e-learning. Respondents were evaluated using the SPSS version 11.0.5 for reliability analysis and factor analysis. According to the results of factor analysis, independent factors were obtained and named.

Stage 2: The DEMATEL method to find the interrelation between entwined criteria

According to the factor analysis results, some experts were invited to discuss the relationship and influence level of criteria under the same factor, and to score the relationship among criteria based on the DEMATEL method. Factors were divided into different types, so the experts could answer the questionnaire in areas they were familiar with. In order to limit information loss from DEMATEL method results, threshold values were decided after discussion with these experts and an acceptable impact-digraph-map was found.

Stage 3: The fuzzy measure approach to find out the weights of intertwined criteria and the fuzzy integral to calculate effectiveness

According to DEAMTEL results, the intertwined criteria structures of a factor were found and the fuzzy measure employed to derive central criteria weights. Based on a map of each factor, after setting the λ value as -0.99 and 1, the substitute effect and multiplicative effect, the fuzzy measure was used to calculate two different weight sets of final affected elements. Concurrently, Questionnaire 2 was designed to investigate criteria effectiveness for using the fuzzy integral method. Questionnaire 2, a web questionnaire, asked Masterlink Securities Corporation employees to score the utility value of criteria of two programs.

Stage 4: The AHP method to find the weights and derive e-learning program effectiveness

A further goal for Questionnaire 2 was to use a pair-comparing method to find the factor weights and reduced criteria by AHP methods, and ask employees to score the satisfaction utility of criteria. The score is based on the Likert five-point scale; 1 stands for very dissatisfied, 2 for dissatisfied, 3 for neither dissatisfied or satisfied, 4 for satisfied, 5 for very satisfied. Because there were two different program types and objectives, Questionnaire 2 was delivered to different employee groups. Twenty-six and twenty-eight e-learning questionnaire surveys were returned, after which, factor weights and criteria were obtained and program effectiveness calculated.

4.3.3 Results and Analysis

Followed the stages we described in section 4.2.2, we derived the results as follow:

Result of Stage 1

Questionnaire reliability analysis was analyzed following responses received. According to reliability analysis results, Cronbach's α value is higher than 0.8 and the standardized element α value is 0.977 showing questionnaire reliability to be significant and effective (Reliability analysis results shown in Table 4-2).

Table 4-2. Reliability analysis results

Source of variance	Sum of sq.	d.f.	Mean square	F-test	Probability
Between people	4541.418	65	69.868		
Within people	6210.810	376	1.651		
Between measures	308.001	57	5.404		
Residual	5902.809	371	1.593	3.392	0.000
Total	10752.229	383	2.81		
Grand mean	6.973				
Alpha	0.977				
Standardized element alpha = 0.978					

KMO and Bartlett's test was used to measure the appropriate usage of factor analysis. According to Kaiser's research, KMO > 0.7 is middling to do factor analysis, and KMO >0.8 is meritorious. The KMO value of this research is 0.737 (Bartlett's Test of Sphericity: Approx. Chi-Square=4740, d.f.=1653, Significance=0.000); therefore, it is suitable for factor analysis. This method uses a correlation coefficient to test whether it is suitable and significant to use factor analysis. According to the results of KMO and Bartlett's test, this questionnaire is suitable to use factor analysis.

The principle component analysis was used to extract factors from fifty-eight criteria and the varimax method was used for factor rotation. Then, nine factors whose eigenvalue was more than 1.0 were chosen. Nine factors were named based on the loading of each factor: "Personal Characteristics and System Instruction," "Participant Motivation and System Interaction," "Range of Instruction Materials and Accuracy," "Webpage Design and Display Of Instruction Materials," "E-Learning Environment," "Webpage Connection," "Course Quality and Work Influence," "Learning Records" and "Instruction Materials" (Shown in Table 4-3).

Result of Stage 2

According to factor analysis results, some experts and professionals were invited to discuss and scored the relation between criteria of each factor based on the DEMATEL approach. Experts and professionals included system designers, webpage designers, instructors, managers, and human resources experts. Factor 1 and factor 2 managers and human resources experts. Factor 4 was discussed with webpage designers. Factor 5 and factor 6 were discussed with system designers. Instructors were responsible to factor 3, factor 7, factor 8, and factor 9.

Table 4-3. Factor analysis result: names and components (criteria) of factors

	Factor	Components	λ^a	A^b	B^c
1	Personal Characteristics and System Instruction	Personal Motivation, Rewards, Work Attitude, Learning Expectation, Work Characteristics, Self-Efficacy, Ability, Career Planning, Organization Culture, Instruction Goals, System Functions, System Instructions	25.98	44.8	44.8
2	Participant Motivation and System Interaction	Operating Skills, Solving Solutions, Mastery, Managerial Skills, Professional Skills, Inspire Originality, Supervisor's Support, Colleagues, Work Environment, Causes of Problem, Understanding Problems, Pre-Course Evaluation, Multi-Instruction, Communication Ways	4.926	8.494	53.3
3	Range of Instruction Materials and Accuracy	Accuracy, Range of Instruction Materials, Sequence of Instruction Materials, Usage of Multimedia	3.945	6.802	60.1
4	Webpage Design and Display of Instruction Materials	Text & Title, Display of WebPages, Sentence Expression, Length of WebPages, Graphs and Tables, Colors of WebPages	2.533	4.368	64.5
5	E-Learning Environment	Browser Compatibility, Browsing Tool, Path of WebPages, Transferring Time, Available, Reflection of Opinions	1.956	3.372	67.83
6	Webpage Connection	Under-constructing WebPages, System Prompts, Connecting to Main Page, Connection of WebPages	1.846	3.183	71.02
7	Course Quality and Work Influence	Course Arrangement, Course Design, Personal Satisfaction, Technical Evaluation, Course Contents, ROI/Work Influence	1.667	2.874	73.9
8	Learning Records	Learning Records, Instruction Activities, Course Subject	1.505	2.596	76.5
9	Instruction Materials	Level of Instructional Materials, Update Frequency, Readable	1.282	2.21	78.7

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
[a] Eigenvalue.
[b] % of Variance.
[c] Cumulative %.

Thus, after experts and professionals scored the relation of criteria, the Full Direct/Indirect Influence Matrix and the impact-digraph-map of each factor was calculated and drawn. According to the results of DEMATEL, the threshold value of each factor was decided by the experts. The threshold value of each factor from factor 1 to factor 9 is 0.85, 0.47, 1.5, 2.1, 1.6, 6.5, 2.1, 3.8 and 3.5. The impact-digraph-maps of DEMATEL method results were obtained and shown as Figure 4-9.

Result of Stage 3

According to **Figure 4-9**, the intertwined structures of several criteria, affected by other criteria, were illustrated. Therefore, the fuzzy measure for the final affected elements of each factor could be calculated out. Using factor 1 as an example, the criteria, “Rewards” and “Learning Expectations,” are two final affected elements affected by other criteria, but they did not influence other criteria.

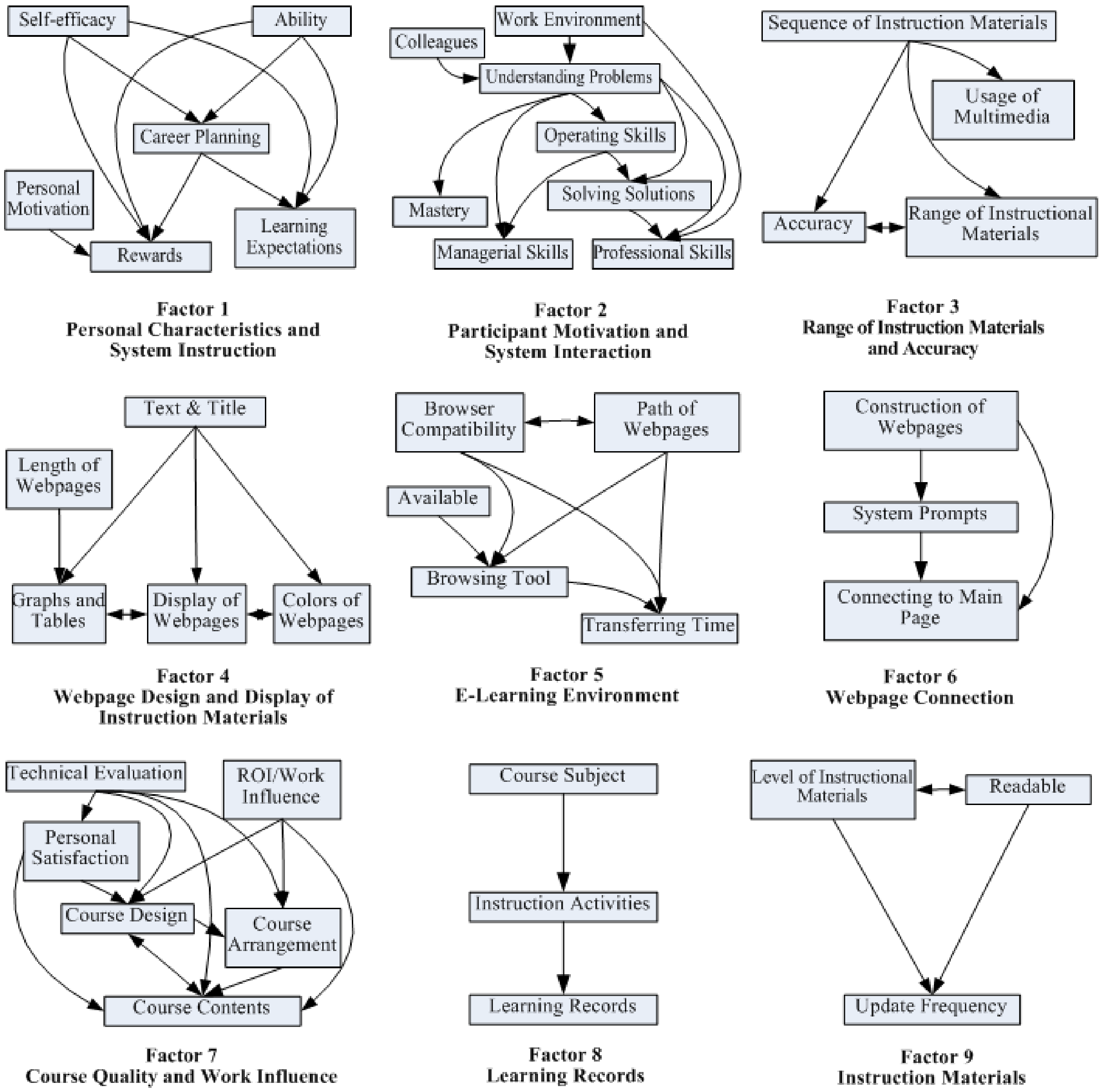


Figure 4-9. The impact-digraph-maps of nine factors derived by DEMATEL method

“Rewards” was affected by “Personal Motivation,” “Self-Efficacy,” “Career Planning,” and “Ability;” “Learning Expectations” was affected by “Career Planning,” “Ability,” and “Self-Efficacy.” Since these criteria have an influential relationship, the fuzzy measure should be employed to evaluate the weights of "Rewards" and "Expectations." The λ value was set as 1 and -0.99, indicating different synthetic effects of criteria. Fuzzy measure results of final affected elements of factor 1 are listed in **Table 4-4**. The e-learning satisfaction survey could then be implemented to calculate the fuzzy integral value of each factor. For example, the satisfaction value of the criteria, "Personal Motivation," "Self-Efficacy," "Ability," and "Career Planning" in program 2 are 3.597, 3.792, 3.719 and 3.370, and the integral value of "Rewards" at λ=1 is 3.589. The fuzzy integral values of the final affected elements are shown in **Table 4-5**. These results could be implemented to calculate final results of each program.

Result of Stage 4

Weights of nine factors and the reduced criteria were calculated out and used to find the effectiveness of each program. The final score for each program is shown in **Table 4-6**.

Table 4-4. Fuzzy measure for two final affected elements of factor 1

Factor	Element	λ	Fuzzy measure
1	Rewards	1	$g_{1\text{-}1}$=0.192, $g_{1\text{-}6}$=0.190, $g_{1\text{-}7}$=0.190, $g_{1\text{-}8}$=0.189 $g_{(1\text{-}1,1\text{-}6)}$=0.416, $g_{(1\text{-}1, 1\text{-}7)}$=0.416, $g_{(1\text{-}1,1\text{-}8)}$=0.417, $g_{(1\text{-}6,1\text{-}7)}$=0.411, $g_{(1\text{-}6,1\text{-}8)}$=0.412, $g_{(1\text{-}7,1\text{-}8)}$=0.412, $g_{(1\text{-}1, 1\text{-}6, 1\text{-}7)}$=0.683, $g_{(1\text{-}1,1\text{-}7, 1\text{-}8)}$=0.683, $g_{(1\text{-}1,1\text{-}6,1\text{-}8)}$=0.683, $g_{(1\text{-}6,1\text{-}7,1\text{-}8)}$=0.678 $g_{(1\text{-}1,1\text{-}6, 1\text{-}7, 1\text{-}8)}$=1
		-0.99	$g_{1\text{-}1}$=0.696, $g_{1\text{-}6}$=0.689, $g_{1\text{-}7}$=0.689, $g_{1\text{-}8}$=0.690 $g_{(1\text{-}1,1\text{-}6)}$=0.910, $g_{(1\text{-}1, 1\text{-}7)}$=0.910, $g_{(1\text{-}1,1\text{-}8)}$=0.910, $g_{(1\text{-}6,1\text{-}7)}$=0.908, $g_{(1\text{-}6,1\text{-}8)}$=0.910, $g_{(1\text{-}7,1\text{-}8)}$=0.908, $g_{(1\text{-}1, 1\text{-}6, 1\text{-}7)}$=0.978, $g_{(1\text{-}1,1\text{-}7, 1\text{-}8)}$=0.978, $g_{(1\text{-}1,1\text{-}6,1\text{-}8)}$=0.978, $g_{(1\text{-}6,1\text{-}7,1\text{-}8)}$=0.978 $g_{(1\text{-}1,1\text{-}6, 1\text{-}7, 1\text{-}8)}$=1
	Learning Expectations	1	$g_{1\text{-}6}$= 0.260, $g_{1\text{-}7}$=0.260, $g_{1\text{-}8}$=0.260 $g_{(1\text{-}6,1\text{-}7)}$=0.587, $g_{(1\text{-}6,1\text{-}8)}$=0.588, $g_{(1\text{-}7,1\text{-}8)}$=0.588, $g_{(1\text{-}6,1\text{-}7,1\text{-}8)}$=1
		-0.99	$g_{1\text{-}6}$= 0.792, $g_{1\text{-}7}$= 0.792, $g_{1\text{-}8}$=0.793 $g_{(1\text{-}6,1\text{-}7)}$=0.963, $g_{(1\text{-}6,1\text{-}8)}$=0.963, $g_{(1\text{-}7,1\text{-}8)}$=0.963, $g_{(1\text{-}6,1\text{-}7,1\text{-}8)}$=1

Elements: 1-1: "Personal Motivation"; 1-6: "Self-Efficacy"; 1-7: "Ability"; 1-8: "Career Planning"

Table 4-5. Fuzzy integral results of each element in different programs

Factor	Elements of Factor	λ Value	Integral Value: Program 1	Integral Value: Program 2	Directive Impact Elements	Indirective Impact Elements
1	Rewards	1	2.475	3.589	Self-Efficacy, Ability, Career Planning, Personal Motivation	
		-0.99	2.552	3.753		
	Learning Expectations	1	2.447	3.593	Self-Efficacy, Ability, Career Planning	
		-0.99	2.476	3.764		
2	Managerial Skills	1	2.529	3.641	Understanding Problems, Operating Skills	Work Environment, Colleagues,
		-0.99	2.548	3.693		
	Professional Skills	1	2.507	3.609	Work Environment, Understanding Problems, Solving Solutions	Colleagues, Operating Skills,
		-0.99	2.623	3.761		
	Mastery*		2.585	3.684	Understanding Problems	Work Environment, Colleagues
3	Accuracy	1	2.671	3.626	Sequence of Instruction Materials, Range of Instruction Materials	
		-0.99	2.763	3.682		
	Range of Instruction Materials	1	2.641	3.604	Sequence of Instruction Materials, Accuracy	
		-0.99	2.696	3.678		
	Usage of Multimedia[a]		2.484	3.745	Sequence of Instruction Materials	
4	Display of WebPages	1	2.537	3.697	Text &Title, Graphs and Tables, Colors of WebPages	Length of WebPages,
		-0.99	2.645	3.740		
	Graphs and Tables	1	2.471	3.688	Text &Title, Length of WebPages, Display of WebPages	Colors of WebPages
		-0.99	2.577	3.739		
	Colors of WebPages	1	2.508	3.736	Text &Title, Display of WebPages	Length of WebPages, Graphs and Tables
		-0.99	2.601	3.745		
5	Transferring Time	1	2.360	3.602	Browser Compatibility, Browsing Tool, Path of WebPages	Available
		-0.99	2.413	3.643		
6	Connect To Main Page	1	2.498	3.608	Construction of WebPages, System Prompts	
		-0.99	2.498	3.620		
7	Course Contents	1	2.604	3.718	Technical Evaluation, ROI/Work Influence, Personal Satisfaction, Course Design, Course Arrangement	
		-0.99	2.676	3.771		
8	Learning Records[a]		2.318	3.658	Instruction Activities	Course Subject
9	Update Frequency	1	2.520	3.720	Level of Instructional Materials, Readable	
		-0.99	2.546	3.741		

[a] Without synthetic effect, the element did not use the fuzzy measure and fuzzy integral for evaluation.

Table 4-6. Final score of each program

Factor	AHP Weight (Factor)	AHP Weight (Criterion)	Elements of Factor	Fuzzy Integral λ= -0.99 Program 1	Program 2	λ=1 Program 1	Program 2
1	0.105	0.249	Rewards	2.552	3.753	2.475	3.589
		0.249	Learning Expectations	2.476	3.764	2.447	3.593
		0.086	Work Attitude[a]	2.438	3.729	2.438	3.729
		0.082	Work Characteristics[a]	2.517	3.666	2.517	3.666
		0.084	Organization Culture[a]	2.451	3.537	2.451	3.537
		0.085	Instruction Goals[a]	2.186	3.703	2.186	3.703
		0.086	System Functions[a]	2.362	3.640	2.362	3.640
		0.082	System Instructions[a]	2.258	3.615	2.258	3.615
2	0.115	0.183	Managerial Skills	2.548	3.693	2.529	3.641
		0.183	Professional Skills	2.623	3.761	2.507	3.609
		0.180	Mastery [b]	2.585	3.684	2.585	3.684
		0.077	Inspire Originality[a]	2.281	3.518	2.281	3.518
		0.077	Supervisor's Support[a]	2.578	3.799	2.578	3.799
		0.078	Causes of Problem[a]	2.475	3.597	2.475	3.597
		0.073	Pre-Course Evaluation[a]	2.498	3.495	2.498	3.495
		0.074	Multi-Instruction[a]	2.592	3.729	2.592	3.729
		0.074	Communication Ways[a]	2.438	3.684	2.438	3.684
3	0.109	0.378	Accuracy	2.763	3.682	2.671	3.626
		0.378	Range of Instruction Materials	2.696	3.678	2.641	3.604
		0.245	Usage of Multimedia [b]	2.484	3.745	2.484	3.745
4	0.109	0.284	Display of WebPages	2.645	3.740	2.537	3.697
		0.276	Graphs and Tables	2.577	3.739	2.471	3.688
		0.278	Colors of WebPages	2.601	3.745	2.508	3.736
		0.167	Sentence Expression[a]	2.601	3.719	2.601	3.719
5	0.114	0.835	Transferring Time	2.413	3.643	2.360	3.602
		0.165	Reflection of Opinions[a]	2.331	3.631	2.331	3.631
6	0.111	0.679	Connect To Main Page	2.498	3.620	2.498	3.608
		0.321	Under-constructing Web Pages[a]	2.498	3.597	2.498	3.597
7	0.109	1	Course Contents	2.676	3.771	2.604	3.718
8	0.104	1	Learning Records [b]	2.318	3.658	2.318	3.658
9	0.110	1	Update Frequency	2.546	3.741	2.520	3.720
Final Score				2.489	3.644	2.452	3.610

[a] The criteria whose *influence level* did not reach the threshold value were considered independent criteria.
[b] Without synthetic effect, the element did not use the fuzzy measure and fuzzy integral for evaluation.

4.3.4 Discussions

The proposed novel Hybrid MCDM method should be a useful model for evaluating e-learning program effectiveness. Based on our empirical experiments of the Masterlink Securities Corporation's e-learning program survey, factor analysis was used to classify each element into nine different independent factors. Those criteria under the same factor had some interrelations with each other. The direct/indirect influential relationship of criteria was figured using the DEMATEL method. Affected criteria effectiveness was determined with the fuzzy integral value. Then, program effectiveness values were calculated by considering independent criteria effectiveness results, fuzzy integral value of intertwined criteria, and AHP factor weights. The Hybrid MCDM Model proposed in this research contains the following properties:

(1) *The key elements found and improvement alternatives illustrated*

Using the proposed model, a company may find factors that improve e-learning effectiveness. This research also used the DEAMTEL method to find the direct/indirect influential relationship of criteria that helps reduce the number of criteria and find factor improvement direction. Therefore, interactive effects accurately reflect in the final evaluation.

According to weights derived by the AHP, central factors, which are more important and will affect e-learning effectiveness, could be found. Therefore, the evaluator could determine the score of one e-learning program. After using this e-learning effectiveness evaluation model, evaluators found the aspects needing improvement, for e-learning effectiveness to increase. Although the difference of each factor weight is not significant, as shown in **Table 4-6**, factor 5, "E-Learning Environment", with the highest weight (0.114) should be given more attention to effectiveness. The performance of factor "E-Learning Environment" will affect the entire program effectiveness.

Using the DEMATEL can reduce the number of criteria for evaluating factor effectiveness; concurrently, a company can improve the effectiveness of a specific factor based on the impact-digraph-map. For example, the effectiveness of factor "Personal Characteristics and System Instruction," can be represented by the effectiveness of central criteria "Rewards" and "Learning Expectations," but the key element for improving factor "Personal Characteristics and System Instruction" are "Self-efficacy" and "Ability." It is easier for a company to find the exact department or persons responsible for improvement using results from the proposed model.

(2) *The fuzziness in effectiveness perception considered*

The non-additive multi-criteria evaluation techniques, fuzzy measure and fuzzy integral, are employed to refine the situations which conform to the assumption of independence between criteria. The λ value used in the fuzzy measure and fuzzy integral affords another viewpoint for evaluating how to remove the mechanical additive evaluating method. This means improving individual criterion performance by considering the effect from the others if the synthetic effect exists. In another words, if the evaluator investigates the types of synthetic effects of learners, designer, managers, and other respondents, program effectiveness can be improved on the dependent criteria with a multiplicative effect.

Moreover, the concepts of the fuzzy measure and fuzzy integral approach used in the proposed model will make evaluation more practical and flexible by using different λ values. For example, the original satisfaction value of criterion "Rewards" of factor, "Personal Characteristics and System Instruction" in program 1 is 2.416. According to **Table 4-5**, the synthetic effect comes from "Personal Motivation," "Self-Efficacy," "Ability," and "Career Planning" criteria. After calculating the effectiveness using fuzzy measure (λ= -0.99) and fuzzy integral, the effectiveness value of element "Rewards" changed to 2.552. This also conforms to the situation that "Rewards" is not the single criterion for a learner to express the satisfaction on factor "Personal Characteristics and System Instruction." If the criteria are independent, the λ value can be set to 0.

(3) *The result of Hybrid MCDM Model is consistent with the traditional additive model*

According to **Table 4-6**, the effectiveness of the general administration training (program 2) is better than the novice training (program 1). Whether from substitutive effects (λ=-0.99) or multiplicative effects (λ=1), the effectiveness (satisfaction) of novice training is less than general administration training. The main reason for this result is that new employees go through novice training for the first time and are not familiar with e-learning type training. Therefore, they may not feel comfortable using this system and attending these kinds of programs. Furthermore, general administration training is an e-learning program relative to daily work. The program consists of professional skills helpful to work; hence, employee satisfaction is high.

Comparing the proposed Hybrid MCDM Model with the traditional additive models, the results are consistent. Program effectiveness is calculated by the traditional AHP method and the scores for program1 and program 2 are 2.451 and. 3.617. Another survey, which asked employees to score the programs according to the Likert five-point scale for program satisfaction using the Simple Additive Weighting (SAW) method, showed scores for program1 and program 2 at 2.697 and. 3.828. These results show novice training to be less satisfactory than general administration training which is consistent with results from the proposed model. The results also mean that the Hybrid MCDM Model is a reasonable tool to evaluate e-learning programs.

4.4 The Usage of MMDE Algorithm in the E-learning Case

The empirical experiments of this dissertation are demonstrated with two e-learning company-training programs [20]. In section 4.3, we applied the DEMATEL method to illustrate the interrelations among criteria and found the central criteria to represent the effectiveness of factors/aspects. The principle component analysis was used to extract factors from fifty-eight criteria and nine factors were chosen. Nine factors were named: "Personal Characteristics and System Instruction," "Participant Motivation and System Interaction," "Range of Instruction Materials and Accuracy," "Webpage Design and Display Of Instruction Materials," "E-Learning Environment," "Webpage Connection," "Course Quality and Work Influence," "Learning Records" and "Instruction Materials". According to factor analysis results, some experts and professionals were invited to discuss and scored the relation between criteria of each factor based on the DEMATEL approach. Experts and professionals included system designers, webpage designers, instructors, managers, and human resources experts. Thus, after experts and professionals scored the relation of criteria, the impact-digraph-map of each factor was calculated and drawn. According to the results of DEMATEL, the threshold value of each factor was decided by the experts. The threshold value of each factor from factor 1 to factor 9 is 0.85, 0.47, 1.5, 2.1, 1.6, 6.5, 2.1, 3.8 and 3.5.

Based on the subset obtained in Step 6, the threshold value could be determined and then the impact-relations map can be structured. In the E-learning case, the impact-relations maps derived from the MMDE algorithm are similar as that shown in Table 4-7. We compare the results obtained from the respondents and from our method, and find that there are six factors will be structured by same components. Another three factors, although the numbers of components are different, have similar threshold values. This means that MMDE is a suitable method to determine a threshold value in the first, or the final, step in order to discuss the adequacy of the impact-relations map.

Table 4-7: The results obtained from the respondents and from MMDE method

Factors	Number of Components	Threshold values by experts	Number of Components	Threshold values using MMDE	Number of Components using MMDE
1.Personal Characteristics and System Instruction	12	0.85	6	0.84	9
2.Participant Motivation and System Interaction	14	0.47	8	0.50	7
3.Range of Instruction Materials and Accuracy	4	1.5	4	1.19	4
4.Webpage Design and Display of Instruction Materials	6	2.1	5	2.09	6
5. E-Learning Environment	6	1.6	5	1.65	5
6. Webpage Connection	4	6.5	3	6.58	3
7.Course Quality and Work Influence	6	2.1	6	1.92	6
8. Learning Records	3	3.8	3	3.43	3
9. Instruction Materials	3	3.5	3	5.67	3

Chapter 5 Conclusions and Remarks

In this chapter, we discuss the properties of the proposed MMDE for resolving the threshold value problem in the DEMATEL method. We also discuss its application for identifying the evaluation structure of planning and evaluating problems in the fields of technology management. We then draw conclusions and discuss further works for MMDE in technology management fields.

5.1 Discussions

The proposed MMDE algorithm has some properties that differ from the traditional method in determining the threshold value, as discussed below:

1. *MMDE mainly serves to select the "node" rather than the "map".*

Using traditional methods, the main issue of discussion is whether a "map" is suitable to the problematique after a threshold value is set. In traditional methods, the researcher sets a subject adequate threshold to draw the impact-relations map, discussing it with experts to obtain a consistent opinion. In the proposed MMDE, the main issue is in regards to whether it is suitable to add a new "node". If adding a new node can improve the "mean de-entropy", then it can be helpful for understanding a problematique by decreasing the uncertainty of information. Using MMDE in the SIP Mall case, we first decide that the nodes 1, 3, 9, 13, 15 and 16 must be the dispatch-nodes in the impact-relations map while the nodes 13, 14, and 17 must be the receive-nodes in the map. We then set the threshold value at 0.4201. The processes and results for these two methods differ, but the impact-relations maps are the same. This means that MMDE is a suitable method for determining a threshold value in the first or final step in order to discuss the adequacy of the impact-relations map.

2. *MMDE considers the properties of both the dispatch- and receive- influences of a factor*

In the DEMATEL method, after a suitable map is obtained, the focus of the problem can be shown by analyzing the values w_i and v_i of the factors in the map. The value (w_i + v_i)—the index representing the strength of the influence of both dispatched and received—shows the central role that factor *i* plays in the problem. Commonly, a higher (w_i + v_i) value means that the factor has a stronger connection with the other factors and plays a central role in the evaluation structure.. A higher (w_i - v_i) value means that this factor has a stronger influence *on* other factors compared to the influence it *receives* from them. If (w_i - v_i) is positive, then factor *i* influences the other factors. Different (w_i + v_i) and (w_i - v_i) values will be explained along with the structure of the factors' effects.

In the SIP Mall and E-Learning cases, by using the proposed MMDE, we search the nodes simultaneously, including the dispatch- and receive-nodes. The MMDE not only considers the factors which strongly influence others, but also the factors which are easily influenced by other factors. The results obtained through the proposed algorithm follow the goals of DEMATEL in exploring the inter-relationships of "important" factors for allocating resources efficiently.

3. *MMDE can obtain a unique threshold value*

To create a total relation matrix, the threshold value is determined subjectively by the researcher or through discussions with respondents, so the threshold value may differ if the experts or researcher change. In the traditional method, the researcher may determine the threshold value by decreasing the value (this will change the impact-relations map from simple to complex) or increasing the value (this will change the impact-relations map from complex to simple), so the results of these two methods may differ. If too many factors are included, the problematique becomes too complex. Using MMDE, a researcher can obtain a unique threshold value, which is helpful to solve the problem in regards to selecting a consistent threshold value.

In the E-Learning case, according to factor analysis results, some experts and professionals were invited to discuss and score the relation between the criteria of each factor based on the DEMATEL approach. The threshold value of each factor from factor 1 to factor 9 is 0.85, 0.47, 1.5, 2.1, 1.6, 6.5, 2.1, 3.8, and 3.5, respectively. By using the MMDE algorithm, the threshold value of each factor is 0.84, 0.50, 1.19, 2.09, 1.65, 6.58, 1.92, 3.43, and 5.67. Although the threshold values differ for the two approaches, the number of components of the 9 factors is similar, and the threshold value of each factor is unique. The proposed MMDE algorithm can save effort by having discussions with experts, especially when the number of experts is too many to aggregate at the same time or the undecided evaluation structures are numerous.

5.2Conclusions

In the DEMATEL process, an appropriate threshold value is important in order to obtain adequate information to delineate the impact-relations map for further analysis and decision-making. Until now, the threshold value has been determined through discussions with respondents or the subjective choices of researchers. It is time-consuming to make a consistent decision on the threshold value, especially when the number of factors in the problematique makes it too difficult to discuss the adequacy of an impact-relations map. If the threshold is determined by the researcher alone, it is important to clarify how the specific value is chosen. A theoretical method to assist in choosing the threshold value is necessary.

The premise of the DEMATEL method is that the factors are not totally pair-wise independent. One important reason for using the DEMATEL method to solve a specific problematique is to understand the interrelations between factors and express the relationships in a directed graph. If all information in the *total relation matrix* is displayed in the impact-relations map, then the impact-relations map is defined as a "complete graph" in graph theory, and every distinct vertex is connected by an edge. For a decision maker, this is no better than a situation with no information. Another purpose for using DEMATEL is to avoid including too much useless information. Selecting an adequate threshold value to judge whether a relation is obvious is a key question for the DEMATEL method.

This dissertation proposed an MMDE algorithm to determine the threshold value for the DEMATEL method. MMDE uses the approach of entropy, but also uses two other measures for the stability of information: "de-entropy" and "mean de-entropy". MMDE is mainly used to decide whether a node is suitable to express in the impact-relations map.

With this method, a unique threshold value can be obtained, solving the problem of choosing the threshold value in the traditional way.

In the numerical examples, one for applications in the field of the planning problems and another for applications related to program evaluation, we showed that MMDE can be used to obtain adequate threshold values to decide the evaluation structures. The first case is the Semiconductor Intellectual Property (SIP) Mall case. It is an example of a planning problem where it is necessary to discover and illustrate the key services needed to attract SIP users and providers in an SIP Mall. By using the proposed MMDE algorithm to determine the threshold value, we derived the same impact-relationship maps obtained through traditional methods and the algorithm, although the analytical procedures used were different. The second case is the E-learning case, which is an example of the evaluation problem. It is analyzed to establish a new e-learning evaluation model to determine e-learning program effectiveness with consideration to intertwined relationships and synthetic utility among the criteria. In this case, we used the MMDE algorithm to determine the interrelationships between the criteria for evaluating effects in E-learning programs. We demonstrated that MMDE is a suitable method for determining a threshold to obtain the impact-relationship map.

In the SIP Mall example, the traditional method involves finding a "suitable" threshold value, 0.36, and then raising the threshold value from 0.36 to 0.45 in increments of 0.01 and conferring with experts regarding the impact-relations map corresponding to each value, finally determining the optimal value to be 0.42. In the SIP Mall case, we show that the results from the MMDE are the same as those obtained with the traditional method. By using the proposed MMDE algorithm to determine the threshold value, we derived the same impact-relationship maps with traditional methods and the algorithm, although the analytical procedures used were different.

In the E-learning program evaluation case, we outlined a hybrid MCDM model to evaluate e-learning effectiveness. Based on several aspects of E-learning effectiveness evaluation, this research integrated several methods to make the proposed model, the Hybrid MCDM Model, much closer to reality. According to the results of the empirical study, the Hybrid MCDM Model should be a workable and useful model for evaluating E-learning effectiveness and displaying the interrelations of intertwined criteria. As a result, if the effectiveness of an E-learning program is deficient, we could find out the problem based on AHP weights and the interrelations based on the impact-digraph map of each factor. After using this E-learning effectiveness evaluation model, the evaluators could find the aspects requiring improvement, so that e-learning program effectiveness could increase. Compared with traditional E-learning evaluation, this model considers more aspects and criteria which may affect program effectiveness. We use the proposed MMDE algorithm with the DEMATEL method to structure the interrelationships among the criteria. We found that the results are similar to those derived through discussions with experts.

5.3 Remarks

The DEMATEL method is used to solve a specific problematique in order to understand the interrelations among factors and express the relationships in a directed graph, and the MMDE is a suitable algorithm for determining a threshold value for the DEMATEL method. In future research, we aim to apply this algorithm to other areas in information science and data mining in order to measure “adequate information”, especially when faced with concerns about “too much information to make a decision”. Like the directed graph, which is usually used in the fields of social network analysis, the proposed MMDE maybe a suitable algorithm for determining an adequate network for researchers in order to explain the interrelationships among cliques.

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Appendixes

Appendix A. The eighteen services identified as necessary to have a successful SIP Mall

Services	Notation	Description
Verification	x_1	An SIP Mall offers test/certification services to verify whether a product meets generally accepted specifications or specific requirements such as system-level verification, block-level verification, analog/mixed signal simulation, simulation, hardware/software co-verification, static net-list verification, and physical verification.
Financial Assistance	x_2	Through SIP management and valuation, the mall provides incentive loans, insurance solutions, and finds venture capitalists or banks to invest in the project that pushes the expected cash from a licensing effort up front.
Research Institutions Questing	x_3	The mall identifies a research institution with the breadth and depth of technical expertise to handle all phases of chip design, testing, manufacturing, and packaging. The business scope involves technology transfers, joint R&D, cross-licensing, consulting, exchange, and other transactions.
Credit Investigation	x_4	The mall provides investigation of both parties' credit worthiness through gathering information and keeping track of their latest financial developments. Both parties can also find out the credit of their current or potential business partners.
Business Process Streamlining	x_5	The mall standardizes the whole process from SIP searching to contract-settlement, which involves contract creation workflow, processes and controls, business models classification, management of contract negotiation procedures, and timescales.
SIP Support and Maintenance	x_6	The mall traces and ensures the provision of minor updates, bug fixes, current standards related to SIPs, consultation on process technologies, supported EDA tools and formats, and any other revisions needed by the different SIP types.
Increasing Company Awareness	x_7	The mall facilitates company awareness and partnership in different global target markets. This indicates that market trends and advertising strategies have had little effectiveness so far, and need improvement.
Patent Analysis	x_8	The mall provides a patent analysis service which reviews pre-existing and forthcoming technology to determine if infringement might exist, suggests alternate means and methods to avoid potential infringement, creates an SIP portfolio for future plans, and performs a number of reverse engineering functions for infringement analysis.
Technology Valuation	x_9	The mall provides expert individual SIP valuation which is essential, particularly in cases of litigation, major licensing transactions or joint ventures, mergers and acquisitions. The mall also evaluates SIP strength and scope by looking at sale revenues, royalties, and growth rates of business units.

Services	Notation	Description
Establishing Strategic Partnership	x_{10}	The mall provides an arena where business unit management can forge appropriate SIP strategies and marry them with the overall business strategy to leverage SIPs across the whole organization and beyond, as well as within a particular group in the SIP portfolio.
Licensing Support	x_{11}	The mall provides a broad range of litigation support in the area of intellectual property and technology litigation in a number of key technology areas which involve licensing practices, license gap analysis, commitment and obligation management, and mediation and arbitration solutions with public trust.
Project Assessment	x_{12}	The mall recognizes the actual and potential future value of an SIP and the actual and potential use of it by various business units. This assessment will guide the strategy planning phase where the primary form of SIP is placed in groups for competitive purposes, commercial purposes, or to be abandoned.
SIP Grading	x_{13}	The mall specifies industry-accepted SIP grading metrics for different SIP classifications and markets. The grading system helps designers to rationally choose the appropriate SIP and integrate it into their system and product.
Better Price Negotiation	x_{14}	The mall offers an SIP provider platform using allied purchasing to negotiate joint tendering that includes business model designs and advice, fee structure, payment terms, methods, currency and taxes, and rights/terms of audit.
Technical Standard Specifying	x_{15}	The mall specifies or recommends a set of hardware and software interface formats and design practices for the creation of functional blocks that enable efficient and accurate integration, and verification and testing of multiple blocks on a single piece to eliminate business barriers.
Market Share Improving	x_{16}	The mall provides precise classification, listing database searching tools and retrieval mechanisms to gain access to matching SIPs and capture the right information to identify the issues, concerns, and product attributes that are important to both providers and users to improve a company's market share.
Overhead Cost Saving	x_{17}	The mall provides services which are not included above for saving costs such as training, business law consultation, accounting, business planning, administration, financing, and government regulatory and incentive program assistance.
Documentation	x_{18}	The mall identifies data representation standards associated with an SIP, presented clearly and concisely with a comprehensive description for designers to design, test, integrate, and install.

Appendix B. Fifty-eight criteria for empirical e-learning programs

No.	Criteria	Description
1	Browser Compatibility	Learning materials could be read by different browsers.
2	Browsing Tool	Browsing tool means the tools that could let users know how to go front page, next page and enlarge or contraction pictures. Browsing tool design, menu button design and interface design are consistency and easy to use.
3	Path of WebPages	System provides suitable function of learner control. Display the path of learning materials.
4	Transferring Time	When a learner is learning online, the waiting time for transferring data is appropriate.
5	Available	Learning materials are easy to access and always be available.
6	Reflection of Opinions	Instruction website could let instructors to know the opinions of learners.
7	Under constructing WebPages	Webpage won't connect to under-construction WebPages and each links are work.
8	System Prompts	When something should be described and give some instructions, system will provide appropriate system prompt. System prompts and instructions match up with learning materials.
9	Connecting to Main Page	Every webpage could link back to main page.
10	Connection of WebPages	Relative WebPages could connect to each other.
11	Text & Title	The size of text and headline are appropriate. The row spacing and spacing are appropriate.
12	Display of WebPages	To display in screen size, general appearance are regularity and adjustment.
13	Sentence Expressions	The reading sequence, paragraphs, erratum and expression of sentence are appropriate.
14	Length of Webpage	The classification of webpage contents and webpage length are comfortable to read.
15	Graphs And Tables	Graphs and tables are suitable expressed, the integration and composition and background are displayed appropriately.
16	Colors of WebPages	Media display skills and usage of color could let learners feel comfortable. The colors of webpage design consider contrast of colors, systematic usage of colors and harmony of colors.
17	Accuracy	The accuracy of learning materials or cited terminology is appropriately used.
18	Range of Instruction Materials	The contents of learning material, such as range, depth, integration and structure are properly display.
19	Sequence of Instruction Materials	The display of learning materials is ordinal. The instruction materials integrate relative subjects and the structures of instruction material contents are appropriate.
20	Usage of Multimedia	Multimedia design is appropriate. The usage of voice and image could attract learners' attention.
21	Course Arrangement	Course arrangement is proper. And course arrangement will affect the intention and the level of learners' transfer what they have learned into their daily work.
22	Course Design	Course design provides what learners want to learn. According to course design principle, the level of transference of implementing what learners have learned into daily work.
23	Personal Satisfaction	Personal satisfaction affects the level of transference of what workpeople have learned into work.
24	Technical Evaluation	Personal attitude toward the reflection of technical evaluation feedback affect the level of transference of what workpeople have learned into work.
25	Course Contents	According to course contents, the level of transference of implementing what workpeople has learned into work.
26	ROI/Work Influence	After participating e-learning courses, the affective level of spending time, investment and the return on investment.
27	Learning Records	System could record learners' learning behavior and evaluate the learning performance.

28	Instruction Activities	Each instructional activity matches up with e-learning. Instruction activities are properly used.
29	Course Subject	The range and subject of course is appropriate
30	Level of Instruction Materials	The level of instruction materials is suitable for learners. The learning materials contain their uniqueness.
31	Update Frequency	The update date of learning materials, the contents, the subjects and the items are fit in with trend and different time or places.
32	Readable	Learning materials are readable. They contain theories and practical issues.
33	Personal Motivation	Personal motivations of participating e-learning affect the level of transference of what learners have learned into work.
34	Rewards	Merit system and rewards affect the transference of what learners have learned into work.
35	Work Attitude	Work attitude affect the level of transference of what learners have learned into work.
36	Learning Expectation	Personal expectations toward e-learning affect the level of transference of what learners have learned into work.
37	Work Characteristics	Personal work characteristics affect the level of transference of what learners have learned into work.
38	Self-Efficacy	Self-efficacy affects the level of transference of what learners have learned into work.
39	Ability	Personal abilities affect the level of transference of what learners have learned into work.
40	Career Planning	Career planning and objectives setting affect the level of transference of what learners have learned into work.
41	Organization Culture	Organization climate and organization culture encourage learners applying what knowledge they have learned to workforce.
42	Instruction Goals	Learners realize the instruction goal of e-learning website.
43	System Functions	Provide the functional label of system operating interface. Provide search function of learning materials.
44	System Instructions	Provide instructions of system software and hardware. Provide the functions of download and print. Provide system menu.
45	Operating Skills	After learning, learners could increase the level of operating skills.
46	Solving Solutions	After learning, learners could find the way to solve problems.
47	Mastery	After learning, learners could master what they have learned during e-learning courses.
48	Managerial Skills	After learning, learners could increase the level of managerial skills.
49	Professional Skills	After learning, learners could increase the level of professional skills.
50	Inspire Originality	After learning, learners could inspire originality.
51	Supervisor's Support	Supervisors support affect learners implement what they have learned into work.
52	Colleagues	Colleagues could discuss and implement what they have learned into work.
53	Work Environment	Working environment encourages learners apply what they have learned to work.
54	Causes of Problem	After learning, learners could know the real reason which leads to occurrence.
55	Understanding Problems	After learning, learners could increase the understanding level of problems which they want to know.
56	Pre-Course Evaluation	According to learners' background, provide pre-course assessment. Attract the motivation and interests of learners.
57	Multi-Instruction	E-learning courses use multi-instructional ways to express.
58	Communication Ways	The communication ways of instruction website are convenient to use.

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