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System on chip design service e-business value maximization through a novel MCDM framework

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ABSTRACT

As the IC (integrated circuit) industry migrates to the System-on-Chip (SOC) era, the SOC design service industry is emerging. Meanwhile, in the past decade, the emergence of Internet has changed the high technology marketing approaches while e-commerce has already become one of the most efficient marketing channels. Thus, most leading SOC design service firms tried to leverage novel e-commerce business models to provide better services including online silicon intellectual property (SIP) sourcing, transactions, integration, etc. to assist customers in enhancing their innovation competences to shorten their time to market and thus, time to money. However, defining appropriate e-business models for commercializing new SIPs or SOC design services is not easy for both aspects of technology as well as business development. On one hand, from the aspect of technology, the technical site R&D or production managers are familiar with SOC technologies while do not really understand the needs of customers' over the Internet. On the other hand, from the aspect of business development, the sales or marketing managers may be familiar with online customers' needs, wants as well as demands while are unfamiliar to SOC technology developments. To overcome the above mentioned problems, an appropriate e-business model definition framework can overcome this cognitive gap and maximize the value-added of online SOC design services. In this paper, a novel analytic framework based on the concept of design service customers' competence set expansions by leveraging high technology service firms' capabilities and resources as well as novel multiple criteria decision making (MCDM) techniques, will be proposed. The framework being proposed can be leveraged by the design service firms to define an appropriate e-business model for possible SIP or design service businesses. Based on the proposed MCDM framework, an empirical study of an SIP commercialization e-business model definition inside an SIP Mall, an SIP e-commerce mechanism being operated by a SOC design service firm, will be provided for verifying the effectiveness of this novel analytic framework. The feasibility of the proposed framework in the real world can be verified by the empirical study. In the future, the novel MCDM framework can be applied to novel e-business model definitions in the SOC design service or other high technology industries.

1. Introduction

In the past decade, the Internet has become an enabling technology in almost any industry and as part of almost any strategy (Porter, 2001). Uses of the Internet and e-commerce have converted the traditional way of running business and have thoroughly changed the channel of enterprise transactions (Shaw, Gardner, & Thomas, 1997). As industries in general, and high technology industries in special, are being reshaped and the nature of competition changes (Raisinghani, Meade, & Schkade, 2007), deciding on an e-business model, a competition strategy for the marketplace and a structure of business processes for the entire electronic trade course (Wang, 2001), has become daily important for modern high technology firms.

As stated by Young and Johnston (2003), there are a number of traditional business strategy theories that have been used to discuss business-to-business (B2B) e-commerce strategies: transaction cost economics, resource-based view, Porter's market forces theory, and channel theory. However, there currently exists no comprehensive framework linking these theories into a method to rigorously assess value delivery strategies, and in particular to determine how to maximize the impact of the Internet as a value delivery channel (Young & Johnston, 2003). Raisinghani et al. (2007) also mentioned that although the strategy to rebuild a

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robust e-business model has not been as widely implemented as had been anticipated, it has had a significant influence on company performance.

Moreover, as the IC (integrated circuit) industry migrates to the System-on-Chip (SOC) era, a novel business model, the SOC design services, is emerging. Now, when the Internet is emerging while e-commerce has already become one of the most efficient marketing channels, most leading design service firms tried to leverage novel e-commerce business models to provide better services. The novel design services include online silicon intellectual property (SIP) sourcing, transactions, integration, etc. to assist customers of SOC design services in enhancing their innovation competences (INCs). The INCs, critical capabilities as well as resources for commercializing SOCs or SIPs, can shorten the time to market and thus, time to money, of both SOC design firms' and design service customers'. However, defining appropriate SOC design service e-business models are not easy. On the technical site, R&D or production managers of the SOC design service firms are familiar with SOC technologies while do not really understand the needs of customers' over the Internet. On the business site, sales or marketing managers of the SOC design service firms are familiar with online customers' needs, wants as well as demands while are unfamiliar to SOC technology developments. Thus, how to establish a decision support framework for defining appropriate SOC design service e-business models to commercialize new SOC/SIP products or services has already become one of the most critical issues for the SOC design service firms. Meanwhile, the proposed framework can also enhance insufficient linkages between traditional business strategy theories and value delivery strategies through the Internet which was mentioned by Young and Johnston (2003) as well as Raisinghani et al. (2007).

Therefore, this research aims to establish a novel multiple criteria decision making (MCDM) framework, which intends to link between INCs being required by novel SOC design services. The proposed MCDM framework intends to maximize values of both the SOC design service e-business models and end SOC products of SOC design service customers'. The INCs, or evaluation criteria, are first summarized using the Delphi method. Then, the relationships between the criteria will be derived by DEMATEL (Decision Making Trial and Evaluation Laboratory). The weights of each criterion versus the goal of the MCDM problem, maximizing the values of SOC design services e-business models, then will be derived based on the structure of the decision problem by using the Analytic Network Process (ANP). After the criteria are derived, the relationships between the INCs (criteria) as well as e-business models will be derived by using the grey relational analysis (GRA) based on the weights of each criterion being derived by the ANP. Finally, the most appropriate e-business model with the highest grey grades which may compensate the current INCs of SOC design service e-business customers and maximize the value of customer's products and thus, the value of the high technology e-commerce channel, will be selected.

A case study on commercializing a silicon intellectual property (SIP) being developed by an IC design house through an SIP Mall, a web based SIP e-commerce mechanism, being operated by an SOC design service firm will be used for demonstrating the effectiveness of the novel MCDM method. The case study results demonstrated that the IP commercialization model of the SIP Mall which may assist a small-scale IC design house without enough resources to commercialize its SIP products and maximize the SIP value through SIP verification, qualification, marketing, sales, technical supports, etc. will be the most appropriate e-business model to maximize the value of this SIP.

The remainder of this paper is organized as follows: In Section 2, the concepts of innovation, INCs, e-business models, e-business model evaluation and INC set expansion are introduced. In Section 3, an analytic framework and methods are proposed for constructing the evaluation criteria and e-business models' definitions. The background of the SOC design service, SIP, SIP market and SIP e-business models will be described in Section 4. Then in Section 5, a case study follows, defining an e-business model for commercializing an SIP being developed by an IC design house which is in lack of SIP commercialization resources. Discussion will be presented in Section 6. Section 7 will conclude the whole article with observations, conclusions and recommendations for further study.

2. Innovation competence and e-business model assessment

Researchers have successfully explored the definitions of business models, e-business models, e-business model evaluation as well as innovation, INC, INC set expansion and resource based view. In the following section, the related literature will be reviewed.

2.1. Business model and e-business

The term business model is widely used in business literature. Lumpkin and Dess (2004) defined business model as a method and set of assumptions that explains how a business creates value and earns profits in a competitive environment. Tsalgatidou and Pitoura (2001) defined the business model as a logical architecture for product, service, and information flows, including a description of the involved business actors and their roles, as well as sources of revenue. Wise and Baumgartner (1999) mentioned that business models are cases or scenarios. Moore (2003) mentioned that a business model is categorically, a way of making money, the form an offer takes, and the manner in which it is paid for.

Externally, a business model is an implicit contract which a customer expects and a vendor commits to. Internally, a business model is a platform for execution, a basis for prioritization and trade-offs, and an infrastructure for resource commitments. Finally, a business model is the methods of doing business by which a company can sustain itself, that is, generate revenue (Moore, 2003). The basic categories of business models include brokerage, advertising, infomediary, merchant, manufacturer, affiliate, community, subscription, and utility (Rappa, 1998).

According to Afuah (2004), a business model is a framework for making money. Chesbrough (2006) also defined the business model to be a useful framework to link ideas and technologies to economic outcomes. It also has value in understanding how companies of all sizes can convert the technological potential value (Chesbrough, 2006). It is the set of activities which a firm performs, how it performs them, and when it performs them so as to offer its customer benefits they want and to earn a profit. Business models are usually represented by a mixture of informal textual, verbal, and ad hoc graphical representations (Gordijn & Akkermans, 2001).

Young and Johnston (2003) defined the strategic options for delivering values from suppliers to customers as specific business models that outline the essential details of how an organization can deliver value to a target customer (Seddon & Lewis, 2003). These business models are a key component to an overall strategy that determines the long-term position of the organization (Porter, 1996, 2001; Young & Johnston, 2003).

As stated by Afuah (2004), a firm makes more money than its rivals if its business model creates and offers superior customer value and positions the firm to appropriate the value. To perform the activities that enable a firm to offer superior customer value and appropriate the value, a firm needs resources. Resources in and of themselves do not, however, produce customer value and profits. Firms must also have the ability or capacity to turn resources into customer value and profits. In summary, resources and capabilities are the roots of business models.

The rapid deployment of electronic business (e-business) is an economically significant issue for today's business (Raisinghani et al., 2007). An e-business solution is defined as: (1) improving business processes using Internet technologies; (2) leveraging the Web to bring together customers, vendors, suppliers, and employees in ways never before possible; and (3) Web-enabling a business to sell products, improve customer service, and obtain maximum results from limited resources (Turban, King, Viehland, & Lee, 2006).

Wang (2001) defined an e-business model to be a competition strategy for the marketplace and structure of business processes for the entire electronic trade course including marketing and advertising, negotiation, purchasing, logistics of products and/or service delivery, payment with the means of security, post-sales service, and post-sales intelligence. As stated by Raisinghani et al. (2007), although the strategy to rebuild a robust e-business model has not been as widely implemented as had been anticipated, it has had a significant influence on company performance. Meanwhile, Hooshang, Salehi-Sangari, and Engstrom (2006) found that inappropriate plan and design of an e-business model to be one of the most significant problems causing dissatisfaction with e-business.

Researchers and practitioners use a variety of diagrammatic conceptual models to illustrate new e-business models (Wang, 2001). After creating detailed models, the next step is to evaluate the economic feasibility of an idea in quantitative terms that are based on an assessment of the value of objects for all actors involved. Feasibility of an e-business model means that all actors involved can make a profit or increase their economic utility (Gordijn & Akkermans, 2001).

2.2. e-Business model assessment

As advised by Gordijn and Akkermans (2001), when developing a specific business idea, we instantiate our ontology concepts and relations for specific use cases. Doing so provides a basis for analyzing the characteristics and implications of alternative e-business models (Gordijn & Akkermans, 2001).

For the development of e-business information systems, three distinct perspectives are important: the value viewpoint represents the way economic value is created, exchanged, and consumed in a multi-actor network; the process viewpoint represents the value viewpoint in terms of business processes; and the system architecture viewpoint represents the information systems that enable and support e-business processes (Gordijn & Akkermans, 2001).

Moreover, as advised by Raisinghani et al. (2007), a systematic framework for the identification and classification of e-commerce strategy using Internet information, communication, distribution, or transaction channels including: (1) the virtual information space (VIS), which presents new channels for economic agents to display and access-related company product and services information (e.g., marketing and advertising); (2) the virtual communication space (VCS), which includes strategies aimed at monitoring and influencing business-related communications between economic agents operating on the Internet (e.g., negotiations between potential and existing customers partners, government agencies, and competitors); (3) the virtual distribution space (VDS), which provides new channels for economic agents to distribute products and services (e.g., software); and lastly, the virtual transaction space (VTS) provides strategies for economic agents with which to initiate and execute business to business (B2B) or business-to-customer (B2C) transactions, such as orders and payments, are used to access the e-business models.

Young and Johnston (2003) also found that there are a number of traditional business strategy theories that have been used to discuss business-to-business (B2B) e-commerce strategy: Transaction Cost Economics, Resource-Based View, Porter's Market Forces Theory, and Channel Theory. However, there currently exists no comprehensive framework linking these theories into a method to rigorously assess value delivery strategies, and in particular to determine how to maximize the impact of the Internet as a value delivery channel (Young & Johnston, 2003).

2.3. Innovation and INC

Innovation is combinations of knowledge that result in new products, processes, input and output markets, or organizations (Sundbo, 2003) which include not only technical innovations, but also organizational and managerial innovations, new markets, new sources of supply, financial innovations, and new combinations (Perlman & Heertje, 1991). The literature distinguishes different types of innovation: incremental, radical, technological, process, product, organizational, operational, managerial, social, or institutional (e.g. Hammer, 2004; Nadler & Tushman, 1999; van Kleef & Roome, 2007). Innovation processes can therefore, be viewed as a sequence of exploration (in which existing products and processes are adapted incrementally or radically through the search for and application of new assets) and exploitation (in which the variety of products and processes decreases while their efficiency increases) (van Kleef & Roome, 2007).

Clark and Guy (1998) mentioned that innovation is a critical factor in enhancing a firm's competitiveness which is generally understood to refer to the ability of a firm to increase in size, market share and profitability at the firm level (Clark & Guy, 1998). Nooteboom (2000) also argued that innovation is not necessarily related to problem solving, but it is usually related to improving competitiveness and economic success, and it is often pushed by technology. In traditional economic theory, comparative costs of production determine relative competitiveness at firm level – the way to become more competitive is to produce more cheaply: for example, by finding ways to reduce labor costs (Clark & Guy, 1998). However, recent studies have consistently pointed to non-price factors, e.g. human resource endowments, technical factors, managerial and organizational factors, which determine the ability of a firm to attain and maintain a profitable position in the face of changing technological, economic and social environments (Clark & Guy, 1998).

In a fast-changing environment, the competitive advantage or competitiveness of many companies is based on the decision to exploit, to develop the power of knowledge development (Carneiro, 2000). Since knowledge underpins a firm's ability to offer products, a change in knowledge implies a change in the firm's ability to offer a new product (Afuah, 1998). Thus, based on the extent to which innovation impacts a firm's capabilities, an innovation can be categorized as radical or incremental (Afuah, 1998). A radical innovation requires the technological knowledge which is very different from existing knowledge, rendering existing knowledge obsolete (Afuah, 1998). Such innovations are said to be competence destroying (Afuah, 1998). A company can decide its competitive advantage or competitiveness as a function of the capability to generate radical change in its processes and technologies and of the flexibility to adapt its resources to the strategic formulation (Carneiro, 2000). If an organization decides to become a fast innovator, managers should co-ordinate the ability to formulate a competitive strategy and to build advantages against competitors. This ability depends on the capacity of speeding up creative operations to generate innovations (Carneiro, 2000; Page, 1993). Thus, companies strengthen their competence to innovate by developing the capabilities of employees within the organization (Hargadon & Sutton, 2000).

Competence is defined after Prahalad and Hamel (1990), as the learning within the organization how to coordinate diverse production skills and how to integrate technologies. Capabilities of employees, combined with each other in teams and connected through structures and routines, are the building blocks of competence (van Kleef & Roome, 2007). Competence, therefore, includes the organization of work, the involvement of employees, the commitment to working and communicating across boundaries within the organization, and the delivery of value to customers and other stakeholders (van Kleef & Roome, 2007). Competence is seen as the basis of competitiveness; it enables a company to offer products and services of value to customers and to innovate to generate new products and services, while adapting to changing circumstances faster than competitors (van Kleef & Roome, 2007).

2.4. Competence set expansion

According to Yu and Zhang (1989, 1993), Yu (2002), Hu (2003), Huang (2006), for each decision problem (e.g. job selection, corporate strategic definition, conflict resolution, etc.), a competence set consisting of ideas, knowledge, information and skills for its satisfactory solution exists. Companies have to expand its competence set to deepen their knowledge base in their core technologies and to stay ahead of the competition in the current markets (Vanhaverbeke & Peeters, 2005) by investing in research and development and external technology sourcing (Chesbrough, 2003; Keil, 2002). This challenge derives largely from the fact that the decision to develop new businesses creates a fruitful misfit between the existing competencies and those that are required (Vanhaverbeke & Peeters, 2005). A well-known classification of INCs and search modes is that which distinguishes between exploration and exploitation (March, 1991). Tushman and Nadler (1996) are among the earliest authors on innovation to write explicitly about the capabilities that contribute to the competence to innovate for purely competitive reasons. van Kleef and Roome (2007) summarized the capabilities that are embedded in the work of leading authors in the field of innovation. Their work mentioned that those capabilities relate to systems thinking, learning, combining, and integrating, thinking inventively, networking, and coalition building.

Finally, as stated by Young and Johnston (2003), there are a number of traditional business strategy theories that have been used to discuss business-to-business (B2B) e-commerce strategy: Transaction Cost Economics, Resource-Based View, Porter's Market Forces Theory, and Channel Theory. However, there currently exists no comprehensive framework linking these theories into a method to rigorously assess value delivery strategies, and in particular to determine how to maximize the impact of the Internet as a value delivery channel (Young & Johnston, 2003).

3. Analytic framework and MCDM-based methods for an innovative e-business model definition

The analytical process for defining e-business models is initiated by collecting the INCs needed to develop design service providers' INC using the Delphi method. Since any INCs to be derived by the Delphi may impact each other, the structure as well as the priorities of every INC will be derived by the ANP. Finally, the GRA will be applied to get the correlation between the INCs and the available e-business models. Based on the grey grades to be derived by the GRA, the most suitable e-business model will be derived. In summary, this evaluation framework (Fig. 1) consists of five main phases: (1) establishing INCs using the Delphi method; (2) building the structure between INCs by using the DEMATEL; (3) deriving the weights versus each INC by using the ANP; (4) correlating the INCs with the available e-business models by using the GRA; (5) deciding the e-business model based on the grey grades versus each e-business model.

3.1. Delphic Oracle's skills of interpretation and foresight

The Delphi method originated in a series of studies conducted by the RAND Corporation in the 1950s (Jones & Hunter, 1995). The objective was to develop a technique to obtain the most reliable consensus from a group of experts (Dalkey & Helmer, 1963). While researchers have developed variations of the method since its introduction, Linstone and Turoff (1975) captured its common

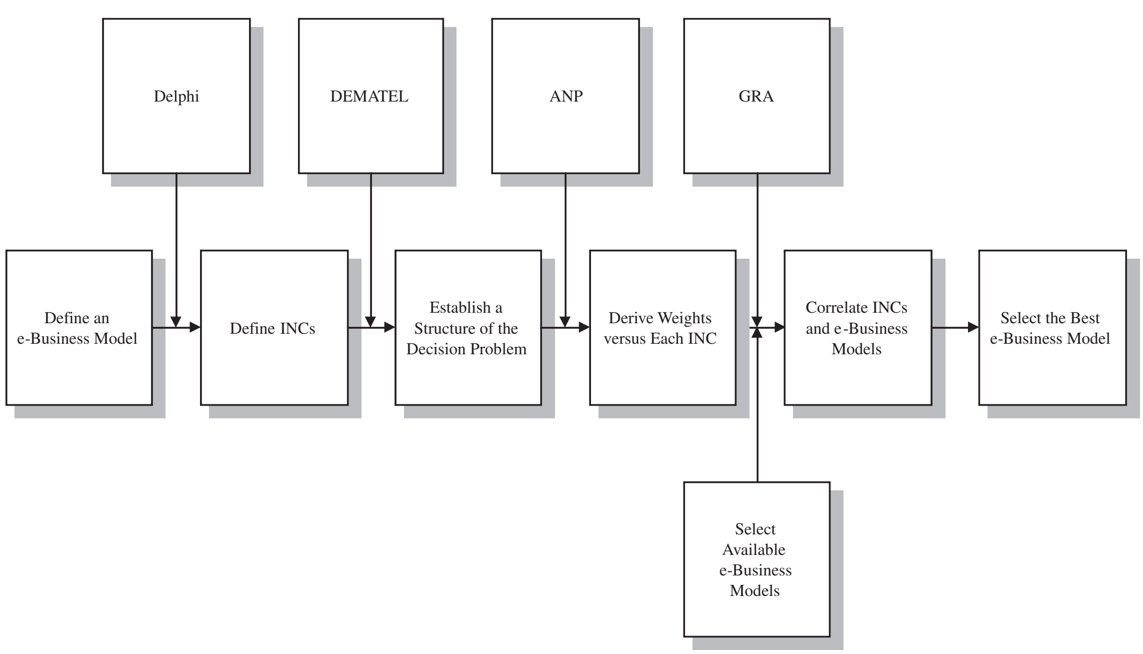


Fig. 1. Analytical framework for innovation mechanisms definition.

characteristics in the following descriptions: Delphi may be characterized as a method for structuring a group communication process; so the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem. To accomplish this 'structured communication', certain aspects should be provided: some feedback of individual contributions of information and knowledge; some assessment of the group judgement or viewpoint; some opportunity for individuals to revise their views; and some degree of anonymity for individual responses (Linstone & Turoff, 1975). The Delphi technique enables a large group of experts to be surveyed cheaply, usually by mail using a self-administered questionnaire (although computer communications also have been used), with few geographical limitations on the sample. Specific situations have included a round in which the participants meet to discuss the process and resolve any uncertainties or ambiguities in the wording of the questionnaire (Jones & Hunter, 1995). The Delphi method proceeds in a series of communication rounds, as follows:

Round 1: Either the relevant individuals are invited to provide opinions on a specific matter, based upon their knowledge and experience, or the team undertaking the Delphi expresses opinions on a specific matter and selects suitable experts to participate in subsequent questionnaire rounds; these opinions are grouped together under a limited number of headings, and statements are drafted for circulation to all participants through a questionnaire (Jones & Hunter, 1995).

Round 2: Participants rank their agreement with each statement in the questionnaire; the rankings then are summarized and included in a repeat version of the questionnaire (Jones & Hunter, 1995).

Round 3: Participants re-rank their agreement with each statement in the questionnaire, and have the opportunity to change their score, in view of the group's response; the re-rankings are summarized and assessed for their degree of consensus: if an acceptable degree of consensus is obtained, the process may cease, with the final results then fed back to the participants; if not, this third round is repeated (Jones & Hunter, 1995).

3.2. DEMATEL method

The DEMATEL method was developed by the Battelle Geneva Institute (1) to analyze complex 'world problems' dealing mainly with interactive man-model techniques; and (2) to evaluate qualitative and factor-linked aspects of societal problems (Gabus & Fontela, 1972). The applicability of the method is widespread, ranging from industrial planning and decision-making to urban planning and design, regional environmental assessment, analysis of world problems, and so forth. It has also been successfully applied in many situations, such as marketing strategies, control systems, safety problems, developing the competencies of global managers and group decision-making (Chiu, Chen, Tzeng, & Shyu, 2006; Liou, Tzeng, & Chang, 2007; Wu & Lee, 2007; Lin & Wu, 2008). Furthermore, a hybrid model combining the two methods has been widely used in various fields, for example, e-learning evaluation (Tzeng, Chiang, & Li, 2007), airline safety measurement (Liou et al., 2007), and innovation policy portfolios for Taiwan's SIP Mall (Huang, Shyu, & Tzeng, 2007). Therefore, in this paper we use DEMATEL not only to detect complex relationships and build a network relation map of the criteria, but also to obtain the influence levels of each element over others; we then adopt these influence level values as the basis of the normalization supermatrix for determining ANP weights to obtain the relative importance. To apply the DEMATEL method smoothly, the authors refined the definitions based on above authors and the ones by Hori and Shimizu (1999), and produced the essential definitions indicated below.

The DEMATEL method is based upon graph theory, enabling us to plan and solve problems visually, so that we may divide multiple criteria into a relationship of cause and effect group, in order to better understand causal relationships. Directed graphs (also called digraphs) are more useful than directionless graphs, because digraphs will demonstrate the directed relationships of sub-systems. A digraph typically represents a communication network, or a domination relationship between individuals, etc. Suppose a system contains a set of elements, $S = \{s_1, s_2, \ldots, s_n\}$, and particular pair-wise relationships are determined for modeling, with respect to a mathematical relationship, *MR*. Next, portray the relationship *MR* as a direct-relation matrix that is indexed equally in both dimensions by elements from the set *S*. Then, extract the case for which the number 0 appears in the cell (i,j), if the entry is a positive integral that has the meaning of:

- the ordered pair (s_i, s_j) is in the relationship *MR*;
- it has the kind of relationship regarding that element such that s_i causes element s_j.

The digraph portrays a contextual relationship between the elements of the system, in which a numeral represents the strength of influence (Fig. 2). The elements s_1, s_2, s_3 and s_4 represent the factors that have relationships in Fig. 2. The number between factors is influence or influenced degree. For example, an arrow from s_1 to s_2 represents the fact that s_1 influences s_2 and its influenced degree is two. The DEMATEL method can convert the relationship between the causes and effects of criteria into an intelligible structural model of the system (Chiu et al., 2006).

Definition 1. The pair-wise comparison scale may be designated as 11 levels, where the scores $0, 1, 2, \ldots, 10$ represent the range from 'no influence' to 'very high influence'.

Definition 2. The initial direct relation/influence matrix $\boldsymbol{A}$ is an $n \times n$ matrix obtained by pair-wise comparisons, in terms of influences and directions between the INCs, in which a_{ij} is denoted as the degree to which the ith INC affects the jth INC.

$$\boldsymbol{A} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}.$$

Definition 3. The normalized direct relation/influence matrix $\boldsymbol{N}$ can be obtained through Eqs. (1) and (2), in which all principal diagonal elements are equal to zero

$$\boldsymbol{N} = z\boldsymbol{A}, \tag{1}$$

where

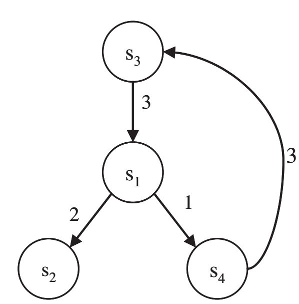


Fig. 2. An example of the directed graph.

$$z = 1/\max_{1\leqslant i\leqslant n}\sum\nolimits_{j=1}^{n} a_{ij}. \tag{2}$$

In this case, $\boldsymbol{N}$ is called the normalized matrix. Since

$$\lim_{k\to\infty}\boldsymbol{N}^k = [0]_{n\times n}.$$

Definition 4. Then, the total relationship matrix $\boldsymbol{T}$ can be obtained using Eq. (3), where $\boldsymbol{I}$ stands for the identity matrix.

$$\begin{aligned}\boldsymbol{T} &= \boldsymbol{N}+\boldsymbol{N}^2+\cdots+\boldsymbol{N}^k\\ &= \boldsymbol{N}(\boldsymbol{I}+\boldsymbol{N}+\boldsymbol{N}^2+\cdots+\boldsymbol{N}^{k-1})(\boldsymbol{I}-\boldsymbol{N})(\boldsymbol{I}-\boldsymbol{N})^{-1},\\ &\Rightarrow \boldsymbol{T} = \boldsymbol{N}(\boldsymbol{I}-\boldsymbol{N})^{-1},\end{aligned} \tag{3}$$

where $k\to\infty$ and $\boldsymbol{T}$ is a total influence-related matrix; $\boldsymbol{N}$ is a direct influence matrix and $N = [x_{ij}]_{n\times n}$; $\lim_{k\to\infty}\left(\boldsymbol{N}^2+\cdots+\boldsymbol{N}^k\right)$ stands for a indirect influence matrix and $0 \leqslant \sum_{j=1}^{n} x_{ij} < 1$ or $0 \leqslant \sum_{i=1}^{n} x_{ij} < 1$, and only one or some $\sum_{j=1}^{n} x_{ij}$ or $\sum_{i=1}^{n} x_{ij}$ equal to 1 for $\forall i,j$, but not all. So $\lim_{k\to\infty}\boldsymbol{N}^k = [0]_{n\times n}$.

The (i,j) element t_{ij} of matrix $\boldsymbol{T}$ denotes the direct and indirect influences of factor i on factor j.

Definition 5. The row and column sums are separately denoted as $\boldsymbol{r}$ and $\boldsymbol{c}$ within the total-relation matrix $\boldsymbol{T}$ through Eqs. (4)–(6)

$$\boldsymbol{T} = [t_{ij}],\quad i,j\in\{1,2,\ldots,n\}m \tag{4}$$

$$\boldsymbol{r} = [r_i]_{n\times 1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1}, \tag{5}$$

$$\boldsymbol{c} = [c_j]_{1\times n} = \left[\sum_{i=1}^{n} t_{ij}\right]_{1\times n}, \tag{6}$$

where the $\boldsymbol{r}$ and $\boldsymbol{c}$ vectors denote the sums of the rows and columns, respectively.

Definition 6. Suppose r_i denotes the row sum of the ith row of matrix $\boldsymbol{T}$. Then, r_i is the sum of the influences dispatching from factor i to the other factors, both directly and indirectly. Suppose that c_j denotes the column sum of the$j$th column of matrix $\boldsymbol{T}$. Then, c_j is the sum of the influences that factor i is receiving from the other factors. Furthermore, when $i = j$ (i.e., the sum of the row sum and the column sum $(r_i + c_i)$ represents the index representing the strength of the influence, both dispatching and receiving), $(r_i + c_i)$ is the degree of the central role that factor i plays in the problem. If $(r_i - c_i)$ is positive, then factor i primarily is dispatching influence upon the strength of other factors; and if $(r_i - c_i)$ is negative, then factor i primarily is receiving influence from other factors (Tamura, Nagata, & Akazawa, 2002).

3.3. The ANP method

The ANP method, a multi-criteria theory of measurement developed by Saaty (1996), provides a general framework to deal with decisions without making assumptions about the independence of higher-level elements from lower level elements and about the independence of the elements within a level as in a hierarchy (Saaty, 2005). Compared with traditional MCDM methods, e.g. AHP (Analytic Hierarchy Process), which usually assume the independence between criteria, ANP, a new theory that extends AHP to deal with dependence in feedback and utilizes the supermatrix approach (Saaty, 2003), is a more reasonable tool for dealing with complex MCDM problems in the real world. In this section, concepts of the ANP are summarized based on Saaty's earlier works (Saaty, 1996, 1999, 2004, 2005).

The ANP is a coupling of two parts. The first consists of a control hierarchy or network of criteria and subcriteria that control the interactions. The second is a network of influences among the elements and clusters. The network varies from criterion to criterion and a different supermatrix of limiting influence is computed for each control criterion. Finally, each of these supermatrices is weighted by the priority of its control criterion and the results are synthesized through the addition for all the control criteria (Saaty, 1999, 2004).

A control hierarchy is a hierarchy of criteria and subcriteria for which priorities are derived in the usual way with respect to the goal of the system being considered. The criteria are used to compare the components of a system, and the subcriteria are used to compare the elements. The criteria with respect to which influence is presented in individual supermatrices are called control criteria. Because all such influences obtained from the limits of the several supermatrices will be combined in order to obtain a measure of the priority of overall influences, the control criteria should be grouped in a structure to be used to derive priorities for them. These priorities will be used to weight the corresponding individual supermatrix limits and add. Analysis of priorities in a system can be thought of in terms of a control hierarchy with dependence among its bottom-level alternatives arranged as a network as shown in Fig. 3. Dependence can occur within the components and between them. A control hierarchy at the top may be replaced by a control network with dependence among its components, which are collections of elements whose functions derive from the synergy of their interaction and hence has a higher-order function not found in any single element. The criteria in the control hierarchy that are used for comparing the components are usually the major parent criteria whose subcriteria are used to compare the elements need to be more general than those of the elements because of the greater complexity of the components.

A network connects the components of a decision system. According to size, there will be a system that is made up of subsystems, with each subsystem made up of components, and each component made up of elements. The elements in each component interact or have an influence on some or all of the elements of another component with respect to a property governing the interactions of the entire system, such as energy, capital, or political influence. Fig. 4 demonstrates a typical network. Those components which no arrow enters are known as source components such as $\boldsymbol{C}_1$ and $\boldsymbol{C}_2$. Those from which no arrow leaves are known as a sink component such as $\boldsymbol{C}_5$. Those components which arrows both enter and exit leave are known as transient components such as $\boldsymbol{C}_3$ and $\boldsymbol{C}_4$. In addition, $\boldsymbol{C}_3$ and $\boldsymbol{C}_4$ form a cycle of two components because they feed back and forth into each other. $\boldsymbol{C}_2$ and $\boldsymbol{C}_4$ have loops that connect them to themselves and are inner dependent. All other connections represent dependence between components, which are thus known to be outer dependent.

A component of a decision network which was derived by the DEMATEL method in Section 3.2 will be denoted by $\boldsymbol{C}_h$, $h = 1,\ldots,m$, and assume that it has n_h elements (INCs), which we denote by $e_{h1}, e_{h2},\ldots,e_{hm}$. The influences of a given set of elements (INCs) in a component on any element in the decision system are represented by a ratio scale priority vector derived from paired comparisons of the comparative importance of one criterion and another criterion with respect to the interests or preferences of the decision makers. This relative importance value can be determined using a scale of 1–9 to represent equal importance to extreme importance (Saaty, 1980, 1996). The influence of elements (INCs) in the network on other elements (innovation competences) in that network can be represented in the following supermatrix:

$$
W = \begin{array}{c c} & \begin{array}{ccccccccccc} & C_1 & & & C_2 & & \cdots & & C_m & \\ e_{11} & \cdots & e_{1n_1} & e_{21} & \cdots & e_{2n_2} & \cdots & e_{m1} & \cdots & e_{mn_m} \end{array} \\ \begin{array}{c c} C_1 & \begin{array}{c} e_{11} \\ e_{12} \\ \vdots \\ e_{1n_1} \end{array} \\ C_2 & \begin{array}{c} e_{21} \\ e_{22} \\ \vdots \\ e_{2n_2} \end{array} \\ \vdots & \vdots \\ C_m & \begin{array}{c} e_{m1} \\ e_{m2} \\ \vdots \\ e_{mn_m} \end{array} \end{array} & \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1m} \\ W_{21} & W_{22} & \cdots & W_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ W_{m1} & W_{m2} & \cdots & W_{mm} \end{bmatrix} \end{array}.
$$

A typical entry $\boldsymbol{W}_{ij}$ in the supermatrix, is called a block of the supermatrix in the following form where each column of $\boldsymbol{W}_{ij}$ is a principal eigenvector of the influence of the elements (INCs) in the ith component of the network on an element (INC) in the jth component. Some of its entries may be zero corresponding to those elements (INCs) that have no influence.

$$
\boldsymbol{W}_{ij} = \begin{bmatrix} w_{i_1 j_1} & w_{i_1 j_2} & \cdots & w_{i_1 j_{n_j}} \\ w_{i_2 j_1} & w_{i_2 j_2} & \cdots & w_{i_2 j_{n_j}} \\ \vdots & \vdots & \ddots & \vdots \\ w_{i_{n_i} j_1} & w_{i_{n_i} j_2} & \cdots & w_{i_{n_i} j_{n_j}} \end{bmatrix}.
$$

After forming the supermatrix, the weighted supermatrix is derived by transforming all column sums to unity exactly. This step is very much similar to the concept of the Markov chain in terms of ensuring that the sum of these probabilities of all states equals 1. Next, the weighted supermatrix is raised to limiting powers, such as Eq. (7) to get the global priority vector or called weights (Huang, Tzeng, & Ong, 2005)

$$
\lim_{\theta \to \infty} \boldsymbol{W}^{\theta}. \tag{7}
$$

In addition, if the supermatrix has the effect of cyclicity, the limiting supermatrix is not the only one. There are two or more limiting supermatrices in this situation, and the Cesaro sum would need to be calculated to get the priority. The Cesaro sum is formulated as follows:

$$
\lim_{\psi \to \infty} \left(\frac{1}{\nu}\right) \sum_{j=1}^{\nu} \boldsymbol{W}_j^{\psi}, \tag{8}
$$

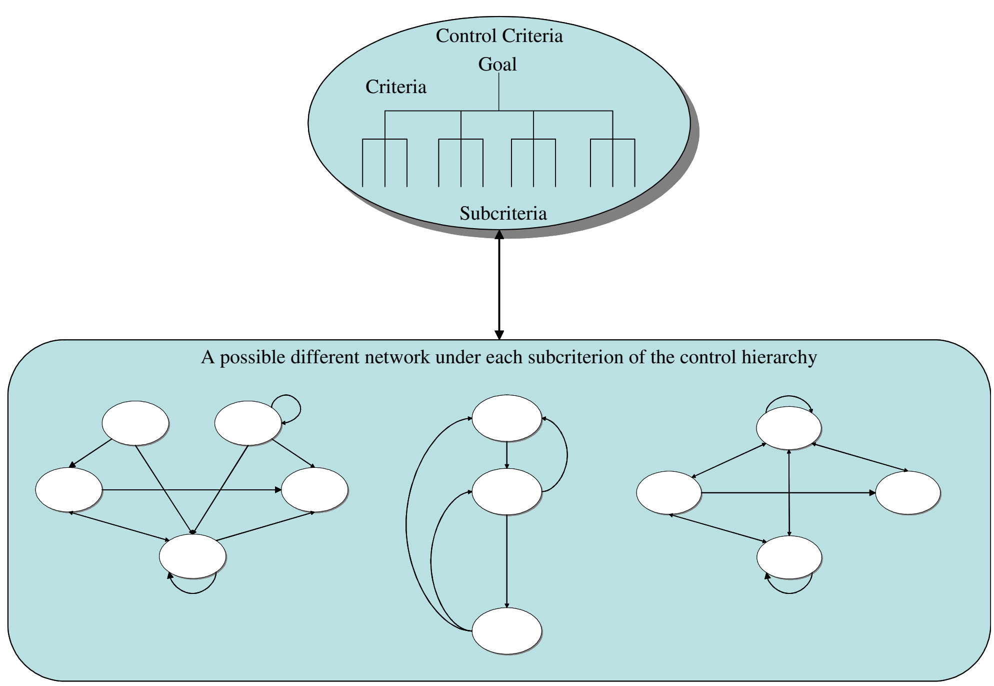
to calculate the average effect of the limiting supermatrix (i.e. the average priority weights) where $\boldsymbol{W}_j$ denotes the jth limiting supermatrix. Otherwise, the supermatrix would be raised to large powers to get the priority weights (Huang et al., 2005).

The weights of the kth INCs derived by using the above ANP processes, namely ω_k, $k \in \{1, 2, \ldots, n\}$, will be used as inputs for summing up the grey coefficients of the kth INC in Eq. (12) in the following GRA analysis.

3.4. Grey relational analysis

Since Deng (1982) proposed Grey theory, related models have been developed and applied to MCDM problems. Similar to fuzzy set theory, Grey theory is a feasible mathematical means that can be used to deal with systems analysis characterized by inadequate information. Fields covered by the Grey theory include systems analysis, data processing, modeling, prediction, decision-making, and control engineering (Deng, 1985, 1988, 1989; Tzeng & Tasur, 1994). In this section, we briefly review some relevant definitions and the calculation process for the Grey relation model. This research modified the definitions by Chiou and Tzeng (2001) and produced the definitions indicated below.

GRA is used to determine the relationship between two sequences of stochastic data in a Grey system. The procedure bears



Source: Saaty (1996)

Fig. 3. The control hierarchy.

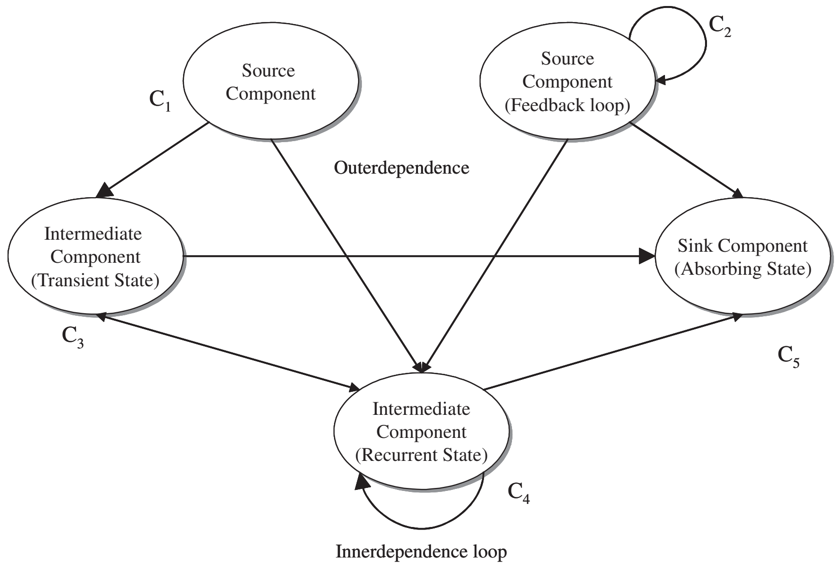


Fig. 4. Connections in a network.

some similarity to pattern recognition technology. One sequence of data is called the 'reference pattern' or 'reference sequence,' and the correlation between the other sequence and the reference sequence is to be identified (Deng, 1986; Tzeng & Tasur, 1994; Mon, Tzeng, & Lu, 1995; Wu, Deng, & Wen, 1996).

Definition 7. The relationship scale also may be designated into 11 levels, where the scores $0,1,2,\ldots,10$ represent the range from 'no relationship' to 'very high relationship' between the specified INC and the e-business models.

Definition 8. The initial relationship matrix $\boldsymbol{G}$ is an $m \times n$ matrix, where there are m e-business models and n INCs, obtained by surveying the relationships, where g_{ki} is denoted as the relationship between the kth INC and the ith e-business model.

$$\boldsymbol{G} = \begin{bmatrix} g_{11} & \cdots & g_{1i} & \cdots & g_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ g_{k1} & \cdots & g_{ki} & \cdots & g_{kn} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ g_{m1} & \cdots & g_{mi} & \cdots & g_{mn} \end{bmatrix}.$$

Definition 9. The normalized relationship matrix $\boldsymbol{G}$ can be obtained through Eqs. (9) and (10)

$$p_i = 1/\max_{1\leqslant k\leqslant m} g_{ki},$$

$$\boldsymbol{X} = \begin{bmatrix} x_{11} & \cdots & x_{1i} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{k1} & \cdots & x_{ki} & \cdots & x_{kn} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mi} & \cdots & x_{mn} \end{bmatrix}, \tag{9}$$

$$\boldsymbol{X}_i = p_i \boldsymbol{G}_i. \tag{10}$$

Definition 10. Let $\boldsymbol{x}_0$ be the reference pattern with n entries (i.e. dependent variable): $\boldsymbol{x}_0 = (x_0(1),x_0(2),\ldots,x_0(n))$ and $\boldsymbol{x}_i$, the matrix containing the normalized mapping information of each e-business model to the INCs, be one of the m patterns with n entries to be compared with the $\boldsymbol{x}_0$ where $\boldsymbol{x}_i$ is written as: when $x_{ki} = x_i(k)$, $k = 1,2,\ldots,n$ in Eqs. (9) and (10), then $\boldsymbol{x}_i = (x_i(1),x_i(2),\ldots,x_i(n))$, $1 \leqslant i \leqslant m$. The sequence x_i generally expresses the influencing factor of $\boldsymbol{x}_0$.

Definition 11. Let $\boldsymbol{X}$ be a normalized factor set of grey relations, $x_0 \in \boldsymbol{X}$ the referential sequence, and $\boldsymbol{x}_i \in \boldsymbol{X}$ the comparative sequence; with $x_0(k)$ and $x_i(k)$ representing the numerals at point k for $\boldsymbol{x}_0$ and $\boldsymbol{x}_i$, respectively. If $\gamma(x_0(k),x_i(k))$ and $\gamma(\boldsymbol{x}_0,\boldsymbol{x}_i)$ are real numbers, and satisfy the following four grey axioms, then call $\gamma(x_0(k),x_i(k))$ the grey relation coefficient, and the grade of the grey relation $\gamma(\boldsymbol{x}_0,\boldsymbol{x}_i)$ is the average value of $\gamma(x_0(k),x_i(k))$.

1. Norm Interval

$$0 < \gamma(x_0(k),x_i(k)) \leqslant 1, \quad \forall k; \qquad \gamma(\boldsymbol{x}_0,\boldsymbol{x}_i) = 1 \quad \textit{iff } \boldsymbol{x}_0 = \boldsymbol{x}_i;$$
$$\gamma(x_0,x_i) = 0 \quad \textit{iff } x_0,x_i \in \phi;$$

where ϕ is an empty set.

2. Duality Symmetric

$$\boldsymbol{x},\boldsymbol{y} \in \boldsymbol{X} \Rightarrow \gamma(\boldsymbol{x},\boldsymbol{y}) = \gamma(\boldsymbol{y},\boldsymbol{x}) \quad \textit{iff } \boldsymbol{X} = \{\boldsymbol{x},\boldsymbol{y}\}.$$

3. Wholeness

$$\gamma(\boldsymbol{x_i},\boldsymbol{x_j}) \overset{often}{\neq} \gamma(\boldsymbol{x_j},\boldsymbol{x_i}) \quad \textit{iff } \boldsymbol{X} = \{\boldsymbol{x_i} | i = 0,1,\ldots,n\}, \ n > 2.$$

4. Approachability

$$\gamma(x_0(k),x_i(k)) \quad \text{decreases when } |((x_0(k) - x_i(k)))| \text{ increases.}$$

Deng also proposed a mathematical equation for the grey relation coefficient, as follows:

$$\gamma(x_0(k),x_i(k)) = \frac{\min_{\forall i}\min_{\forall k}|(x_0(k) - x_i(k))| + \zeta\max_{\forall i}\max_{\forall k}|(x_0(k) - x_i(k))|}{|(x_0(k) - x_i(k))| + \zeta\max_{\forall i}\max_{\forall k}|(x_0(k) - x_i(k))|}, \tag{11}$$

where ζ is the distinguished coefficient ($\zeta \in [0,1]$). Generally, we pick $\zeta = 0.5$.

Definition 12. If $\gamma(\boldsymbol{x}_0,\boldsymbol{x}_i)$ satisfies the four grey relation axioms, then γ is called the Grey relational map.

Definition 13. If Γ is the entirety of the grey relational map, $\gamma \in \Gamma$ satisfies the four axioms of the grey relation, and X is the factor set of the grey relation, then $(\boldsymbol{X},\Gamma)$ will be called the grey relational space, while γ is the specific map for Γ.

Definition 14. Let $(\boldsymbol{X},\Gamma)$ be the grey relational space, and if

$\gamma(\boldsymbol{x}_0,\boldsymbol{x}_j),\gamma(\boldsymbol{x}_0,\boldsymbol{x}_p),\ldots,\gamma(\boldsymbol{x}_0,\boldsymbol{x}_q)$

satisfy $\gamma(\boldsymbol{x}_0,\boldsymbol{x}_j) > \gamma(\boldsymbol{x}_0,\boldsymbol{x}_p) > \cdots > \gamma(\boldsymbol{x}_0,\boldsymbol{x}_q)$, then we have the grey relational order: $\boldsymbol{x}_j \succ \boldsymbol{x}_p \succ \cdots \succ \boldsymbol{x}_q$.

When the grey relational coefficient is conducted with respect to innovation policies, we then can derive the grade of the grey relation $\gamma(\boldsymbol{x}_0,\boldsymbol{x}_i)$ between the reference alternative

$$\gamma(\boldsymbol{x}_0,\boldsymbol{x}_i)=\sum_{k=1}^{n}\omega_k\times\gamma(x_0(k),x_i(k)), \tag{12}$$

where k is the number of INCs, ω_k expresses the weight of the kth INC, and $\gamma(\boldsymbol{x}_0,\boldsymbol{x}_i)$ represents the grade of grey relation in x_i (the kth e-business model) correspondence to x_0. In this study, we make the order of the e-business models following the grade of grey relation.

4. SOC design service, SIP and SIP Mall

In the following section, the industry background of SOC design service, SIP, and SIP Mall will be introduced as a background for the empirical study of this paper.

4.1. SOC design service

Entering the 21st century, the global IC industry already has opened up the third industrial revolution under the driving force of the 3C (computer, consumer electronics, and communication) applications and Systems-on-Chip (SOC) (Lai & Liaw, 2007), a single IC chip that uses computing engines (MPU/DSP), memories, analog blocks (e.g., RF for wireless communication), and some custom logic to "glue" a system together (Tseng, 1999). Several emerging business models are being developed by contenders in this new SOC Olympics (Lu, 2004): SIP providers, design foundries, design service providers, and system design integrators (Lai & Liaw, 2007).

According to James (2005), IC design services suddenly are prominent as the result of a convergence of the following trends: (1) chip design are growing too complex for most companies to handle on their own; (2) SIP is far from plug-and-play, and design teams usually need specialized IP expertise (or even the knowledge and advice of the original designer) to make the IP work correctly; (3) another broad trend, off-shoring, is making design services available to a wider array of companies; and (4) the trend toward design for manufacturing (DFM) also creates more demand for design services.

Design service capabilities of SOCs are the ability to provide customers who finish SOC specification design or SOC circuit design the rest of the procedures of processes required for SOC commercialization. The detailed SOC design service procedures include front end design, backend (place and layout), and turnkey (tape out the layout to semiconductor wafer fab for SOC fabrication) services. The design service capabilities definitely are helpful for SOC design success, since strong design service capability implies strong SIP integration capability, which is a key factor for SOC success.

4.2. SIP

SIP is the subset of intellectual assets that is legally protected. There are five major forms of SIP: patents, trademarks, copyrights, trade secrets, and semiconductor mask works (Sullivan, Harrison, Keeler, & Villella, 2002). SIP is associated with the ownership of knowledge, expertise, innovation and resources that went into the creation of a specific hardware core and/or the software and/or firmware program that is required to perform a system function. Examples of SIP are: microprocessor and DSP cores, peripherals, dedicated function accelerators such as MPEG2 decoders and encoders, mixed signal technology, on chip DRAM, and Flash memory technology. Software/Firmware is intellectual property and may be delivered as an indivisible part of the hardware SIP or separately as a necessary system component. In this report we will differentiate between intellectual property that becomes part of silicon technology and other categories (Baron, 2000).

During the past decade, IC design productivity has failed to keep pace with Moore's Law, which predicts that the number of electronic devices that can be fabricated on an IC chip will double every 18 months (Moore, 1979). Thus, a 'design gap' between IC design complexity increase and productivity increase has emerged (Semiconductor Industry Association, 2002). IC suppliers began looking for ways to narrow the gap by designing ICs with reusable SIP that tended to contain increasingly complex functionality (Ratford, Popper, Caldwell, & Katsioulas, 2003). As IC designs have become more complex, a large number of SIP products are being embedded into the designs. The SIP has become a key segment of the electronic design process, as it can reduce IC development costs, accelerate time-to-market, reduce time-to-volume, and increase end-product value. The nature of SIP, which can narrow the 'design productivity gap', has made SIP critical for the design and implementation of complex systems on chips (SOC), which have become the mainstream solution for realization of electronic system products since the year 2000.

SIP cores can be classified into soft, firm, and hard SIPs. The difference is in the degree of flexibility of the SIP; soft SIP is in the form of RTL code while hard SIP is in GDSII format. Firm SIP is somewhere in between; it is usually presented as a net list with a set of additional views and information pertaining to physical design. Digital designs are commonly defined as RTL code or soft SIP while analog and mixed signal designs come in the form of hard SIP that has been designed and optimized for a specific application and technology (Keating & Bricaud, 1998).

Fabless Semiconductor Association (Ratford et al., 2003) summarized business models in the current SIP product marketplace, what is typical to expect from different providers, and considerations for determining the economic value of different SIP product types. The discussion of each business model includes the purpose of the particular business model, a definition of the payment options, typical structure of the fees paid, and most common SIP use scope for the SIP products.

Table 1 provides a summary of the principal attributes of business models for established providers and SIP products. A typical SIP purchase may involve elements of more than one business model.

Another aspect of determining the economic value of an SIP product is related to the different fees for enabling the successful use of the SIP product. Table 2 provides the typical enabling components that usually represent a secondary revenue stream for providers. These are often structured as separate fees within the SIP License Agreement itself, or sometimes as a separate Statement of Work (SOW) or contract if there are specific.

Table 1
Typical business models for SIP products. Source: Ratford et al. (2003).

	Per use	Time based	Royalty based	Access
Purpose	Fee for each SIP on defined use scope	Multiple uses of SIP over a period of time	Amortize cost of SIP share risk-reward	Fee for SIP portfolio over a period of time
Payments	Event based	Time based	Value based	Subscription based
Structure	One time fee for a design (first or subsequent)	Fee for all designs within a given time	Some or all fees spread across units	Up front fee plus discounted use fee
Scope	Per design per device	Multiple uses per device	Percent of unit value per device	Multiple SIPS per organization

Table 2
Typical enabling components for SIP products. Source: Ratford et al. (2003).

	Maintenance	Support	NRE	Contract service
Purpose	SIP updates, bug fixes, and revisions	Address specific customer needs	Enable SIP use	Enable IC design
Payments	% List price license fee	Scope based	Milestone based	Hourly based
Structure	Part of initial license agreement (may be included)	Basic package or separate contract	Initial fee (SOW) percent milestones	Initial fee (SOW) percent milestones
Scope	Changes in spec, process tech, etc.	Web, email, telephone, on-site, geography	Modifications, re-spins, porting, etc.	Tool runs, IC integration, EDA views, etc.

4.3. SIP Mall and e-business models

As observed by Huang et al. (2007), despite the optimistic future that exists for SIP, potential problems, including complex laws and regulations pertaining to SIP transactions, negotiations over SIP usage rights, technical support including SIP integrations into SOCs, maintenance, and SIP application engineering based upon current business models, have emerged as roadblocks to successful SIP business. Apparently, SIP transactions and integrations are not easy. Thus, an e-Commerce mechanism for SIP transactions, the SIP Mall – that aims to provide a well-established SIP database, to increase SIP transaction efficiency, and to provide SOC designers with well-verified reusable SIPs, design environments, and design services – can resolve the above-mentioned business, legal, and technical issues effectively, and be most helpful in accelerating SIP and IC industry growth.

The well-established SIP Malls fill the vacancy that exists in the IC industry structure, resolve existing SIP transaction problems, and enable innovations in IC. The upstream electronic system houses and the fabless IC design houses may develop synergies, by leveraging the SIPs and design services provided by SIP Malls and integrating the manufacturing capacities of IC foundries and assembly houses to roll out innovative SOC products at the most advanced process nodes. Thus, the well-established SIP Malls enhance the nation's competitiveness in the IC industry.

According to Huang and Shyu (2006), the SIP Mall e-commerce business models for SIP transactions and resolve current problems in SIP transactions include (1) the brokerage model, (2) the distributor model and (3) the commercialization model. The three models are introduced as follows and summarized in Table 3.

(1) The brokerage model: In the brokerage model, the e-commerce mechanism serves as the broker to introduce buyers and sellers and facilitate transactions. The e-commerce mechanism charges commission as part of the transaction fee; (2) the distributor model: for the distributor model, the e-commerce mechanism assists customers in verifying and certifying SIPs, fabricating test chips for SIPs, providing technical supports, negotiating with SIP end users, charging commission as part of the transaction fee and sharing license incomes; (3) IP commercialization model: The e-commerce mechanism provides a special business model called the commercialization model which helps IC design houses or system houses which have already designed circuit cores, but do not have the resources or capabilities, or INCs, for commercializing the circuit cores.

Table 3
e-Business models of the SIP Mall. Source: Huang and Shyu (2006).

SIP e-business model	SIP vendors provide to SIP Mall	SIP Mall's tasks
Distributor	Hard core/firm core/soft core Documentation Share license Income	Verification Certification Test chip fabrication Promotion Technical support License agreement Share license income
Brokerage	Documentation Simulation models Share the commission	High level verification Promotion Share the commission
IP	Commercialization	Hard core/firm core/ soft core
Verification	Share the license income	Certification Documentation Test chip fabrication Promotion Technical support License agreement Co-owner of the SIP Share license income

5. An SIP e-business model definition by using the novel MCDM framework

The authors propose an analytical frame for defining a SOC design service e-business model for an SIP being provided by an SIP provider. SIP experts from the Taiwan Government, industry, and research institutes were invited to evaluate criteria by using the Delphi method. Then the structure between criteria and weights of each criterion will be derived by the novel MCDM framework by the experts. Finally, the relationship between the criteria and available e-business models will be derived through the GRA. Detail procedures and results are illustrated below.

5.1. Capabilities and resources derivation by Delphi

Sixteen INCs and resources which serve as the criteria for evaluating the e-business models were collected from interviewing SIP experts from government, industry, and academic institutes by the Delphi procedures. Following are illustrations of the results.

(1) *Design capability in digital and mixed signal design*: Both digital designs as well as analog and mixed signal designs are the essential capabilities for developing SIP cores. Lack of these design capabilities will definitely cause fatal errors of the SIP cores in both function and timing of circuits.
(2) *Time to market capability*: Time to market is always the most important factor for vendors to help customers achieve time to money. As the complexity of SOC increases, the ability of vendors to roll out the solutions in the shortest time is the critical point for maintaining a customer relationship.
(3) *SIP integration service capability*: SIP integration service helps customers implement designs from concept to production within the shortest time. SIP integration services also help customers narrow the gap between system companies and silicon foundries, enable process technology deployment, and shorten time-to-design, and therefore, time-to-revenue (Global Unichip Corporation, 2005). For system houses and middle to small design houses, SIP integration services help customers finish their SOCs.
(4) *SIP qualification capability*: Well-qualified SIP cores are necessary conditions for SOC success for both engineering and business aspects. Thus, SIP qualification capabilities of SIP providers are essential for innovation. Typical SIP qualification includes SIP documentation and a specification check, SIP verification results check, and availability of SIP pilot-run reports.
(5) *SIP verification capability*: SIP verification is the design procedure used to verify the function and timing of SIP cores. Thus, SIP verification capability is as important as SIP qualification to guarantee the final success of SIP.
(6) *Market leadership and customer education*: Technology push is becoming the marketing trend in the IC and SOC industry. Those who have the capability to educate their customers will win at the end. Market leaders can then define specifications for their next generation products. With higher market shares and profits from already developed products, market leaders can also get returns from investment sooner than their competitors. More and more resources can thus be invested into innovation activities to accelerate the time to market of next generation products. Thus, market leaders can confirm their situation for even longer and to a greater degree.
(7) *SIP e-commerce capability*: More and more SIP e-commerce mechanisms are being funded by both governments and private institutes to shorten the time to market of SIP and enable SIP business. SIP e-commerce capability will be an important issue. SIP Malls have been established in Taiwan. Many design companies, universities, and industrial research labs have launched efforts to develop their own SIP and are attempting to find more opportunities to license or exchange SIPs (Lu, 2004).
(8) *SIP design management capability*: Major SIP design management capabilities include project management, database management and revision control, design tool management, design flow management, and security control.
(9) *Human resources*: The IC industry has become one of the fastest growing and highly invested industries in Taiwan. In order to keep pace with the technology advancement of nanometer semiconductor manufacturing, IC design and SOC techniques are evolving. This evolution is leading to a strong demand from the industry for a large number of well-trained IC design engineers as well as support human resources in business and law (Advisor Office of Ministry of Education, 2004).
(10) *MPW services*: As technology evolves, mask and engineering run costs grow exponentially with each process generation. MPW (Multiple Project Wafer) services aim to reduce IC and SIP developer costs to develop and facilitate faster prototyping by sharing the costs of a common mask set and engineering-run. Moreover, this service encourages innovation, and offers its customers a great opportunity to prove their design/product and market test samples.
(11) *Customer relationship management*: Customer relationship management is a strategy used to learn more about customer needs and behaviors and thereby develop stronger relationships with them. Customer relationship management is especially important for service-oriented Taiwanese IC companies, including silicon foundries, design services companies, and SIP providers.
(12) *Funding capability*: SIP designs have become more and more complicated in advanced processes. The most up-to-date SIP design flows and EDA tools are required to achieve higher speed, lower power, and lower cost. MPW blocks in advanced processes are more expensive. How to leverage various funding tools, including loans, venture capital investments, IPOs (Initial Public Offerings), and CBs (Changeable Bonds) has become the most important factor influencing operation efficiency.
(13) *Electronic systems know-how establishment*: SOC needs a great deal of electronic system know-how for final success of SIP applications onto the chips. Establishment of electronic system know-how is also important for SIP success in engineering and business.
(14) *Joint development and technology transfer capability*: Individual organizations can no longer rely on their own resources to compete in today's world. Rather, they should look for strategic interactions that will allow them effectively to leverage internal resources by investing in core competencies and contracting out other knowledge domains (Sobrero & Roberts, 2002). Various specifications for embedded processors, peripherals, memories, analog, and mixed signal cores are emerging for future needs of 3C applications. Since there is almost no single company, no matter how professional an SIP provider, fabless IC design house, semiconductor foundry, or even IDMs that can afford human resources and R&D capabilities to develop every SIP needed, especially at a time when the time to market SOC products is rapidly shortening, a joint development capability (including technology transfer) has become the key aspect for SIP innovations.
(15) *SIP porting capability*: Moving an SIP to an existing process of other semiconductor Fabs or foundries always involves redesign, extensive product development, and often multiple expensive iterations. A better way is to "port" the process, i.e. move it cell by cell without changing the SIP made to use it. By adopting the basic methods used in the silicon industry and paying attention to process details that affect performance, successful porting is faster, much less expensive and less disruptive to the flow of the product. Porting also results in multiple qualified fab sites for a given SIP. An added benefit is that multiple geographically separated production facilities make the supply chain immune to disruption by natural disaster or power interruption. Porting also eliminates the need for customers to re-qualify a product containing chips from a new source (Williams, Chao, Wang, & Wu, 2002).
(16) *Close relationship with foundries*: SIPs, especially mixed signal and analog SIPs from professional SIP providers, always target major foundries, for example, TSMC, UMC, or IBM, to target major foundry SOC customers. Close relationships with

foundries are essential for professional SIP providers; so they can have an SIP verification, qualification and marketing channel.

5.2. Decision problem network relation map structuring by DEMATEL

Since the inter-relationships between the 16 INCs summarized through above Delphi process seem too complicated to be analyzed, the decision problem structure will be deducted with the DEMATEL method introduced in Section 3.2. At first, the direct relation/influence matrix ***A*** is introduced as shown in Fig. 5. After that, the direct relation/influence matrix ***A*** is normalized based on Eq. (1) and the normalized direct relation/influence matrix ***N*** is shown in Fig. 6. Finally, the direct/indirect matrix is deducted based on Eq. (3) and shown in Fig. 7 where major relationships were deducted by setting the threshold value as 0.280. If the threshold value is lower than 0.280, the relationships or linkages in the casual diagram of total relationships will be too many to be analyzed. On the other hand, if the threshold value is higher than 0.280, the total relationships being derived could be too few to demonstrate proper number of relationships. The total relationships being derived will references for calculating weights between INCs in the following ANP processes. Table 4 summarizes symbols for the INCs being used in the empirical study of a SOC design service firm. The $r_i + c_i$ and $r_i - c_i$ values calculated from the direct/indirect matrix ***T*** are demonstrated in Table 5.

5.3. Calculating the weights of INCs by ANP

By setting selecting an appropriate e-business model for commercializing the SIP as the goal, pair wise comparisons of the INCs were executed based on opinions being collected from SIP experts. Following are the illustrations based on the ANP.

First, based on the decision problem structure which was derived by DEMATEL in Section 3.2, INC 4, 6, 8, 13, 14, 15 and 16 were selected as the elements of the major component where the elements belonging to this component impact the goal and other INCs significantly based on $r_i - c_i$ and the casual diagram. Other INCs including INC 1, 2, 3, 5, 7 and 9–12 were selected as the elements of the minor component where elements belonging to the minor component are mainly impacted by INCs in the major component. The inter-relationships between the Goal, the Major component, and the Minor component are illustrated in Fig. 9, where the directions of arrows mean the directions of influences.

Finally, the pair wise comparison results and the decision problem structure serve as inputs for the ANP. With the aid of the Super Decisions (Creative Decisions Foundation, 2006), a software which is used for decision-making with dependence and feedback by implementing the ANP, the limit super matrix ***W*** is calculated and shown in Fig. 10. Weights corresponding to each INC (Table 6) are derived accordingly which will be used for calculations of grey grades in Section 3.4.

The GRA was used so as to derive the relationships between INCs and e-business models. The initial relationship matrix ***G***, a

A =

0.000	5.833	5.667	6.000	7.167	5.333	2.333	5.667	6.333	2.833	3.833	6.333	4.500	5.667	5.333	6.000
5.167	0.000	5.333	4.500	4.500	6.000	4.167	5.500	4.833	4.667	5.667	4.667	3.333	5.000	5.167	4.667
6.167	6.333	0.000	5.333	6.167	5.333	1.333	5.000	5.000	4.000	4.667	5.333	4.000	5.000	2.500	5.000
6.000	5.500	6.833	0.000	7.833	5.000	2.167	5.000	4.333	4.500	3.667	5.167	3.167	4.167	5.000	6.667
6.000	5.500	5.333	6.000	0.000	4.667	1.500	5.000	4.500	3.667	3.833	5.000	3.333	3.833	5.000	6.000
4.333	4.333	5.833	6.000	5.833	0.000	6.333	6.000	7.833	5.333	6.333	7.667	5.667	6.000	4.333	6.833
1.167	2.167	1.000	0.833	1.167	4.667	0.000	2.667	2.500	1.667	3.167	5.167	2.667	2.167	0.667	2.000
6.833	6.500	6.500	6.500	6.833	5.667	2.667	0.000	7.167	3.167	2.833	5.500	3.500	4.333	4.500	3.333
5.000	5.333	4.500	4.500	4.500	5.500	2.333	5.667	0.000	1.167	2.000	4.000	1.667	1.500	1.500	1.833
3.500	3.000	4.500	3.000	4.667	2.333	2.500	2.833	3.333	0.000	3.500	3.333	1.333	2.500	3.333	6.667
3.500	6.000	3.333	3.833	3.500	5.000	2.667	2.667	2.333	3.000	0.000	2.167	3.500	6.167	3.000	5.000
5.500	5.167	4.000	4.667	4.167	6.667	3.833	4.667	5.833	3.833	3.833	0.000	2.500	4.667	2.500	4.667
5.833	4.500	4.833	4.000	5.000	5.000	4.167	5.000	4.333	4.333	4.833	4.667	0.000	3.833	2.833	4.000
5.667	6.333	6.000	5.333	3.500	5.000	1.833	4.000	3.500	4.000	5.500	5.000	4.667	0.000	3.333	4.667
7.333	5.000	6.000	7.167	7.167	3.667	3.000	4.333	3.500	4.167	2.667	3.000	3.167	2.667	0.000	6.167
6.167	6.833	5.167	3.833	4.333	5.833	2.667	3.167	4.667	5.667	5.167	5.167	2.833	5.000	6.667	0.000

Fig. 5. The direct relation/influence matrix ***A***.

N =

0.000	0.066	0.064	0.068	0.081	0.060	0.026	0.064	0.071	0.032	0.043	0.071	0.051	0.064	0.060	0.068
0.058	0.000	0.060	0.051	0.051	0.068	0.047	0.062	0.055	0.053	0.064	0.053	0.038	0.056	0.058	0.053
0.070	0.071	0.000	0.060	0.070	0.060	0.015	0.056	0.056	0.045	0.053	0.060	0.045	0.056	0.028	0.056
0.068	0.062	0.077	0.000	0.088	0.056	0.024	0.056	0.049	0.051	0.041	0.058	0.036	0.047	0.056	0.075
0.068	0.062	0.060	0.068	0.000	0.053	0.017	0.056	0.051	0.041	0.043	0.056	0.038	0.043	0.056	0.068
0.049	0.049	0.066	0.068	0.066	0.000	0.071	0.068	0.088	0.060	0.071	0.086	0.064	0.068	0.049	0.077
0.013	0.024	0.011	0.009	0.013	0.053	0.000	0.030	0.028	0.019	0.036	0.058	0.030	0.024	0.008	0.023
0.077	0.073	0.073	0.073	0.077	0.064	0.030	0.000	0.081	0.036	0.032	0.062	0.039	0.049	0.051	0.038
0.056	0.060	0.051	0.051	0.051	0.062	0.026	0.064	0.000	0.013	0.023	0.045	0.019	0.017	0.017	0.021
0.039	0.034	0.051	0.034	0.053	0.026	0.028	0.032	0.038	0.000	0.039	0.038	0.015	0.028	0.038	0.075
0.039	0.068	0.038	0.043	0.039	0.056	0.030	0.030	0.026	0.034	0.000	0.024	0.039	0.070	0.034	0.056
0.062	0.058	0.045	0.053	0.047	0.075	0.043	0.053	0.066	0.043	0.043	0.000	0.028	0.053	0.028	0.053
0.066	0.051	0.055	0.045	0.056	0.056	0.047	0.056	0.049	0.049	0.055	0.053	0.000	0.043	0.032	0.045
0.064	0.071	0.068	0.060	0.039	0.056	0.021	0.045	0.039	0.045	0.062	0.056	0.053	0.000	0.038	0.053
0.083	0.056	0.068	0.081	0.081	0.041	0.034	0.049	0.039	0.047	0.030	0.034	0.036	0.030	0.000	0.070
0.070	0.077	0.058	0.043	0.049	0.066	0.030	0.036	0.053	0.064	0.058	0.058	0.032	0.056	0.075	0.000

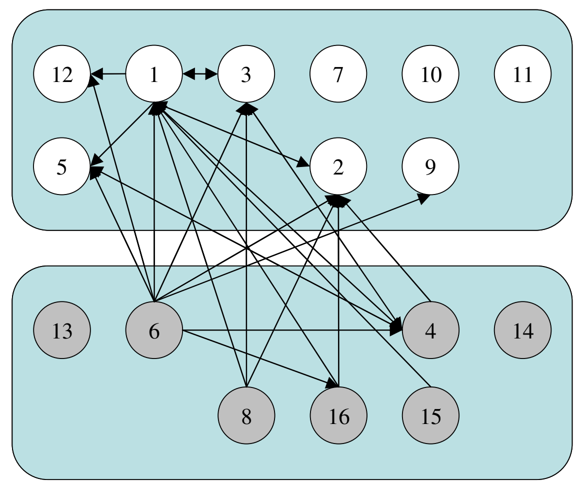
Fig. 6. The normalized direct relation/influence matrix ***N***.

$$
\boldsymbol{T}=\begin{bmatrix}
0.217 & 0.279 & 0.269 & 0.265 & 0.288 & 0.265 & 0.145 & 0.248 & 0.263 & 0.188 & 0.211 & 0.266 & 0.189 & 0.235 & 0.216 & 0.267\\
0.253 & 0.198 & 0.247 & 0.232 & 0.243 & 0.254 & 0.155 & 0.230 & 0.232 & 0.194 & 0.217 & 0.233 & 0.165 & 0.214 & 0.200 & 0.237\\
0.262 & 0.264 & 0.190 & 0.239 & 0.258 & 0.246 & 0.124 & 0.224 & 0.232 & 0.185 & 0.206 & 0.238 & 0.171 & 0.213 & 0.173 & 0.238\\
0.271 & 0.265 & 0.271 & 0.191 & 0.285 & 0.251 & 0.137 & 0.232 & 0.234 & 0.198 & 0.202 & 0.245 & 0.168 & 0.212 & 0.206 & 0.265\\
0.257 & 0.251 & 0.242 & 0.242 & 0.190 & 0.235 & 0.124 & 0.220 & 0.223 & 0.179 & 0.192 & 0.230 & 0.161 & 0.197 & 0.195 & 0.245\\
0.279 & 0.280 & 0.285 & 0.278 & 0.289 & 0.225 & 0.197 & 0.266 & 0.293 & 0.225 & 0.250 & 0.295 & 0.211 & 0.252 & 0.216 & 0.290\\
0.105 & 0.116 & 0.100 & 0.095 & 0.103 & 0.141 & 0.054 & 0.110 & 0.112 & 0.086 & 0.109 & 0.141 & 0.090 & 0.100 & 0.075 & 0.109\\
0.281 & 0.277 & 0.269 & 0.262 & 0.277 & 0.261 & 0.145 & 0.182 & 0.266 & 0.185 & 0.195 & 0.251 & 0.173 & 0.215 & 0.201 & 0.233\\
0.198 & 0.202 & 0.189 & 0.184 & 0.192 & 0.199 & 0.107 & 0.188 & 0.134 & 0.118 & 0.137 & 0.178 & 0.114 & 0.136 & 0.124 & 0.157\\
0.176 & 0.172 & 0.181 & 0.161 & 0.186 & 0.159 & 0.103 & 0.150 & 0.162 & 0.101 & 0.146 & 0.164 & 0.104 & 0.140 & 0.139 & 0.201\\
0.191 & 0.218 & 0.185 & 0.183 & 0.188 & 0.201 & 0.115 & 0.162 & 0.165 & 0.146 & 0.123 & 0.166 & 0.138 & 0.192 & 0.147 & 0.199\\
0.239 & 0.237 & 0.218 & 0.218 & 0.223 & 0.245 & 0.143 & 0.208 & 0.228 & 0.172 & 0.185 & 0.168 & 0.146 & 0.198 & 0.161 & 0.221\\
0.243 & 0.231 & 0.227 & 0.211 & 0.231 & 0.228 & 0.146 & 0.211 & 0.212 & 0.178 & 0.196 & 0.218 & 0.118 & 0.189 & 0.164 & 0.214\\
0.248 & 0.256 & 0.245 & 0.231 & 0.223 & 0.234 & 0.126 & 0.206 & 0.209 & 0.180 & 0.208 & 0.226 & 0.173 & 0.154 & 0.175 & 0.228\\
0.269 & 0.245 & 0.249 & 0.253 & 0.265 & 0.223 & 0.138 & 0.212 & 0.211 & 0.184 & 0.179 & 0.209 & 0.158 & 0.184 & 0.142 & 0.247\\
0.264 & 0.271 & 0.247 & 0.226 & 0.242 & 0.253 & 0.140 & 0.207 & 0.231 & 0.205 & 0.212 & 0.237 & 0.160 & 0.215 & 0.217 & 0.189
\end{bmatrix}
$$

Fig. 7. The direct/indirect matrix $\boldsymbol{T}$.

Table 4
Symbols for the INCs in the empirical study of SIP e-business model definitions.

INC	Symbol	Contents
1	INC1	Design capability in digital and mixed signal design
2	INC2	Time to market capability
3	INC3	SIP integration service capability
4	INC4	SIP qualification capability
5	INC5	SIP verification capability
6	INC6	Market leadership and customer education
7	INC7	SIP e-commerce capability
8	INC8	SIP design management
9	INC9	Human resources
10	INC10	MPW services
11	INC11	Customer relationship management
12	INC12	Funding capability
13	INC13	Electronic systems know-how establishment
14	INC14	Joint development capability
15	INC15	SIP porting capability
16	INC16	Close relationship with foundries



Remark: Threshold = 0.280; shaded circles stand for elements of the major component

Fig. 8. The causal diagram of total relationship.

3×16 matrix mapping the relationship between 3 e-business models and 16 INCs, was obtained by collecting opinions from the experts. The normalized relationship matrix $\boldsymbol{X}$ was then derived based on Eqs. (9) and (10). Symbols for the INCs follow the definitions in Table 4.

5.4. Evaluating an appropriate e-business models for an SIP

To verify the effectiveness of the novel MCDM model, a USB 2.0 Physical layer circuit (summarized as "USB 2.0 PHY") being designed by a medium-sized Taiwanese IC design house was selected. The main business of this medium-sized Taiwanese IC design house is to sell peripheral ICs for networking devices, e.g., 10/100 Ethernet Network Interface Card. When the R&D division of this company finished developing an IC with the USB 2.0 function, the top management decided to commercialize this circuit as an IP through the web-based SIP transaction mechanism, the SIP Mall. Based on the business models being defined in Table 7, three e-business models, distributor, brokerage and IP commercialization, are available. However, how to decide an appropriate e-business model really depends on the current innovation capacity of this company. Thus, the experts were invited to grade whether each e-business model can enhance the current innovation capacity appropriately. Based on the GRA survey results with the global weights being derived by ANP, we may find the IP commercialization model to fit the current status of the IC design house the most appropriately and thus, get the highest Grey grade by using Eq. (12) as 0.8157.

Table 5
$r_i + c_i$ and $r_i - c_i$ values calculated from the direct/indirect matrix $\boldsymbol{T}$.

INC	INC1	INC2	INC3	INC4	INC5	INC6	INC7	INC8
$r_i + c_i$	8.094	7.772	7.513	7.449	7.397	8.004	3.769	7.116
$r_i - c_i$	−0.007	−0.290	−0.343	0.066	−0.309	0.560	−0.503	0.229

INC	INC9	INC10	INC11	INC12	INC13	INC14	INC15	INC16
$r_i + c_i$	5.965	5.128	5.841	7.184	6.006	6.629	6.402	7.318
$r_i - c_i$	−0.909	−0.260	−0.022	−0.134	0.879	0.357	0.546	0.141

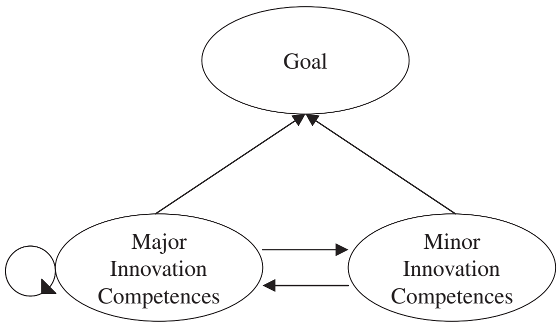


Fig. 9. The analytic network based on the casual diagram of total relationships.

6. Discussion

As stated by Young and Johnston (2003), there are a number of traditional business strategy theories that have been used to discuss business-to-business (B2B) e-commerce strategy: Transaction Cost Economics, Resource-Based View, Porter's Market Forces Theory, and Channel Theory. However, there currently exists no comprehensive framework linking these theories into a method to rigorously assess value delivery strategies, and in particular to determine how to maximize the impact of the Internet as a value delivery channel (Young & Johnston, 2003). Raisinghani et al. (2007) also mentioned that although the strategy to rebuild a robust e-business model has not been as widely implemented as had been anticipated, it has had a significant influence on company performance.

The novel MCDM methods being introduced in this research can overcome the above mentioned problem, link the management theories and maximize the impact of the Internet as a value delivery channel. The Delphi method was introduced to derive the management theories based criteria. The DEMATEL was introduced for extracting the relationships among objects in this complex decision problem. Moreover, the ANP was introduced for deriving weights versus the goal of this decision problem, maximizing the Internet value for innovation or technology commercialization. The ANP was selected based on following three reasons being concluded by Raisinghani et al. (2007): (1) ANP is a system for the analysis, synthesis, and justification of complex decisions such as those characterized by interdependencies between the e-commerce-level and business-level strategies in this study; (2) ANP can model both linear and nonlinear relationships between the elements being considered in a decision, such as feedback and dependencies among problem elements; (3) ANP was chosen from a variety of multiple criteria decision making methods due to its suitability for group decision making, since it allows one to

Table 7
Grey coefficients of each e-business models versus the INCs of the firm.

Innovation competence	e-Business models		
	Distributor	Brokerage	IP commercialization
Design capability in digital and mixed signal design	0.5455	0.4444	0.8571
Time to market capability	0.6000	0.5714	0.9231
SIP integration service capability	0.6316	0.5000	1.0000
SIP qualification capability	0.5714	0.6000	0.7742
SIP verification capability	0.6316	0.5455	0.8000
Market leadership and customer education	0.6857	0.7059	0.6486
SIP e-commerce capability	0.6486	0.7742	0.7273
SIP design management	0.6667	0.5000	0.8571
Human resources	0.6000	0.5217	0.9231
MPW services	0.6000	0.5455	0.8571
Customer relationship management	0.7059	0.7273	0.6667
Funding capability	0.6667	0.5000	0.8889
Electronic systems know-how establishment	0.7059	0.5854	0.9231
Joint development capability	0.6486	0.4444	0.9600
SIP porting capability	0.5714	0.4444	0.8889
Close relationship with foundries	0.6667	0.5217	0.8571
Grey grade	0.6195	0.5576	0.8157

$W =$

	Goal	INC4	INC6	INC8	INC13	INC14	INC15	INC16	INC1	INC2	INC3	INC5	INC7	INC9	INC10	INC11	INC12
Goal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
INC4	0.094	0.094	0.000	0.000	0.000	0.000	0.000	0.000	0.094	0.094	0.094	0.094	0.000	0.000	0.000	0.000	0.094
INC6	0.270	0.270	0.000	0.000	0.000	0.000	0.000	0.000	0.270	0.270	0.270	0.270	0.000	0.000	0.000	0.000	0.270
INC8	0.086	0.086	0.000	0.000	0.000	0.000	0.000	0.000	0.086	0.086	0.086	0.086	0.000	0.000	0.000	0.000	0.086
INC13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
INC14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
INC15	0.038	0.038	0.000	0.000	0.000	0.000	0.000	0.000	0.038	0.038	0.038	0.038	0.000	0.000	0.000	0.000	0.038
INC16	0.066	0.066	0.000	0.000	0.000	0.000	0.000	0.000	0.066	0.066	0.066	0.066	0.000	0.000	0.000	0.000	0.066
INC1	0.244	0.244	0.000	0.000	0.000	0.000	0.000	0.000	0.244	0.244	0.244	0.244	0.000	0.000	0.000	0.000	0.244
INC2	0.095	0.095	0.000	0.000	0.000	0.000	0.000	0.000	0.095	0.095	0.095	0.095	0.000	0.000	0.000	0.000	0.095
INC3	0.106	0.106	0.000	0.000	0.000	0.000	0.000	0.000	0.106	0.106	0.106	0.106	0.000	0.000	0.000	0.000	0.106
INC5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
INC7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
INC9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
INC10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
INC11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
INC12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Fig. 10. The limit supermatrix ***W*** for deriving weights of INCs.

Table 6
Weights of the INCs derived by the limit supermatrix.

INC	INC1	INC2	INC3	INC4	INC5	INC6	INC7	INC8
Weight	0.244	0.095	0.106	0.094	0.000	0.270	0.000	0.086
INC	INC9	INC10	INC11	INC12	INC13	INC14	INC15	INC16
Weight	0.000	0.000	0.000	0.000	0.000	0.000	0.038	0.065

focus on objectives rather than on alternatives, and offers numerous benefits as a synthesizing mechanism in group decisions.

For MCDM problems, GRA has advantages over traditional statistical correlation analysis. GRA is not constrained by sample numbers, whereas the total number of samples should be over thirty for traditional statistical relational analysis. Meanwhile, the weights for criteria can be introduced while calculating the grade in GRA (however, to facilitate the survey, we assumed that the weights of each criterion are equal). Moreover, GRA derives the grade of grey relation between criteria (INC) and alternatives (e-Commerce models), whereas statistical relational analysis derives the pair-wise correlation coefficients only. Finally, with GRA, the concepts of minimum and maximum are introduced, and the reference point is set for calculating the grades, specifically the distances between the variable and the reference point, while the statistical correlation analysis calculates the sum of the products of two standardized values $(z_i = (x_{ij} - \bar{x}_i)/s_i;\ i = 1, 2, \ldots, p)$ only.

Apparently, GRA serves as an effective tool for analyzing the correlation between strategies versus INCs or any criteria, which are necessary for evaluating policies or strategies, especially when available experts in some specific fields of emerging technologies are limited. Thus, this procedure provides a solution for addressing the need to define an e-business model with clear steps, and is more appropriate for real-world e-business model definition problems.

Further, for the e-business definition empirical case being studied in this research, the reasons why the IP commercialization model was selected finally can be illustrated below based on the views from a firm's capability and resources. Based on the INCs being summarized in Section 5.1, the IP commercialization can compensate an SIP provider's insufficiency from the aspects of SIP engineering capabilities in digital and mixed signal design (INC1), time to market (INC2), SIP integration service (INC3), SIP qualification (INC4) as well as SIP porting (INC15). Moreover, a design service firm can compensate its customers' production, marketing, R&D as well as human resources management capabilities in close relationship with foundries (INC16) to get plenty and on-time wafers for SIP verifications, market leadership (INC6) for educating customers for introducing the SIP being verified and R&D management, design management (INC8) for project management, database management and revision control, design tool management, design flow management, and security control of the customer's IP being commercialized by the design service firm.

However, a selection of an appropriate e-business model is not enough for service value maximization. Appropriate strategy definitions for closing the gaps between current states of the design service providers' as well as the aspired levels of each INCs' (see Fig. 11) should be studied further. Based on the Grey coefficients (refer to Table 7) of the best e-business model (IP Commercialization) being derived, enhancement possibilities exist in almost all the INCs except for INC3, SIP integration service capability. Moreover, the INCs can be enhanced through the INCs with the highest strength of influences based on the definition of DEMATEL. Thus, from Table 5 and Fig. 8, the most suitable e-business model can efficiently be enhanced through market leadership and customer education (INC6), management of R&D team (INC8) and close relationship with foundries (INC16) since other INCs will also be impacted by the four INCs. For example, design capability in digital and mixed signal design (INC1) will be impacted by the above mentioned four INCs, INC4, 6, 8, and 16. Moreover, the INCs dispatching and receiving influences simultaneously, that is, $r_i - c_i \approx 0$, should also be enhanced. Therefore, digital and mixed signal design capability (INC1), SIP qualification capability (INC4) and customer relationship management (INC11) should also be enhanced. Finally, the INCs (INC 7, 9, 10, 11, 13, 14 and 15) which are not impacted significantly by other INCs should also be selected and enhanced.

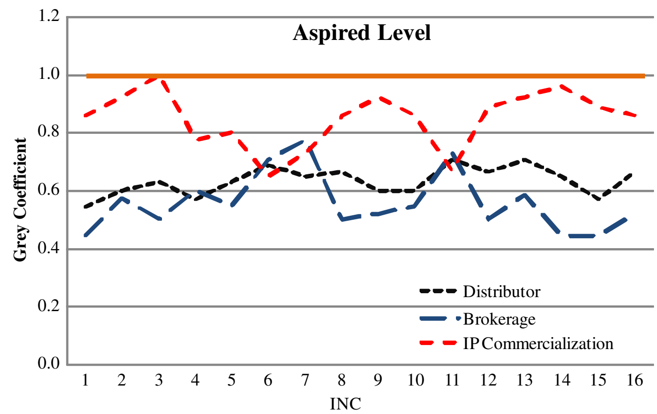


Fig. 11. Grey coefficients of each INC versus the aspired level.

By using the proposed novel MCDM method, the authors successfully linked the business theories into value delivery strategies, and in particular to determine how to maximize the impact of the Internet as a value delivery channel. In the future, the proposed MCDM method can also be used on e-business model definition or selection in other industries.

7. Conclusions

The emergence of the Internet has changed the high technology marketing channels at the moment when e-commerce has already become one of the most efficient channels. High technology firms may skip the intermediaries and reach end customers directly. Albeit a number of traditional business strategy theories have been used to discuss e-commerce strategy, few comprehensive frameworks linking these theories into methods to rigorously assess value delivery strategies as well as Internet impact maximization. Thus, this research proposed an e-business model definition method to overcome the above mentioned cognitive gap by developing a novel MCDM methodology to choose the appropriate e-business model for enabling the SIP transactions by Delphi, DEMATEL, ANP and GRA. Following are conclusions and recommendations.

In this research, an SIP Mall based e-commerce model to maximize the value of an SIP is recommended based on INCs derived with the Delphi. A recommended e-business model was derived by mapping INCs to the feasible e-business models by GRA with weights of each criterion being derived by the DEMATEL and the ANP. Finally, an empirical analysis based on Taiwan's SOC industry is provided to illustrate the analytic procedures. The authors found that IP commercialization is the most efficient e-business model which may compensate an SIP provider's insufficiency of innovation capabilities. Furthermore, strategies for enhancing the e-business model being selected to reach the aspired levels of INCs were suggested also. For future research, applications of the analytic framework for e-business model definitions of other industries or other innovative services will be appropriate topics for studies.

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