

Value Driver Derivations for Embedded Memories by Fuzzy DEMATEL based Hybrid MCDM Methods

Chi-Yo Huang

Department of Industrial Education
National Taiwan Normal University
Taipei, Taiwan
cyhuang66@ntnu.edu.tw

Gwo-Hshiung Tzeng

Institute of Project Management
Kainan University
Luchu, Taiwan
ghtzeng@mail.knu.edu.tw

Abstract — The embedded memories have already played a very important role in the modern system on a chip (SoC) designs from the aspects of performance enhancement, power reduction, form factor optimization, etc. Meanwhile, embedded memories usually occupied for the major portion of an SoC layout. Thus, how an embedded memory IP (intellectual property) provider can differentiate the product to maximize the value of that IP has already become a key factor for profit maximization. However, very few scholars tried to resolve such problems. The product and service differentiation problem of memory IPs is in nature a multiple attribute decision making (MADM) problem. Moreover, the differentiators of an embedded memory IP usually interact with each other. Furthermore, evaluations of customers' needs and wants, which are vague, are often required for such a product marketing strategy definition problem. Thus, a fuzzy DEMATEL based multiple criteria decision making (MCDM) framework will be proposed for maximizing the value of an embedded memory IP. The value driver for differentiating an embedded memory IP will first be derived by literature review. The most influential value drivers will be selected. Then, strategies will be proposed for maximizing the value through the most influential value drivers. An empirical study based on an embedded memory IP being provided by an SOC design service provider will be used for verifying the feasibility of the framework. Based on the empirical study results, both power consumption as well as the area of the embedded memory core are the most important value drivers. The proposed product marketing strategies can also be used for maximizing the value of the embedded IP.

Keywords – *Embedded memory; system on a chip (SOC); differentiation; Fuzzy DEMATEL; Fuzzy MCDM (Multiple Criteria Decision Making, MCDM).*

I. INTRODUCTION

Memory plays a critical role in achieving the performance, power or cost goals of an electronic system [1]. For an SoC (System on a Chip), the memory and processors are implemented on the same chip while in this particular case, the memory is called the embedded memory [2]. Nowadays, over 50 % of the area in an SoC is occupied by the embedded memory [3]. As the integrated circuit migrates to the SoC era, the embedded memory technique is playing a daily important role. Furthermore, provisions of embedded memory intellectual properties (IP) and design services have become novel business models which emerged in the past decade.

Embedded memory may be more expensive to fabricate than separate memory chips, since the fabrication processes for memories and processors must be compatible [2]. Nevertheless, a large percentage of the total chip area maybe consumed by the memory [2]. Thus, the selection of an embedded memory IP and supplier is critical to the success of the design and the ramp to volume [3]. When designed correctly, an SoC incorporating embedded memory can offer higher speeds or lower power consumption and maintain the same or lower cost than a system designed with stand-alone memory [4].

Differentiation in the embedded memory IP can occur in the four mutually interacted dimensions, including the function, the speed, the area and the power consumption; albeit some RAMs offer functional differentiation, the key areas in which differentiation can exist are the trade-offs between the remaining three dimensions [5]. Further, from the SOC design service view, differentiation can happen in the time to market capability, SIP integration service capability, SIP verification capability, as well as the close relationship with foundries.

The embedded memories are usually provided by IP providers, design service providers or professional silicon foundries. However, providing a “me too” embedded memory product cannot assist a provider help customer maximize their value. Thus, how a design service provider can differentiate their products and maximize the value of their services has become a critical issue.

A company can differentiate its market offering through product, services, etc. [6]. The essence of differentiation advantage, to increase the perceived value of the offering to the customer either more effectively or at lower cost than do competitors, requires that the firm match the requirements and preferences of customers with its own capacity for creating uniqueness [7]. Products, services and technologies should be seen as vehicles for value creation [8]. Product managers are expected to set prices that capture the value offered by their products and that also maximize profits [9]. In order to build effective marketing strategy companies must first understand the factors that drive customer perceptions of value [10], or namely, value drivers, which can be defined as (1) customer needs upon which our product or service could have an impact [9] or (2) the decision-related attributes that are perceived by the customer to be the most important to the choice process [11].

Apparently, how the value of a product can be maximized is a multiple attribute decision making problem (MADM) in nature. Further, due to the uncertainty of human beings' evaluations of needs, wants and intentions in their mindsets, applications of the fuzzy theory into the MADM framework(s) are very straightforward. Therefore, this research intends to define a fuzzy DEMATEL based multiple criteria decision making (MCDM) based framework for selecting product differentiation strategies for a company providing embedded memory products. At first, literature regarding to differentiating value drivers will be reviewed. The literature will serve as a basis for the MCDM framework development as well as possible alternatives for suitable fuel cell battery technologies. Then, the GRA will be used for deriving the relationships between the possible courses as well as the competences to be expanded. The courses with the highest Grey grades will be selected as the suitable courses of the curriculum.

An empirical study on maximizing the embedded memory IP belonging to an SoC design service firm will be provided for maximizing the value of the embedded memory IPs. The empirical study results can serve as a basis for the design service firm's value maximization of its IPs.

This research is organized as follows. The related literature regarding to differentiation and value drivers will be reviewed in Section II. The theory which is based on MCDM framework and using the GRA method will be introduced in Section III. An introduction to the embedded memory technologies will be given in Section IV. An empirical study on maximizing developing the product marketing strategies will be demonstrated in Section V for demonstrating the feasibility of this framework. Implications as well as discussion will be presented in Section VI. Finally, the whole article will be concluded in Section VII.

II. PRODUCT DIFFERENTIATION AND PROFIT MAXIMIZATION

An early study by Dickson and Ginter [12] summarized definitions of product differentiation from marketing textbooks as an alternative to market segmentation or a complement or means of implementing market segmentation. The potential for differentiation in any business is vast while differentiation extends beyond technology, design, and marketing to include all aspects of a firm's interactions with its customers [7].

Six factors affecting customer purchase decisions include relative advantage, compatibility, complexity, trialability, ability to communicate product benefits and observability [8]. A company can differentiate its market offering through product, services, personnel, channel, and image while the decision variables belonging to the obvious means of product and services include form, features, conformance, durability, reliability, style, design, quality, ordering ease, delivery, installation, customer training, customer consulting, maintenance and repair, etc. [6]. Some physical products can be highly differentiated [13] through (1) form, (2) features, (3) performance quality, and (4) conformance quality [6]. Further, according to Kotler and Keller, Products, services and technologies should be seen as vehicles for value creation [8]. The essence of differentiation advantage, to increase the perceived value of the offering to the customer either more effectively or at lower cost than do competitors, requires that the firm match the requirements and preferences of

customers with its own capacity for creating uniqueness [7]. A product's total economic value, then, is the price of the customer's best alternative (the reference value) plus the economic value of whatever differentiates the offering from the alternative (the differentiation value) [9]. Value appropriation means investing in strategies that allow the firm to differentiate its existing offerings in order to extract profits in the market [8]. Even for high technology markets, the investors react more favorably when a firm increases its emphasis on value appropriation relative to value creation, constantly innovating and investing in R&D [8].

Only the part of economic value being associated with differentiation, or the differentiation value, can potentially be captured in the price; differentiation value comes in two forms: monetary and psychological, both of which may be instrumental in shaping a customer's choice but require very different approaches to estimate them [9]. In order to create the foundation for setting prices, it is critical to understand what the customer's value drivers are and how the purchase decision can be influenced [14]. The customers' value drivers need to be reflected in the design requirements of the software if the value is to be subsequently captured by the pricing mechanism on the product's launch [14].

In order to build effective marketing strategy companies must first understand the factors that drive customer perceptions of value [10], or namely, value drivers, which can be defined as the decision-related attributes that are perceived by the customer to be the most important to the choice process [11]. The value at the heart of pricing strategy is not use value, but is what economists call exchange value or economic value, which depends on the alternatives customers have available to satisfy the same need [9].

Value hypothesis development usually begins with a list of your offering's potential value drivers including superior performance, greater reliability, additional features, reduced maintenance costs, smaller startup costs, faster service, etc. [9]. Harmon and Laird [10] summarized the value drivers to be economic-value driver, performance/functional value, buyer's perceptions about the supplier, buyer's motivations and goals, and the buying situation.

Finally, the three steps for economic value include: study customer economics, quantify value drivers and finally, estimate differentiation value [9].

III. ANALYTIC FRAMEWORK FOR MAXIMIZING PROFITS THROUGH PRODUCT DIFFERENTIATION

The analytical process for designing a capabilities-driven curriculum is initiated by collecting the capabilities and possible fuel cell courses being required to develop the national fuel cell industry by using the Delphi method. Then, the relations between the capabilities and the possible courses will be derived by using the Grey Relation Analysis.

A. Fuzzy DEMATEL Method

The Fuzzy DEMATEL can deal with the DEMATEL problem by introducing Fuzzy linguistic variables and matrices. According to the definition of Fuzzy DEMATEL, the linguistic matrices present the relationships between criteria. In the matrices, the numeral value depicts the influence versus each

criterion. Therefore, the Fuzzy DEMATEL method can transform the causes and effects relationship into a perspicuous structural model. The Fuzzy DEMATEL method has been studied and applied in many areas these years [15,16]. According to the advantages of Fuzzy DEMATEL, this research attempts to evaluate the preferences of lead users by using Fuzzy DEMATEL based on the definitions by Prof. Tzeng, Gwo-Hshiung [17]. The calculation process is demonstrated as below:

Step 1: Establishing the fuzzy linguistic scale

Establishing the linguistic sets of criteria is an essential procedure for Fuzzy DEMATEL. The major advantage of Fuzzy DEMATEL method is that it's effective to obtain the structural mode and divide the criteria into cause and effect groups, which consist of many complex aspects. To deal with the ambiguities of human feeling and evaluations, Li [18] introduces the fuzzy linguistic scale into the DEMATEL evaluation process. The strength of influence are divided into five linguistic levels as "Strong", "High", "Low", "No" and the linguistic levels will correspond to the triangular fuzzy numbers.

Step 2: Establishing the directed relation matrix

To measure the relationship versus each criterion $C = \{c_1, c_2, \dots, c_n\}$, p lead users made evaluations in terms of linguistic terms toward the criteria. Thus, p fuzzy matrices $\tilde{Z}^1, \tilde{Z}^2, \dots, \tilde{Z}^p$ each corresponds to a lead user. The Fuzzy matrix is called the initial direct relation fuzzy matrix. For simplicity, denote $\tilde{Z}$ as $c_1, c_2, \dots, c_n$, or

$$\tilde{Z} = \begin{matrix} & c_1 & c_2 & \dots & c_n \\ \begin{matrix} c_1 \\ c_2 \\ \vdots \\ c_n \end{matrix} & \begin{bmatrix} 0 & \tilde{z}_{12} & \dots & \tilde{z}_{1n} \\ \tilde{z}_{21} & 0 & \dots & \tilde{z}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{z}_{n1} & \tilde{z}_{n2} & \dots & 0 \end{bmatrix} \end{matrix},$$

where $\tilde{z}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ are triangular fuzzy numbers, elements $\tilde{z}_{ii} = 0, i = 1, 2, \dots, n$.

Step3: Establishing the structural model

In order to transform the criteria scales into comparable scales, the linguistic scale will be transformed into a normalization formula.

$$\text{Let } \tilde{a}_{ij} = \sum_{j=1}^n \tilde{z}_{ij} = \left(\sum_{j=1}^n l_{ij}, \sum_{j=1}^n m_{ij}, \sum_{j=1}^n u_{ij} \right) \text{ and } u = \max_{1 \leq i \leq n} \left(\sum_{j=1}^n u_{ij} \right).$$

Then, the normalized direct relation fuzzy matrix, denoted by $\tilde{X}$, equals $\tilde{x} = u^{-1} \otimes \tilde{z}$. Or

$$\tilde{X} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{bmatrix},$$

$$\text{where } \tilde{x}_{ij} = \frac{\tilde{z}_{ij}}{u} = \left(\frac{l_{ij}}{u}, \frac{m_{ij}}{u}, \frac{r_{ij}}{u} \right). \quad (1)$$

Fuzzy DEMATEL also assume that $\sum_{j=1}^n u_{ij} < u$ and

$$\lim_{k \rightarrow \infty} \tilde{x} = [0]_{0 \times 0}.$$

Step 4: Deriving the total relation matrix

After calculating the normalized direct relation fuzzy matrix, the total relation matrix $\tilde{T}$ can be derived by the equation below:

$$\tilde{T} = \tilde{X} + \tilde{X}^2 + \dots + \tilde{X}^n = \tilde{X}(\mathbf{I} - \tilde{X})^{-1},$$

$$\text{When } \lim_{k \rightarrow \infty} \tilde{X} = [0]_{n \times n}$$

$$\tilde{T} = \begin{bmatrix} \tilde{t}_{11} & \tilde{t}_{12} & \dots & \tilde{t}_{1n} \\ \tilde{t}_{21} & \tilde{t}_{22} & \dots & \tilde{t}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{t}_{m1} & \tilde{t}_{m2} & \dots & \tilde{t}_{mn} \end{bmatrix}; \tilde{t}_{ij} = (l_{ij}^*, m_{ij}^*, r_{ij}^*)$$

$$\begin{aligned} [l_{ij}^*] &= X_l - (\mathbf{I} - X_l)^{-1}, [m_{ij}^*] = X_m - (\mathbf{I} - X_m)^{-1}, \\ [r_{ij}^*] &= X_r - (\mathbf{I} - X_r)^{-1} \end{aligned}$$

Step 5: Analyzing the sum of rows and columns

The row and column sums are individually indicated the sum of rows and columns of the total relation matrix $\tilde{T}$ by using following equations (2), (3), and (4),

$$\tilde{T} = [\tilde{t}_{ij}], \quad i, j \in \{1, 2, \dots, n\} \quad (2)$$

$$\tilde{r} = [\tilde{r}_i]_{n \times 1} = \left[\sum_{j=1}^n \tilde{t}_{ij} \right]_{n \times 1} \quad (3)$$

$$\tilde{c} = [\tilde{c}_j]_{1 \times n} = \left[\sum_{i=1}^n \tilde{t}_{ij} \right]_{1 \times n} \quad (4)$$

where the $\tilde{r}$ and $\tilde{c}$ represent the sums of the rows and columns.

Step 6: Analyzing the results from $\tilde{r}$ and $\tilde{c}$

According to the sum of rows and columns, $(\tilde{r}_i + \tilde{c}_i)$ depicts the strength of the influence. If $(\tilde{r}_i - \tilde{c}_i)$ is positive, then criteria i is dispatching influence on other factors. On the other hand, if $(\tilde{r}_i - \tilde{c}_i)$ is negative, factor i is receiving influence from other criteria [15,19,20].

B. Analytic Network Process (ANP)

The ANP method, a multi criteria theory of measurement developed by Saaty [21], 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 [21]. In this section, concepts of the ANP are summarized based on Saaty's earlier works [21, 22].

A component of a decision network which was derived by the DEMATEL method in Section 3.1 will be denoted by $C_h, h = 1, 2, \dots, m$, and assume that it has n_h elements, which we denote by $e_{h1}, e_{h2}, \dots, e_{hm}$. The influences of a given set of

elements 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 [21]. The influence of elements in the network on other elements in that network can be represented in the supermatrix as $W_{ij} = [w_{ij}]$, $i \in \{1, 2, \dots, m\}$, $j \in \{1, 2, \dots, m\}$. A typical entry $W_{ij} = [w_{i_{nx}j_{ny}}]$, $nx \in \{1, 2, \dots, n_i\}$, $ny \in \{1, 2, \dots, n_j\}$ in the supermatrix, is called a block of the supermatrix in the following form where each column of W_{ij} is a principal eigenvector of the influence of the elements (objective) in the i th component of the network on an element (objective) in the j th component. Some of its entries may be zero corresponding to those elements (objective) that have no influence.

After forming the supermatrix, the weighted supermatrix is derived by transforming all columns sum 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 $\lim_{\theta \rightarrow \infty} W^\theta$ to get the global priority vector or called weights [23].

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.

IV. AN EMPIRICAL STUDY OF AN EMBEDDED MEMORY VALUE MAXIMIZATION STRATEGIES DEFINITIONS

As embedded memories are playing a daily critical role in modern SoC designs, novel techniques emerged. Further, embedded memory vendors, SoC design service providers, and professional foundry vendors are dedicated in providing novel services so as to fulfill customers' needs of one stop shopping, time to market, and thus, time to money.

Based on literature review and an expert's (with experiences in SoC design service and semiconductor memory sales and marketing for more than 10 years) opinions regarding to the value drivers of the embedded memory intellectual properties, the value drivers can be divided into two aspects, technology and service. From the technology aspect, the functionality (f_1), speed (f_2), area (f_3), and power consumption (f_4) of the memory IPs can be defined as the value drivers for an embedded memory IP. Further, from the service aspect, the time to market capability (f_5), the provision of the one stop shopping environment (f_6), the SIP design capability (f_7), the SIP integration service capability (f_8), the SIP verification capability (f_9) as well as the supply chain management capability (f_{10}) can be defined as the value drivers for an embedded memory IP.

At first, according to the expert's opinion, the linguistic variables can be defined as Figure 1(a) while the initial direct relation fuzzy matrix $\tilde{Z}$ can be defined as Figure 1(b).

Then, by introducing the Fuzzy DEMATEL ANP process being introduced in Section 3, the weights being associated with each work barrier can be derived (see Table II).

According to the empirical study results, the power consumption as well as the area is the most important value drivers for differentiating the embedded memory from both aspects of technology and services.

V. DISCUSSION

In this research, embedded memory value drivers for product differentiation were derived from both aspects of technology and services. Following, managerial implications and future research possibilities will be presented.

At first, the embedded memory design and selection is in nature an MCDM problem by considering interdependences between criteria. Very limited scholars tried to address this issue by introducing the MCDM framework though the integrated circuit industry is migrating into the SoC era which embedded memories are playing a significant role from the aspects of area and its influences in SoC speed, power consumption, cost, etc. Thus, this research advanced the research in the related fields.

	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	f_9	f_{10}
f_1	0	VH	VH	VH	VH	VL	VL	VL	VL	VL
f_2	L	0	M	VH	VL	VL	VL	VL	VL	VL
f_3	VL	M	0	M	VL	VL	VL	VL	VL	VL
f_4	VL	VL	VL	0	VL	VL	VL	VL	VL	VL
f_5	VL	VL	VL	VL	0	VL	VL	VL	VL	H
f_6	VL	VL	VL	VL	VH	0	VL	VH	VL	VH
f_7	VH	VH	VH	VH	VH	VL	0	VH	VH	VH
f_8	VL	VL	VL	VL	VH	H	L	0	L	VH
f_9	VL	VL	VL	VL	VH	H	VL	VH	0	VH
f_{10}	VL	VL	VL	VL	VH	H	M	VH	M	0

(a)

(b)

Figure 1. (a) Linguistic variables and (b) the fuzzy matrix $\tilde{Z}$

Table II. The weights versus criteria

Driver	f_1	f_2	f_3	f_4	f_5
Weight	0.068	0.068	0.114	0.341	0.068
Driver	f_6	f_7	f_8	f_9	f_{10}
Weight	0.068	0.068	0.068	0.068	0.068

Further, very few scholars tried to analyze how an embedded memory IP can be analyzed from both aspects of technology and services. In this research, the authors adopted literature from both technology side and the business side and analyzed the casual relationships between two aspects. Further, the most important value drivers which can influence other criteria were also derived.

For the empirical study results, the functionality factor was weighted lower than the power consumption factor. Such tradeoff is common for SOC(s) being designed for portable devices. The empirical study results will be changed if the target applications are changed.

Finally, in this research, a conceptual framework was developed based on the opinions of sole expert. In the future,

empirical studies based on industry experts from both the management and technology departments can be very helpful for developing the embedded memory business. Further, how the innovation strategies can be introduced for differentiating the value drivers will also be beneficiary for the marketers in the future.

VI. CONCLUSIONS

Embedded memory has played a daily important role in SoC designs. However, how to differentiate an embedded memory and maximize the profits from both aspects of technology and business were seldom addressed. Due to the interdependence nature of the embedded memory technology and business models, the authors adopted a Fuzzy DEMATEL based MCDM framework for deriving the most important value drivers. In the future, the concepts and frameworks being derived in this research can further be adopted as the basis for differentiation and product marketing strategy definitions.

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