Selection of Developing Color Calibration Device Based on Fuzzy Delphi and Dematel-ANP

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Abstract: The Medical Display Monitors (MDMs) are commonly used in medical service centers and the industry has been growing rapidly in the past decades. The technical specifications of MDMs are very stringent due to the requirements of high quality medical judgment and functions, as well as growing market competition. The technological requirements of MDMs are higher than those of display monitors used for general purposes but their gross profit margins are larger as well. There are many multiple criteria decision making (MCDM) problems in manufacturing industry. The purpose of this research is to build a hybrid MCDM model that is useful in developing new color calibration device for the MDM industry. The proposed MCDM model uses the fuzzy Delphi method to filter performance criteria and then applies the Analytic Network Process (ANP) to prioritize three alternatives of new product development. In this study, DEMATEL is used to build a relations-structure for ANP criteria. The study also presents a case study on model implementation in a LCD high-tech company. The results indicate that the proposed model is efficient and effective in making decision for the case problem.

Key words: Fuzzy Delphi, color calibration device, ANP, DEMATEL

INTRODUCTION

A survey done by Product Development and Management Association (PDMA) reveals that more than 50% of the sales in successful companies were coming from new products and that the percentage was even over 60% in the most successful overall company (Balbontin et al., 2000). As a result, the advanced-technology product development and introduction process need to be improved to enhance a company’s competitive advantage. However, successful execution of new product development must be implemented in most stages of product lifecycle management including market requirement, product concept, detailed design, process plan, production, etc. (Chen et al., 2008).

There are Many Multiple Criteria Decision Making (MCDM) problems in manufacturing industry. Different from single criterion decision making problems, in multiple criteria problems, a decision maker (DM) has to choose the most appropriate alternative that satisfies the evaluation criteria among a set of candidate solutions (Wang et al., 2013). For the situation where the evaluation criteria are in conflict with each other, how to make a scientific decision becomes a difficult problem (Kuo et al., 2008). MCDM is one of appropriate approaches in dealing with the new product development selection problem. The MCDM approach enables experts and decision makers to simultaneously consider the relevant factors or criteria and then integrate their opinions in building an MCDM model. Subsequently, the model is applied to weight the alternatives and select the best.

In general, decision-making is the study of identifying and choosing alternatives based on the values and preferences of the decision-maker. Among various MDCM methods, Analytic Hierarchy Process (AHP) (Saaty, 1980) is a common and practical method which makes use of relative assessment and prioritization of alternatives. A simple AHP model consists of a goal, criteria and alternatives. The hierarchical structure of AHP shows the relationships among the three levels from top to bottom. The modeling process consists of three phases: decomposition, comparative judgment and synthesizing (Buyukyazici and Sueu, 2003). In practice, the evaluation index on performance systems frequently has a hierarchical structure; for example, reference (Tung, 2013) applies AHP to evaluate the performance of IDSS. The Analytic Network Process (ANP), introduced in (Saaty, 1996), is a generalization of AHP. Whereas AHP represents a framework with a uni-directional hierarchical

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relationship, ANP allows for more complex interrelationships among decision levels and attributes (Chen et al., 2008). The ANP feedback approach provides a flexible means in modeling MCDM problems, where the relationships between criteria are not easily represented with higher or lower level, dominating or being dominated, direct or indirect influence (Meade and Sarkis, 1999). For instance, the ANP not only allows to assess the impacts of the criteria on the alternatives as in AHP but also the impacts of the alternatives on the criteria. Saaty (1996) proposed “supermatrix” technique which uses Markov chain convergence theory to synthesize ratio scales.

There are many studies in literature using ANP to solve decision making problems. In two separate studies (Lee and Kim, 2000; Lee and Kim, 2001) used ANP to prioritize interdependent information system projects. The studies (Karsak et al., 2003; Mohanty et al., 2005; Agarwal et al., 2006) also employed ANP to solve R&D project selection problems. Ref. (Hu et al., 2012) also used ANP to evaluate the homestay industry in north Taiwan. Recently, hybrid MCDM models are frequently used to solve complex decision problems. Liou and Chuang (2010) studied the outsourcing provider selection problem and developed a hybrid MCDM model that combines DEMATEL, ANP and VIKOR to prioritize the alternatives. In their model, the DEMATEL builds a relations-structure among criteria, the ANP determines the relative weights of criteria with dependence and feedback and the VIKOR ranks the alternatives. Fazli and Jafari (2002) applied the same hybrid model to solve the investment decision problem in Iranian stock exchange. Ref. (Gong and Qi, 2013) developed a model based on AHP and Delphi methods for evaluating the performance of marine industries from the perspective of eco-economics. Ref. (Hsu, 2012) presented a model hybridizing ANP and DEMATEL for the selection of independent media agencies, where DEMATEL performs a role similar to TOPSIS in (Shyu, 2006; Dagdeviren, 2010).

The purpose of this study is to present a solution model for the decision problem on new color calibration device, allowing the consideration of interactions among decision levels and criteria. The device is used in medical display monitors. The fuzzy Delphi method is utilized to filter the elements of “criteria”, whereas DEMATEL is used to build a relations-structure among elements of the model. The fuzzy Delphi method was first introduced by (Ishikawa et al., 1993).

The study is structured as follows: Section 2 describes the process for establishing the hybrid MCDM model; Section 3 presents the numerical results of a case study utilizing this model; Section 4 concludes the study.

**PROPOSED MODEL**

This study presents a model adapted for developing color calibration device in the LCD high-tech industry. The overall process of the proposed approach is shown in Fig. 1. A company in the industry was chosen and acts as the case study to validate the model. To build the model, ten experts and decision-makers were invited to participate in the activity. All are members of high management, including Departments of R&D, Marketing, Production, Information Technology and Product Planning. Subsequently, a four-level hierarchical model with inner- and outer-dependence is proposed. We shall refer to the top element as the goal, the clusters at the second level as “perspectives”, the clusters at the third level as “criteria” and the elements at the lowest level as “alternatives”.

The evaluation process consists of the following steps:

**Step 1:** Form an expert/decision-maker group for this problem

**Step 2:** Establish a preliminary evaluation framework via literature review and discussion with the group

**Step 3:** Apply fuzzy Delphi method to filter the elements in the framework, including the perspectives and their respective criteria

**Step 4:** Employ DEMATEL to identify the relationships between elements in the framework and finalize the ANP

**Step 5:** Use DEMATEL method to calculate the strength of influence between criteria and the introduction of mixed weights (Tamura and Akazawa, 2005)

**Step 6:** Perform ANP calculations to evaluate and rank the alternatives

**FUZZY DELPHI METHOD**

The max-min Delphi method (Ishikawa et al., 1993) is used to screen and establish the criteria.

The preliminary decision framework considers three perspectives and fifteen criteria. After applying the max-min Delphi, nine criteria are considered for the studied problem.

The resulting decision framework contains the following:

**Level 1:** Goal (G): Determine the device to be developed

**Level 2:** Perspectives (P): Technical Capability (P₁), Marketing Environment (P₂), Organizational Management (P₃)

**Level 3:** Criteria for each perspective
Form an expert/decision-maker group

Remove unnecessarily criteria by fuzzy Delphi method

**DEMATEL**

- Initial direct influence matrix

- Full direct/indirect influence matrix \( F \)

- Direct relation graph

**ANP**

- ANP structure

- Limiting supermatrix and limiting criteria weights

- Calculate composite importance \( z \) with \( F \) and \( w \)

- Normalize \( z \) to obtain decision criteria weights

Perform pair-wise comparisons and obtain the relative evaluation scores for each criterion alternatives, sum the scores with their corresponding criteria for each alternative. Prioritize the alternatives based on the weighted scores.

**Level 4:** Three alternatives

- \( A_1 \): Front sensor-size: 18×10 mm; weight: 30g; imbeded USB; automatic control; technical difficulty: high; current market share: 30%; precision: ±1.5%; applicable MDM: 15-27 inch; investment: USD100000; estimated selling price: USD1000; warranty: 3 years

- \( A_2 \):...

- \( A_3 \):...

**P_1:** Technical capability

**C_1:** Technology patent

**C_2:** Customization capacity

**C_3:** R&D capability

**P_2:** Marketing Environment

**C_4:** Product profitability

**C_5:** Competitiveness

**C_6:** Brand image

**P_3:** Organizational management

**C_7:** Relations and corporate support

**C_35:** Integration ability

**C_36:** Marketing capability
Integrating DEMATEL and ANP with composite importance (DEMATEL-ANP): DEMATEL method can cope well with the causal relationship among the elements but unable to assess the weights of criteria which are at the same or different levels. Reference (Tamura and Akazawa, 2005) uses composite importance to solve this weight-assignment problem while incorporating DEMATEL with ANP for building a MCDM model. The formula for calculating the composite importance \( z \) is given in (1), where \( I \) is an identity matrix, \( F \) is the full influence matrix generated in DEMATEL and \( w \) is the limiting weights of criteria obtained by ANP.

\[
\begin{align*}
 z &= (I + F) \cdot w \\
\end{align*}
\]

The following example illustrates the calculation of \( z \) for a case of 3 criteria. Suppose that \( w^T = (0.333, 0.333, 0.333) \) and \( F \) is calculated as shown below.

\[
F = \begin{bmatrix}
0.117 & 0.195 & 0.671 \\
0.555 & 0.107 & 0.866 \\
0.051 & 0.027 & 0.040 \\
\end{bmatrix}
\]

By applying Eq. 1, we obtain \( z^T = (0.660, 0.842, 0.372) \). Note that the sum of the elements in \( z^T \) is not necessarily one.

**Analytic network process (ANP):** From subsections A and B, an ANP model can be established for the studied problem. The left side of Fig. 2 displays the ANP in graphical form and the right side of Fig. 2 presents the corresponding unweighted supermatrix. Fig. 3 shows the detailed network structure of the ANP. Matrix \( W_{21} \) is 3×1

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**DECISION MAKING TRIAL AND EVALUATION LABORATORY (DEMATEL)**

DEMATEL is a comprehensive method for designing and analyzing structural models of causal relationships between complex factors (Wu and Lee, 2007). The method is capable of integrating experts' opinions to clarify the connections and causal relationships among criteria and represents their inter- and inner-dependencies through a network structure. This scientific research method could improve understanding of the problem's specific features and the identification of relationships between factors and produces workable solutions (Tzeng et al., 2007). The observed method is based on graph theory, allowing visual planning and problem solving so that the relevant factors can be divided into causal group and consequential group for a better understanding of mutual relations (Li and Tzeng, 2009). For the procedure to calculate the level of interdependence among the factors with DEMATEL method, please refer to (Fontela and Gabus, 1976).
which indicates the relative weights (importance) of the three perspectives with respect to the Goal. Matrix \( W_{12} \) is \( 3 \times 3 \) which shows the influential strength among the three perspectives. Matrix \( W_{32} \) is \( 11 \times 3 \) which specifies the relative importance of the criteria with respect to their individual perspectives. Matrix \( W_{21} \) is \( 11 \times 11 \) which signifies the dependencies for criteria within the same cluster and between two distinct clusters. Matrix \( W_{30} \) is \( 3 \times 11 \) which shows the relative weights of the three alternatives for each criterion. I is a \( 3 \times 3 \) identity matrix which implies that the three alternatives are independent.

**NUMERICAL RESULTS**

Table 1 illustrates the calculated results for \( W_{30} \). The other matrices can be similarly obtained. First, arithmetic mean is used to integrate the pairwise comparisons of group members. For example, \( a_{32} = 0.327 \) in \( W_{30} \) is the mean of the values in the same position given by the group members. Afterwards, the geometric mean method is used to calculate the relative weights: \( 0.541 = (1 \cdot 0.327 \cdot 0.485)^{1/3}, 1.493 = (3.061 \cdot 1 \cdot 1.087)^{1/3} \) and \( 1.238 = (2.062 \cdot 0.921)^{1/3} \). The weight of \( P_i \) in \( W_{21} \) is \( 0.541/(0.541+1.493+1.238) = 0.165 \). By similar calculations, we obtain that the weights of \( P_1 \) and \( P_2 \) are respectively 0.456 and 0.378. Further calculations indicate that \( CR = 0.009 \) which confirms the consistency of the group’s evaluations.

ANP uses limiting or convergent weights to rank the perspectives, criteria and alternatives. To calculate the limiting supermatrix, we apply the Markov chain theory (Buyukozzyaci and Staciu, 2003). A Markov chain requires the sum of each column to be 1. Thus, the supermatrix MS in Fig. 2 needs to be normalized for the column sum requirement. A weighted supermatrix \( M_w \) can be obtained by dividing any column in \( P \) and \( C \) by \( 2 \), as shown in Fig 4. The details of the weighted supermatrix \( M_w \) is provided in Table 2.

The limiting weight vectors of the respective three perspectives, eleven criteria and three alternatives can be obtained by a series of matrix computations on the three matrices in Fig. 4 until they converge.

**For perspectives:** Compute \((M_{w}^{T})^n\) for large \( n \), where \( T \) represents matrix transpose. As a result, the limiting weight vector \((P_1, P_2, P_3) = (0.544, 0.134, 0.322)\). Technical capacity ranks first, Product profitability second, Organizational management third.

**For criteria (DEMATEL-ANP):** Computed by the ANP \((M_{w}^{T})^n\) for large \( n \), \((C_{12}, C_{12}, C_{21}, C_{21}, C_{21}, C_{12}, C_{12}, C_{12}, C_{12}) = (0.137, 0.128, 0.120, 0.093, 0.109, 0.102, 0.123, 0.095, 0.095)\).
Fig. 4: Weighted matrices

\[
M_i = \begin{bmatrix}
0 & 0 & 0 \\
W_{i1} & W_{i2} \\
W_{i3} & W_{i4} \\
W_{i5} & W_{i6}
\end{bmatrix}, \quad M_2 = \begin{bmatrix}
0 & 0 & 0 \\
W_{i1} & W_{i2} & 0 \\
W_{i3} & W_{i4} & 0
\end{bmatrix},
\]

For alternatives: Weights obtained by the DEMATEL-ANP obtained the best solution. \((A_1, A_2, A_3) = (0.412, 0.338, 0.250)\). Product \(A_1\) has the advantage of compactness and long warranty. All other features are between \(A_2\) and \(A_3\). The group concludes that the case company should develop product \(A_3\) due to its ease of mobility and long availability. Product \(A_3\) will best fit the company’s R&D capacity and market profitability.

**CONCLUSION**

This study presents a hybrid MCDM model for selecting the best alternative in developing new color calibration device for medically used LCD. This model integrates several effective decision making methods and assesses alternatives based on the following three phases: (1) Apply fuzzy Delphi method to identify the relevant factors for the studied problem; (2) Employ a DEMATEL relation analysis method to recognize the interdependency among perspectives, as well as criteria and thus build the ANP model and generate composite importance for each criterion; (3) Evaluate three alternatives and select the best one based on the ANP results which are derived from the opinions of the high level management group in the case company. We are confident that the model can also be applied to various examples and deliver similar conclusions. This model is innovative, as it utilizes fuzzy Delphi method and integrates DEMATEL and ANP with different concept. Combining these two methods allows decision-makers to capture key factors and identify interrelationships.

**REFERENCES**


