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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 Sucu, 2003). In practice, the evaluation index on performance systems frequently has a hierarchical structure; for example, reference (Tang, 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 scale.

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; Mohantry *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 (Shyur, 2006; Dagdeviren, 2010).

The purpose of this study is to present a solution model for the decision problem on developing 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 (P_1), Marketing Environment (P_2), Organizational Management (P_3)

Level 3: Criteria for each perspective

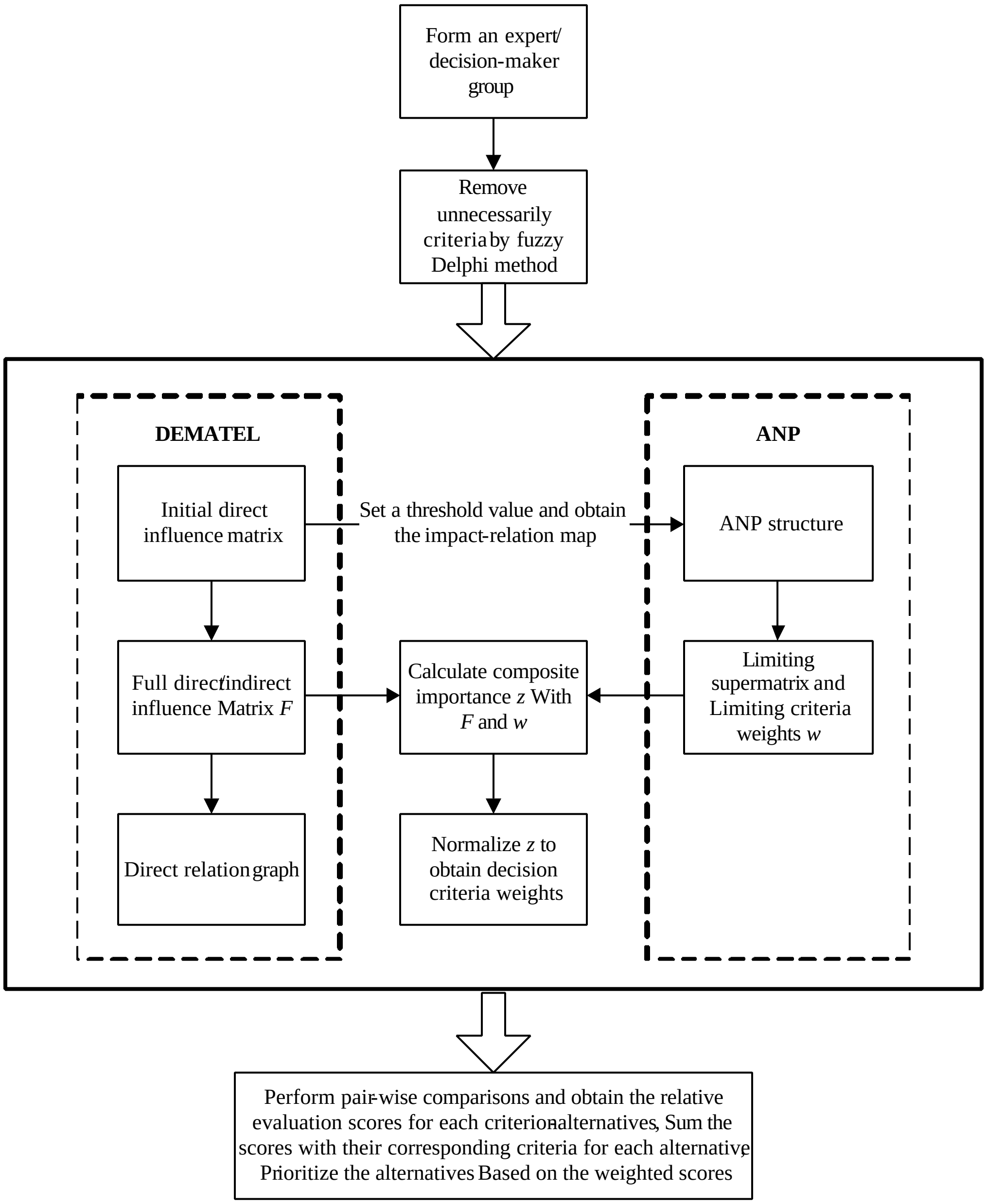


Fig. 1: Overall process of proposed approach

P_1: Technical capability
C_{11}: Technology patent
C_{12}: Customization capacity
C_{13}: R&D capability
P_2: Marketing Environment
C_{21}: Product profitability
C_{22}: Competitiveness
C_{23}: Brand image
P_3: Organizational management
C_{31}: Relations and corporate support
C_{32}: Integration ability
C_{33}: Marketing capability

Level 4: Three alternatives

A_1: Front sensor-size: 18×10 mm; weight: 30g; imbedded USB; automatic control; technical difficulty: high; current market share: 30%; precision: ±15%; applicable MDM: 19-27 inch; investment: USD100000; estimated selling price: USD1000; warranty: 3 years

A_2: Color sensor-size: 68×41 mm; weight: 140 g; external USB; manual control; technical difficulty: medium; current market share: 60%; precision: ±5%; applicable MDM: 19-60 inch; investment: USD60000; estimated selling price: USD300; warranty: 1 year

A_3: Swing sensor-size: 117×29×96 mm; weight: 160 g; external USB; automatic control; technical difficulty: very high; current market share: 10%; precision: ±10%; applicable MDM: 19-27 inch; estimated selling price: USD1200; warranty: 2 years

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).

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.

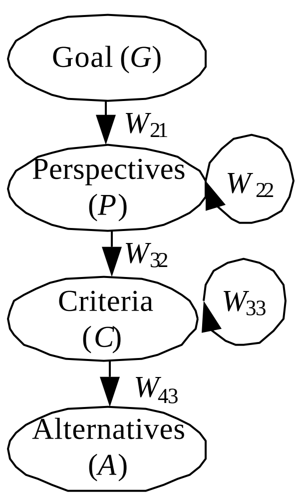
$$z = (I + F) \cdot w \qquad (1)$$

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



$$M_S = \begin{array}{c} \\ G \\ P \\ C \\ A \end{array} \begin{array}{c} \begin{array}{cccc} G & P & C & A \end{array} \\ \begin{bmatrix} 0 & 0 & 0 & 0 \\ W_{21} & W_{22} & 0 & 0 \\ 0 & W_{32} & W_{33} & 0 \\ 0 & 0 & W_{43} & I \end{bmatrix} \end{array}$$

Fig. 2: Graphical form and supermatrix of ANP

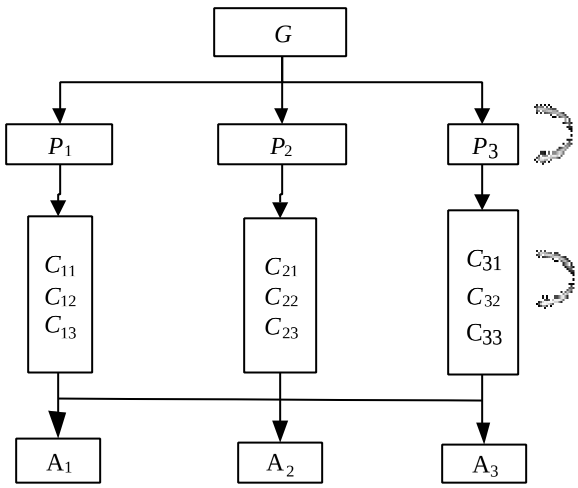


Fig. 3: ANP decision framework

which indicates the relative weights (importance) of the three perspectives with respect to the Goal. Matrix W_{22} is 3×3 which shows the influential strength among the three perspectives. Matrix W_{32} is 11×3 which specifies the relative importance of the criteria with respect to their individual perspectives. Matrix W_{33} is 11×11 which signifies the dependencies for criteria within the same cluster and between two distinct clusters. Matrix W_{43} is 3×11 which shows the relative weights of the three alternatives for each criterion. I is a 3×3 identity matrix which implies that the three alternatives are independent.

NUMERICAL RESULTS

Table 1 illustrates the calculated results for W_{21}. The other matrices can be similarly obtained. First, arithmetic mean is used to integrate the pairwise comparisons of group members. For example, a_{12} = 0.327 in W_{21} 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 $1.238 = (2.062\cdot 0.92\cdot 1)^{1/3}$. The weight of P_1 in W_{21} is 0.541/(0.541+1.493+1.238) = 0.165. By similar calculations, we obtain that the weights of P_2 and P_3 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 (Buyukyazici and Sucu, 2003). A Markov chain requires the sum of each column to be 1. Thus, the supermatrix MS

Table 1: Pairwise comparisons and weight matrix W21

	P1	P2	P3	GM	W21
P1	1.000	0.327	0.485	0.541	0.165
P2	3.061	1.000	1.087	1.493	0.456
P3	2.062	0.920	1.000	1.238	0.378

Table 2: Weighted supermatrix Mw

	G	P1	P2	P3	C11	C12	C13	C21
G	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000
P1	0.083	0.194	0.357	0.370	0.000	0.000	0.000	0.000
P2	0.228	0.080	0.052	0.051	0.000	0.000	0.000	0.000
P3	0.189	0.226	0.091	0.080	0.000	0.000	0.000	0.000
C11	0.000	0.093	0.000	0.000	0.040	0.047	0.098	0.087
C12	0.000	0.223	0.000	0.000	0.056	0.127	0.054	0.019
C13	0.000	0.184	0.000	0.000	0.096	0.107	0.012	0.048
C21	0.000	0.000	0.117	0.000	0.041	0.083	0.026	0.024
C22	0.000	0.000	0.193	0.000	0.069	0.027	0.016	0.131
C23	0.000	0.000	0.190	0.000	0.016	0.016	0.13	0.039
C31	0.000	0.000	0.000	0.173	0.137	0.018	0.022	0.122
C32	0.000	0.000	0.000	0.246	0.035	0.011	0.103	0.015
C33	0.000	0.000	0.000	0.081	0.011	0.064	0.038	0.013
A1	0.000	0.000	0.000	0.000	0.083	0.34	0.138	0.374
A2	0.000	0.000	0.000	0.000	0.180	0.06	0.276	0.042
A3	0.000	0.000	0.000	0.000	0.237	0.1	0.085	0.084

	C22	C23	C31	C32	C33	A1	A2	A3
G	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
P1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
P2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
P3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C11	0.054	0.069	0.105	0.047	0.073	0.000	0.000	0.000
C12	0.099	0.045	0.108	0.017	0.018	0.000	0.000	0.000
C13	0.013	0.099	0.014	0.02	0.131	0.000	0.000	0.000
C21	0.022	0.014	0.055	0.125	0.027	0.000	0.000	0.000
C22	0.093	0.028	0.031	0.1	0.012	0.000	0.000	0.000
C23	0.118	0.021	0.019	0.09	0.016	0.000	0.000	0.000
C31	0.029	0.013	0.125	0.028	0.043	0.000	0.000	0.000
C32	0.059	0.084	0.033	0.011	0.081	0.000	0.000	0.000
C33	0.012	0.128	0.011	0.062	0.099	0.000	0.000	0.000
A1	0.185	0.402	0.083	0.074	0.185	1.000	0.000	0.000
A2	0.237	0.043	0.237	0.208	0.248	0.000	1.000	0.000
A3	0.078	0.055	0.181	0.219	0.067	0.000	0.000	1.000

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 $(M_{w1}^T)^n$ 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 $(M_{w2}^T)^n$ for large n; (C_{11}, C_{12}, C_{13}, C_{21}, C_{22}, C_{23}, C_{31}, C_{32}, C_{33}) = (0.137, 0.128, 0.120, 0.093, 0.109, 0.102, 0.123, 0.095,

$$M_1 = \begin{bmatrix} 0 & 0 \\ W_{23} & W_{22} \end{bmatrix} \quad M_{w2} = \begin{bmatrix} 0 & 0 & 0 \\ W_{22} & W_{22}/2 & 0 \\ 0 & W_{32}/2 & W_{33} \end{bmatrix}$$

$$M_1 = \begin{array}{c} \\ G \\ P \\ C \\ A \end{array} \begin{array}{c} \begin{array}{cccc} G & P & C & A \end{array} \\ \begin{bmatrix} 0 & 0 & 0 & 0 \\ W_{21} & W_{21}/22 & 0 & 0 \\ 0 & W_{32/2} & W_{23}/2 & 0 \\ 0 & 0 & W_{34}/2 & I \end{bmatrix} \end{array}$$

Fig. 4: Weighted matrices

0.093). Equation 1 calculated DEMATEL-ANP composite importance; (C_{11}, C_{12}, C_{13}, C_{21}, C_{22}, C_{23}, C_{31}, C_{32}, C_{33}) = (0.269, 0.158, 0.336, 0.255, 0.157, 0.251, 0.192, 0.255, 0.233). ANP order to comply with a weight of 1, the normalized weights DEMATEL-ANP: (C_{11}, C_{12}, C_{13}, C_{21}, C_{22}, C_{23}, C_{31}, C_{32}, C_{33}) = (0.128, 0.075, 0.159, 0.121, 0.075, 0.119, 0.091, 0.121, 0.111).

For alternatives: Weights obtained by the DEMATEL-ANP obtain 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_1, due to its ease of mobility and long availability. Product A_1 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.

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