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多準則決策模式於運輸政策制定之應用—以花蓮為例

TRANSPORTATION POLICY MAKING USING MCDM MODEL: THE CASE OF HUALIEN

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摘 要

本研究旨在應用多準則決策模式(MCDM)進行運輸政策決策過程之評估，進而檢驗運輸政策各種準則之間的相依關係。以決策實驗室分析法(DEMATEL)建立影響關係圖(IRM)與網路關係圖(NRM)，探討影響運輸政策決策之因果關係。再以分析網路程序法(ANP)取得準則之權重，接著以最佳化妥協解方法(VIKOR)找出最佳運輸模式。以花蓮對外交通為例，實證結果顯示此模式可有效處理複雜問題，辨識其因果關係，評估準則之優先順序，進而挑選出最佳妥協解。

關鍵詞：運輸政策；多準則決策模式；決策實驗室分析法；分析網路程序法；最佳化妥協解方法

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ABSTRACT

The purpose of this study is to propose a transport policy decision-making process using a MCDM (multiple criteria decision-making) model to examine the dependent relationships among variable criteria of transport policies. DEMATEL (decision-making trial and evaluation laboratory) is employed to construct the IRM (impact relation map) and NRM (network relation map), which illustrate the influential network of the transport policy decision-making model. ANP (analytic network process) is adopted to evaluate the weights of criteria. VIKOR is then used to select the best transport mode. The case of Hualien is demonstrated and the empirical results reveal the proposed model is powerful and effective to identify the influential network, priority of criteria, and select the best compromise solution to a complicated problem.

Key Words: *Transport policy; MCDM; DEMATEL; ANP; VIKOR*

I. INTRODUCTION

Taiwan lies off the southeastern coast of mainland Asia. Hualien County, Taiwan's biggest county, borders the Pacific Ocean to the east and is hemmed in by the Central Range to the west. In 1590, Portuguese sailors passed by the eastern coast of Taiwan and were moved by the grandeur and then named it "Formosa" (beautiful island). Today, Hualien has become one of Taiwan's main travel destinations for local and international visitors [1].

In addition to the Central Cross-Island Highway (Provincial Highway No. 8), another road that offers considerable attractions for the tourists is the Suao-Hualien Highway (Provincial Highway No. 9), which starts at Suao, Yilan and ends at Hualien [2]. The 20-kilometer section between Chongde and Heping is the most spectacular part of the route, as highway winds its way between the cliffs that rise to more than a thousand meters.

Both landform and geological structure mean that Suao-Hualien Highway is often affected by landslides caused by typhoons, heavy rain, and earthquakes. In order to provide a safer route, in 2002 the Executive Yuan approved plans to build a new “Suao-Hualien National Freeway” to improve the relatively poor infrastructure of Hualien area. However, this project has now been suspended after it failed to pass an environmental impact evaluation [3]. In 2010, the Executive Yuan approved the “Suao-Hualien Highway mountain sections improvement plan” to replace some dangerous sections of the original highway. By avoiding geologically fragile sections, the initiative is expected to increase both the safety and carrying capacity of the highway, and reduce the journey time [4].

Travel north of Hualien now relies on the Suao-Hualien highway and the northern line railway. While the island-wide railway network, including western, eastern, northern, and southern lines, is often very popular for passengers [5], it is difficult to get train tickets during the holidays and weekends. In addition, the flight capacities between Hualien and Taipei are relatively limited [6]. From 1975 to 1983, passenger shipping had traveled between Hualien and Keelung, but this was often affected by typhoons in the summer and the monsoons in the winter. Moreover, with the operation of the northern line railway in 1980, the number of passengers going by sea declined very quickly, and this service was eventually discontinued [7].

In addition to the Central Cross-Island Highway and Suao-Hualien Highway, the Hsuehshan Tunnel through the Hsuehshan Range is another important infrastructure connecting the eastern and northern sections of Taiwan. The total length of the tunnel is 12.9 km, making it the second longest road tunnel in East Asia and the fifth in the world [8]. While excavating the tunnel, engineers encountered serious geological problems, like fractured rocks and massive inflows of water, which caused severe delays to the project. Since 2006, Chiang Wei-Shui Memorial Freeway (National Freeway No. 5) has connected Taipei City to northeastern Yilan County, cutting the journey time from two hours to half an hour. One of the key aims of constructing the tunnel and freeway was to connect the western plain of Taiwan, where 95% of the population lives, to the eastern coast, and mitigate the problem of unbalanced development.

The construction of transport infrastructure is usually welcomed by the local governments in Taiwan, due to the benefits with regard to greater convenience and growth in the local economy, tourism industry, and employment rate. However, environmental protection must be taken into consideration when such projects are proposed, and if mistakes are made then this can lead to considerable waste with regard to time and money. This makes transport policy decision-making a particularly difficult task.

In summary, a country's transport infrastructure is closely connected to its economy, society, environment, and politics. The question thus arises as to whether it is possible to develop a systematic and scientific decision support system to consider the various conflicting factors associated with transport policies, and to find an optimal compromise solution. This study aims to provide a MCDM (multiple criteria decision-making) transport policy decision-making model by investigating the case of Hualien. The results of this work demonstrate that the proposed model is able to identify the influential network, priority of criteria, and select the best compromise solution for a complicated transport policy problem.

The remainder of this paper is structured as follows. Section 2 summarizes transport policy decision-making in Taiwan and some important previous research regarding transport policy decision-making. Section 3 reviews the basic concepts of the DEMATEL (decision- making trial and evaluation laboratory), ANP (analytic network process), and VIKOR approaches. An empirical case of Hualien is illustrated to show the usefulness of the proposed model in Section 4, and the results of this empirical study are discussed in Section 5. Finally, the conclusions of this work are drawn in Section 6.

II. REVIEW OF TRANSPORT POLICY DECISION-MAKING

Public policy decision-making may be regarded as the process by which a government translates its political vision into projects and actions to achieve desired outcomes in the real world. Many techniques are available which can assist with in this process, such as Political System Theory [9], the Garbage Can Model [10], and Rough Sets Theory [11].

In Taiwan, the Institute of Transportation (IOT) serves as a think tank for the Ministry of Transportation and Communications (MOTC), and has helped in the development and completion of many major projects. It not only carries out the horizontally integrated policy coordination for MOTC, but also provides vertical implementation with regard to technical support and supervision [12].

The various departments of the Executive Yuan in Taiwan are staffed by many experts and scholars, and most cabinet members have doctoral degrees. On the other hand, Taiwanese society is highly democratized, with two major parties that campaign to win public office at all levels of the system. In other words, the Taiwanese political system has two conflicting characteristics: elitism and populism. Moreover, the content in which policies have to be developed is becoming increasingly complicated, uncertain and unpredictable, and key issues, such as transport infrastructure, economic development, social security, and environmental protection, are connected and cannot be tackled easily by the specific departments acting alone.

Although several traditional approaches have been proposed for solving public policy decision-making problems, different techniques may yield different results for the same problem. Recently, the MCDM method has been presented as a way to aggregate individual judgments into a group judgment, and it has become a very active area of research. However, relatively few studies have devoted to examine transport policy decision-making.

Yedla and Shrestha [13] examined the impact of including various qualitative criteria for the selection of alternative transportation options in Delhi. Three alternative transport options: two-wheelers, cars and buses were prioritized based on six different criteria: energy saving potential, emission reduction potential, cost of operation, availability of technology, adaptability of the option, and barriers to implementation. Integrated quantitative and qualitative criteria gave contrasting results as compared to those obtained from the conventional quantitative and qualitative approaches, which can explain the reasons for failure of many potential alternative urban transport options.

Tudela et al. [14] compared the outcome of cost benefit analysis and a multi-criteria method when applied to a transport project. The results showed that the outcome of the multi-criteria method was different to the one from the cost benefit analysis, but it matched the final decision made by the authority. These two earlier studies show that it is possible to improve transport policy decision-making by using an MCDM model.

MCDM [15] has also been proved for its usefulness in many fields, such as economy, management and engineering. The DEMATEL technique, which originates from the Geneva Research Centre of the Battelle Memorial Institute, is widely used to investigate and solve complicated problems [16], and is particularly useful for visualizing the structure of complicated causal relationships with matrices and digraphs. DEMATEL has recently attracted more attention in Japan and Taiwan, and has been widely applied in many contexts, including transportation [17], tourism [18], and many other industries [19, 20]. The ANP method [21] is an extension of the AHP approach [22], which is used to overcome the problem of interdependence and feedback between criteria [23]. The VIKOR method was developed to determine the compromise ranking list with the given weights for multi-criteria optimization of complicated systems [24]. It focuses on ranking and selecting from a set of alternatives in the presence of conflicting criteria [25]. This compromise ranking algorithm introduces the multi-criteria ranking index based on a measure of closeness to the ideal solution [26]. The normalized value in the VIKOR method does not depend on the evaluation unit of a criterion function, whereas the ones by vector normalization in the TOPSIS method may depend on the evaluation unit [25].

DEMATEL and ANP were adopted to efficaciously investigate the intertwined effects [27,28], while ANP and VIKOR were adopted to select a restaurant location [29]. In addition, DEMATEL, ANP and VIKOR were applied to select an outsourcing provider [30] and improve tourism policy implementation [18]. Accordingly, this study proposes a transport policy decision-making process using a MCDM approach to examine the dependent relationships among various transport–related criteria. DEMATEL is employed to construct IRM (impact relation map) and NRM (network relation map), which illustrate the influential network of the transport policy decision-making model. Besides, ANP is used to evaluate the weights of criteria, while VIKOR is applied to select the best transport mode.

Yeh et al. [31] stated that transportation projects do not follow a united process in Taiwan. In their study, four dimensions: namely economy, society, environment, and policy, were measured by 24 attributes extracted from previous studies that reviewed the contextual aspects of Taiwan's transport policies.

However, too many criteria may dramatically increase the difficulty of completing the DEMATEL and ANP questionnaires, as the number of questions produced by pairwise comparisons is proportional to the square of the number of criteria. In addition, the influential network of a model with too many criteria may become too complicated to analyze. After investigating the content of criteria, some criteria may be combined into a single criterion. For example, the following seven attributes were included in economy dimension: local economic development, tourism development, employment opportunity, investment cost, maintenance cost, transport cost, and travel time [31]. It seems that the first three criteria, namely local economic development, tourism development, employment opportunity may be combined in a single criterion as “economic development”. The last four criteria (i.e., investment cost, maintenance cost, transport cost, travel time) may be combined in a single criterion as “eligible cost”.

Therefore, in this work 24 attributes are condensed to eight criteria, as follows: (1) economic development: local economic development, tourism development, and employment opportunities; (2) eligible cost: eligible investment, maintenance, and transport cost, and reasonable travel time; (3) equity & justice: resident rights, balanced development, and mass transport; (4) social security: safety, reliability, accessibility, and disaster reduction; (5) environmental protection: ecological and natural resources protection (6) energy efficiency & carbon reduction: green transport, pollution prevention, and sustainable development; (7) political climate: the aims of the government, pressure groups, and public opinion; (8) feasibility & execution: engineering technology, feasibility, laws and regulations. This set of criteria provides the current research with an overall evaluation system that will facilitate further prioritization using the techniques of DEMATEL, ANP, and VIKOR for the four transport modes, as follows: (1) Highway: Suao-Hualien Highway mountain sections improvement plan; (2) Rail: Taipei-Yilan Direct Railway, extra carriages; (3) Marine: High speed ferry among Keelung, Wushih, Yilan , Suao, Yilan, and Hualien; (4) Air: increasing Taipei-Hualien flights, launching Taoyuan-Hualien flights.

III. MCDM MODEL: DEMATEL, ANP, AND VIKOR

3.1 The DEMATEL approach

The DEMATEL approach can be summarized as follows:

Step 1: Obtain the direct influence matrix $[A]$ based on scores given by experts.

The experts are asked to indicate the direct effect they believe that each factor i exerts on each factor j using an integer scale ranging from 0, 1, 2, 3, and 4, with 0 meaning “no influence” and 4 “a very high influence”. Each element of the direct influence matrix $[A]$ is the average of the same elements in the different matrices of the respondents.

Step 2: Calculate the initial influence matrix $[D]$.

The initial influence matrix $[D]$ is obtained by normalizing the direct influence matrix

$[A]$ as

$$[D]=\frac{1}{k}[A] \tag{1}$$

where $k=Max\left(\underset{i}{Max}\sum_{j=1}^{n}A_{ij},\underset{j}{Max}\sum_{i=1}^{n}A_{ij}\right)$

Step 3: Derive the total influence matrix $[T]$.

As $0\le D_{ij}<1$ and $\lim_{m\to\infty}[D]^m=[0]$, the total influence matrix $[T]$ can be obtained as

$$\begin{aligned}[T] &= [D]+[D]^2+[D]^3+......+[D]^m\\ &=[D]\left([I]+[D]+[D]^2+......+[D]^{m-1}\right)([I]-[D])([I]-[D])^{-1}\\ &=[D]\left([I]-[D]^m\right)([I]-[D])^{-1}\\ &=[D]([I]-[D])^{-1}\end{aligned} \tag{2}$$

where $[I]$ denotes the identity matrix.

Step 4: Calculate the sum of rows $\{r\}$ and the sum of columns $\{c\}$.

$$\{r\}=\left[\sum_{j=1}^{n}T_{ij}\right] \tag{3}$$

$$\{c\}=\left[\sum_{i=1}^{n}T_{ij}\right]^T \tag{4}$$

where r_i shows the sum of direct and indirect effects of factor *i* on the other factors, c_i shows the sum of direct and indirect effects that factor *i* has received from the other factors. Furthermore, r_i+c_i shows the impact level (the strength of influences given and received) that factor *i* has with regard to the problem. If the relation level (r_i-c_i) is positive, then factor *i* is affecting other factors, otherwise it is being influenced by them.

Step 5: Construct the IRM and NRM.

To reduce the complexity of the IRM, a threshold value for the influence level may be decided by the decision maker or based on the opinions of experts. Only elements whose influence level in the matrix $[T]$ are higher than the threshold value are chosen and converted into the IRM [27].

There is another way to construct the NRM without the threshold value and using single-headed arrows to represent the impact direction [18], in which the net influential impact in the network flow may be expressed as

If $T_{ij} > T_{ji}$, the flow is drawn from factor *i* to factor *j*.

If $T_{ij} < T_{ji}$, the flow is drawn from factor *j* to factor *i*.

3.2 The ANP method

The ANP method can be summarized as follows:

Step 1: Obtain the unweighted supermatrix $[\overline{w}]$ based on scores given by experts.

The initial step of the ANP is to compare the criteria in the entire system to form a supermatrix through pairwise comparisons. The relative importance is determined using a scale of 1–9 representing equal importance to extreme importance [23].

Step 2: Derive the weighted supermatrix $[w]$.

After forming the unweighted supermatrix $[\overline{w}]$, the weighted supermatrix $[w]$ is derived by transforming all the columns sum to unity exactly.

Step 3: Compute the weight of each criterion.

The weighted supermatrix is raised to limiting powers to calculate the overall priorities. Each row of the limit supermatrix represents the weight of each criterion.

$$\lim_{m \to \infty} [w]^m \tag{5}$$

3.3 The VIKOR method

The VIKOR method can be summarized as follows:

Step 1: Obtain the evaluation matrix $[f]$ based on scores given by experts.

The experts are asked to indicate the evaluation of the *i*th criterion function and *j*th alternative using an integer scale ranging from 1, 2, 3, 4, and 5, with 1 meaning “strongly disagree” and 5 “strongly agree”.

Step 2: Determine the best f_i^* and the worst f_i^- values of all criteria.

If the ith criterion function represents a benefit then:

$$f_i^* = \underset{j}{Max}\, f_{ij} \tag{6}$$

$$f_i^- = \underset{j}{Min}\, f_{ij} \tag{7}$$

If the ith criterion function represents a cost then:

$$f_i^* = \underset{j}{Min}\, f_{ij} \tag{8}$$

$$f_i^- = \underset{j}{Max}\, f_{ij} \tag{9}$$

Step 3: Compute the distance from each alternative to the positive ideal solution.

$$S_j = \sum_{i=1}^{n} X_{ij} \tag{10}$$

$$R_j = \underset{i}{Max} X_{ij} \tag{11}$$

where $X_{ij} = w_i(f_i^* - f_{ij})/(f_i^* - f_i^-)$, w_i represents weights of criteria, S_j is the distance of the *j*th alternative achievement to the positive ideal solution, and R_j implies the maximal regret of each alternative.

Step 4: Compute the index value Q_j.

$$Q_j = v(S_j - S^*)/(S^- - S^*) + (1-v)(R_j - R^*)/(R^- - R^*) \tag{12}$$

where $S^* = \underset{j}{Min}\ S_j$, $S^- = \underset{j}{Max}\, S_j$, $R^* = \underset{j}{Min}\ R_j$, $R^- = \underset{j}{Max}\, R_j$, and v is the weight of the decision-making strategy, representing the majority of criteria. In Eq. (12), when v =1, it represents a decision-making process that can use the strategy of maximum group utility. On the other hand, when v =0, it represents a decision-making process that can use the strategy of minimum individual regret. The best alternative is the one with the minimum value of Q_j.

IV. EMPIRICAL RESULTS

4.1 Measuring the relationships by DEMATEL

For the purpose of remaining independent and neutral, professors who teach in transportation, tourism, economy, and ecology related departments, and who have carried out related research, were invited to score the relationships among the eight criteria. Twenty-four questionnaires were distributed and 16 valid samples were returned, representing a 67% return rate. The average direct influence matrix [*A*] is an 8×8 matrix obtained by pairwise comparisons in terms of influences and directions between the eight criteria, as shown in Table 1.

Table 1　The direct influence matrix $[A]$

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
C_1	0	1.6875	2.6875	1.5	2.875	3.125	1.5625	3
C_2	3	0	2.1875	1.1875	1.3125	1.5625	1.4375	2.9375
C_3	2.5625	2.4375	0	3.0625	1.625	1.5625	3.0625	2.6875
C_4	1.75	1.625	3.1875	0	1.125	1.0625	2.5	1.8125
C_5	2.5625	2.625	2.5625	2.4375	0	3.375	2.625	2.5625
C_6	2.5	2.8125	2.125	1.1875	3.25	0	1.3125	2.5
C_7	2.875	2.6875	2.875	3	2.6875	2.625	0	2.875
C_8	2.75	3	2.5	2.625	2.5	2.5	2.625	0

The normalized initial influence matrix $[D]$ is obtained through Eq. 1. The total influence matrix $[T]$ is then derived by using Eq. 2 (Table 2).

Table 2　The total influence matrix $[T]$

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
C_1	0.6393	**0.6845**	**0.7579**	0.6131	**0.6865**	**0.7102**	0.6213	**0.7846**
C_2	**0.6716**	0.506	0.6365	0.5129	0.5318	0.5539	0.5276	**0.6799**
C_3	**0.7649**	**0.7212**	0.6521	**0.6892**	0.6389	0.6503	**0.693**	**0.7825**
C_4	0.5989	0.5631	**0.6597**	0.4432	0.5016	0.5098	0.5587	0.6118
C_5	**0.826**	**0.7881**	**0.8252**	**0.7107**	0.6181	**0.7805**	**0.7237**	**0.8396**
C_6	**0.7237**	**0.7012**	**0.7048**	0.5726	**0.6737**	0.5458	0.5838	**0.7354**
C_7	**0.8663**	**0.816**	**0.8675**	**0.7596**	**0.7608**	**0.7744**	0.6322	**0.8806**
C_8	**0.8232**	**0.7922**	**0.8131**	**0.7102**	**0.7197**	**0.7352**	**0.7156**	**0.7138**

Note: Numbers *in bold* denote that they are higher than the threshold value of 0.655.

Using Eqs. 3 and 4, the influences given to and received by each factor are shown in Table 3. The $r_i + c_i$ values represent the total influence levels. The $r_i - c_i$ values represent net influence levels where positive values indicate that the factor will influence other factors more than other ones influence it. The impact level of the eight criteria can be prioritized as Feasibility & Execution (C8) > Equity & Justice (C3) > Political Climate (C7) > Economic Development (C1) > Environmental Protection (C5) > Energy Efficiency & Carbon Reduction (C6) > Eligible Cost (C2) > Social Security (C4) based on the $r_i + c_i$ values. Based on the $r_i - c_i$ values, Political Climate (C7) and Environmental Protection (C5) are net causes, whereas the others are net receivers. It is worth noting that the vertical coordinates (-0.0052 and -0.0191) of the two points, Feasibility & Execution (C8) and Energy Efficiency & Carbon Reduction (C6), are both close to zero.

Table 3 The results of the criteria analysis

Criteria	r_i	c_i	$r_i + c_i$	$r_i - c_i$
Economic Development (C_1)	5.4973	5.9139	11.4113 (4)	-0.4166 (6)
Eligible Cost (C_2)	4.6203	5.5723	10.1925 (7)	-0.9520 (8)
Equity & Justice (C_3)	5.5921	5.9167	11.5088 (2)	-0.3246 (5)
Social Security (C_4)	4.4469	5.0116	9.4585 (8)	-0.5647 (7)
Environmental Protection (C_5)	6.1118	5.1311	11.2429 (5)	0.9807 (2)
Energy Eff. & Carbon Red. (C_6)	5.2410	5.2601	10.5011 (6)	-0.0191 (4)
Political Climate (C_7)	6.3574	5.0559	11.4133 (3)	1.3015 (1)
Feasibility & Execution (C_8)	6.0230	6.0282	12.0513 (1)	-0.0052 (3)

Note: The numbers in parentheses denote rankings.

The IRM can be drawn based on the matrix $[T]$. However, there is a need to simplify the causal relationships by setting a threshold value to filter insignificant ones. For this reason, discussions were carried out with the respondents, and a consensus was reached on a threshold value of 0.655, which was deemed as the most appropriate one to acquire a suitable relationship. Based on this threshold value, the IRM of the DEMATEL method is obtained and shown in Fig. 1. The elements of matrix $[T]$ exceeding the threshold value (0.655) are shown in bold in Table 2.

The net influential impact in network flow [18] is shown in Table 4, and the NRM is obtained and shown in Fig. 2. In fact, the net influential impact in the NRM may also be determined by comparing the vertical coordinates of the criteria. The upper criteria in the NRM affect the lower ones. The only exception is the relation between Feasibility & Execution (C8) and Energy Efficiency & Carbon Reduction (C6), as their vertical coordinates are very close to each other. The double-headed arrows are then replaced by single-headed ones, and the 40 relations (12 single arrow lines and 14 double arrow lines) of the IRM can be simplified to 28 relations (28 single arrow lines) of the NRM. It is interesting to note that the IRM does not show the three lines between C1 and C4, C6 and C4, C4 and C2, but indicates the feedback of C8. Although the number of the arrows is reduced significantly in the NRM, the criteria are intertwined with the others in this complicated relationship.

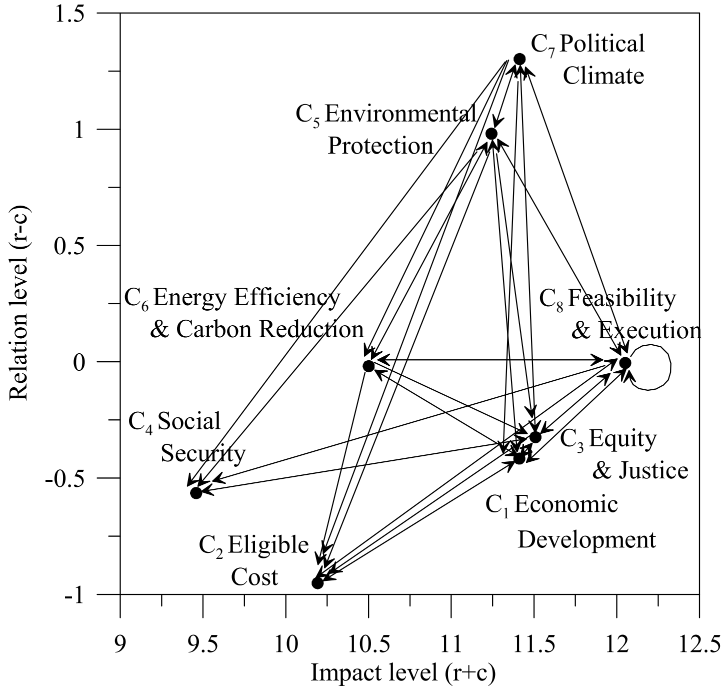

Fig. 1　Impact relation map (the threshold value = 0.655)

Table 4　The net influential impact in network flow

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
C_1	-	0.0128	-	0.0142	-	-	-	-
C_2	-	-	-	-	-	-	-	-
C_3	0.007	0.0847	-	0.0295	-	-	-	-
C_4	-	0.0502	-	-	-	-	-	-
C_5	0.1395	0.2563	0.1863	0.2091	-	0.1068	-	0.1199
C_6	0.0136	0.1473	0.0545	0.0628	-	-	-	0.0002
C_7	0.245	0.2884	0.1745	0.2009	0.0371	0.1907	-	0.165
C_8	0.0386	0.1123	0.0306	0.0985	-	-	-	-

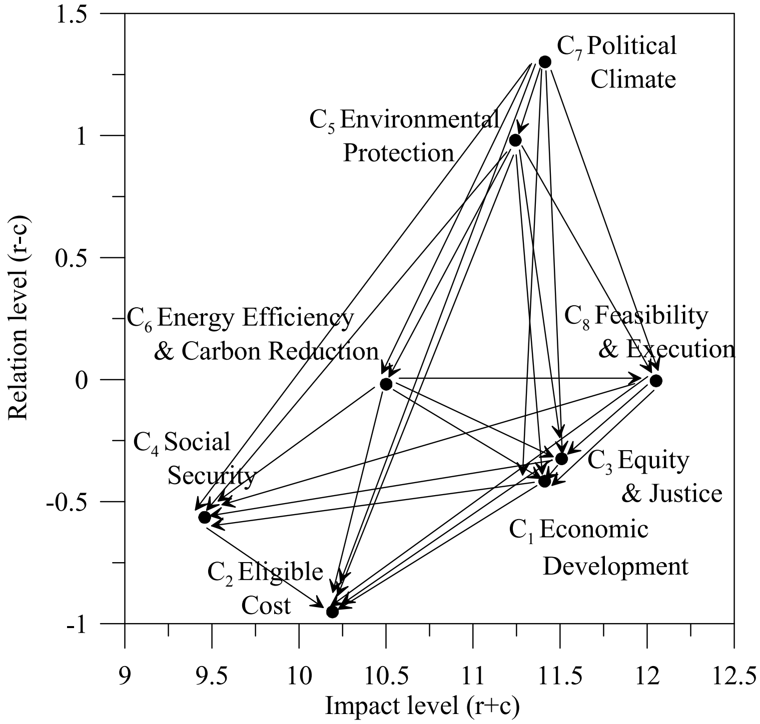

Fig. 2 Network relation map

4.2 Deriving the weights of criteria by ANP

After the DEMATEL, which confirms the structure of the relationships among the criteria of the evaluating systems, ANP is adopted to form an unweighted supermatrix (Table 5) through pair-wise comparisons. The limiting power of the weighted supermatrix is obtained until a steady-state condition is reached (Table 6). Each row represents the weight of each criterion. As shown in Table 6, the top three priorities in the evaluating systems are: Social Security (C4) (16.98%), Environmental Protection (C5) (16.13%), and Equity & Justice (C3) (15.19%).

Table 5 The unweighted supermatrix $[\overline{w}]$

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
C_1	1	3.849	1.8427	1.3183	1.9079	2.4382	5.1339	2.9083
C_2	0.8462	1	1.2621	1.0685	0.998	1.2188	3.0148	1.8142
C_3	2.6652	2.3438	1	1.6131	1.9625	2.9792	4.2049	2.9673
C_4	2.487	3.7104	1.4861	1	2.5984	3.2329	5.0729	4.1979
C_5	3.524	3.8385	1.7309	1.5022	1	2.6875	4.2882	3.1632
C_6	2.1027	1.901	1.258	1.1714	0.6715	1	2.9757	2.4065
C_7	0.6315	1.3604	1.1891	0.5805	1.3385	1.4784	1	1.3374
C_8	0.9625	2.3943	1.575	0.7601	1.4627	2.1943	3.9444	1

Table 6 The limit supermatrix matrix $\lim_{n\to\infty}[w]^n$

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
C_1	0.1452	0.1452	0.1452	0.1452	0.1452	0.1452	0.1452	0.1452
C_2	0.0881	0.0881	0.0881	0.0881	0.0881	0.0881	0.0881	0.0881
C_3	0.1519	0.1519	0.1519	0.1519	0.1519	0.1519	0.1519	0.1519
C_4	0.1698	0.1698	0.1698	0.1698	0.1698	0.1698	0.1698	0.1698
C_5	0.1613	0.1613	0.1613	0.1613	0.1613	0.1613	0.1613	0.1613
C_6	0.1040	0.1040	0.1040	0.1040	0.1040	0.1040	0.1040	0.1040
C_7	0.0758	0.0758	0.0758	0.0758	0.0758	0.0758	0.0758	0.0758
C_8	0.1039	0.1039	0.1039	0.1039	0.1039	0.1039	0.1039	0.1039

4.3 Selecting the best transport mode by VIKOR

After the weights of the evaluating systems are determined, the selection of transport mode is further illustrated based on the VIKOR method. The performance score for each transport mode, and the results of the VIKOR and traditional simple additive weight (SAW) method are shown in Table 7. Rail has the highest scores in seven criteria, and highway has the highest in only one. On the other hand, air transport has the lowest scores in five criteria, while marine transport and highway have the lowest scores in two criteria. The scores in Environmental Protection (C5) and Energy Efficiency & Carbon Reduction (C6) are less than three for highway, which thus does not reach the threshold value for these criteria. The same is true for air transport in Eligible Cost (C2), Environmental Protection (C5), and Energy Efficiency & Carbon Reduction (C6).

S_j, R_j, and Q_j values may be calculated using Eqs. 10-12, and rail holds the lowest Q_j values. Since Q_j represents the gap between the alternative and ideal solutions, a smaller Q_j value is desirable. As may be expected, rail contains the smallest gap (0) according to a VIKOR analysis for three cases (v =1, 0.5, and 0), while rail also holds the highest value (4.0866) based on the SAW method. The ranks of the overall scores of the four transport modes were found to be Rail $\succ$ Highway $\succ$ Marine $\succ$ Air, where A $\succ$ B represents that A is preferred over B.

Table 7 The results of the VIKOR and SAW analyses

Criteria	Weights	Highway	Rail	Marine	Air
Economic Development (C_1)	0.1452 (4)	3.9375	**4**	3.375	3.25
Eligible Cost (C_2)	0.0881 (7)	3.8125	**4.1875**	3.5625	2.9375
Equity & Justice (C_3)	0.1519 (3)	3.625	**4**	3.25	3.0625
Social Security (C_4)	0.1698 (1)	3.375	**4.4375**	3.25	3.25
Environmental Protection (C_5)	0.1613 (2)	2.75	**3.9375**	3.1875	2.9375
Energy Eff. & Carbon Red.(C_6)	0.1040 (5)	2.9375	**4.375**	3.375	2.6875
Political Climate (C_7)	0.0758 (8)	**3.625**	3.5625	3.0625	3.125
Feasibility & Execution (C_8)	0.1039 (6)	3.4375	**4**	3.5	3.5625
S_j		0.6014	0.0088	0.7868	0.9424
R_j		0.1597	0.0088	0.1630	0.1630
VIKOR (Q_j) $v=1$		0.6383(2)	0(1)	0.8342(3)	1 (4)
$v=0.5$		0.7928(2)	0(1)	0.9171(3)	1 (4)
$v=0$		0.9473(2)	0(1)	1(3)	1 (3)
SAW		3.4123(2)	4.0866(1)	3.3104(3)	3.1081(4)

Note: The numbers in parentheses denote rankings, and those *in bold* denote f_i^*.

V. DISCUSSION

The proposed MCDM model provides a systemic analytic model for the selection of transport mode based on the gap from the ideal solution. This model can simultaneously consider the strategy of maximum group utility (S_j) and minimum individual regret (R_j) while quantifying many subjective judgments, which is necessary for the evaluation of different alternative transport modes. The empirical results indicate that the ranks of the overall scores of the four candidates were found to be Rail $\succ$ Highway $\succ$ Marine $\succ$ Air. Rail beats other transport mode in most criteria, except for Political Climate (C7).

The local government has claimed that the residents of Hualien need a safe way home (by construct a new national freeway). This appeal successfully attracted attention and put political pressure on the Executive Yuan. However, the weight of Political Climate (C7) is the lowest, and the scores of highway and rail are very close. In addition, rail beats highway in other seven criteria, even in Social Security (C4), which is an important criterion with the highest weight.

Therefore, rail is the best transport mode between Hualien and Yilan based on the proposed MCDM model. That also explains why the new “Suao-Hualien National Freeway” project was temporarily suspended by the Executive Yuan. After all, some sections of Central Cross-Island Highway and Southern Cross-Island Highway are often damaged and closed, as they run through exceedingly rugged and unstable terrain. The experience of the Hsuehshan Tunnel construction also made the government more cautious when making transport policy decision.

Some have argued that marine transport could be a good alternative, and that the new national freeway could be replaced by a “blue highway”. However, based on the relatively low scores of marine transport, this mode may be served as a back-up. In addition, air transport is not an appropriate mode, and its innate disadvantages meant that it had the lowest scores for five criteria.

In summary, rail is the best choice as it has the smallest gap according to a VIKOR analysis for three cases (v =1, 0.5, and 0). No matter what the v value is, the ranking of the transport modes is the same. It is interest to note that the values of Q_j decrease as v increases for the highway and marine modes. That means these two modes are more likely to be adopted if the strategy of maximum group utility is used. Unlike the ranking of traditional SAW is different from the one of VIKOR in the study by Liou and Chuang [30], the ranking of SAW is exactly the same as the one of VIKOR for the three cases in this study. It seems that simple SAW may be still a feasible and reliable approach although elaborate VIKOR is available.

If the “Taipei-Yilan Direct Railway” between Taipei and Yilan is constructed, and railway electrification between Hualien and Taitung is accomplished to increase the operating speed, the benefits of rail may be further increased. Moreover, not only people living in Hualien would benefit from this, but also the rest of the population of Taiwan, as well as tourists from home and abroad. It is believed that rail may be a particularly good tourism and transport mode with regard to overcoming the traffic jams in the Hsuehshan Tunnel on holidays, and vulnerability of original Suao-Hualien Highway. Moreover, the highway mode is the second best choice, and thus the authorities should regard this as an acceptable alternative mode.

The case of Hualien examined in this work demonstrates the possibility of solving a complicated problem and finding the best compromise solution using the proposed MCDM model. The experts’ opinions were collected and a group decision-making process was carried out systematically, with a qualitative approach replaced by a quantitative one. Moreover, a single aspect evaluation is improved by adopting a multiple criteria decision-making approach, thus overcoming time-consuming and fruitless discussions. Consequently, the two conflicting characteristics of Taiwanese politics, elitism and populism, can coexist productively. Based on the empirical results of this work, the authorities are advised to make more efforts to communicate with the public to make them realize the advantages of rail transport, as it is believed that they will respond better to reasoned explanations than to orders or arguments.

As seen in Table 3, the impact level of the eight criteria can be prioritized as Feasibility & Execution (C8) > Equity & Justice (C3) > Political Climate (C7) > Economic Development (C1) > Environmental Protection (C5) > Energy Efficiency & Carbon Reduction (C6) > Eligible Cost (C2) > Social Security (C4). The relationships among the eight criteria can be prioritized as Political Climate (C7) > Environmental Protection (C5) > Feasibility & Execution (C8) > Energy Efficiency & Carbon Reduction (C6) > Equity & Justice (C3) > Economic Development (C1) > Social Security (C4) > Eligible Cost (C2).

From Table 7, the importance of the eight criteria can be sorted as Social Security (C4) > Environmental Protection (C5) > Equity & Justice (C3) > Economic Development (C1) > Energy Efficiency & Carbon Reduction (C6) > Feasibility & Execution (C8) > Eligible Cost (C2) > Political Climate (C7). However, these results do not necessarily imply that one should pay less attention to Political Climate (C7) and Feasibility & Execution (C8). In fact, Table 3 indicates that Political Climate (C7) has the highest degree of ($r_i - c_i$), which shows that it will influence the other criteria more than it is influenced by them. On the other hand, Feasibility & Execution (C8) has the highest value ($r_i + c_i$), which means it will affect other criteria and will also be significantly affected by them. The ranks of the impact level based on the $r_i + c_i$ values are different from those of importance based on the weights. The proposed hybrid model demonstrates that it is capable of handling the various interdependencies in the complicated relationships among the various criteria.

A comparison of the results of IRM and NRM (Fig. 1 and Fig. 2) is both interesting and meaningful. IRM may provide a clear picture for the loop of interdependence and feedback between criteria, while NRM may provide a clear vision of the direction of influence. It thus seems that both the IRM and NRM provide an overview of this complicated problem.

VI. CONCLUSIONS

A MCDM method has been employed in this work to examine the dependent relationships among the various criteria together with DEMATEL, ANP, and VIKOR. The case of Hualien is used to illustrate this approach, and the empirical results reveal the proposed model is both powerful and effective with regard to identifying the influential network and priority of criteria, and thus select the best compromise solution for a complicated problem. Political Climate (C7) and Environmental Protection (C5) are the causes (starting points). Feasibility & Execution (C8), Equity & Justice (C3), and Political Climate (C7) are the top three criteria with the strongest influences given and received. Social Security (C4), Environmental Protection (C5), and Equity & Justice (C3) are the top three priorities with the highest weights. Rail is the best choice among the four transport modes. The MCDM model provides a simple decision support system to solve complicated problems that are involved with many different departments or units in the real word, such as developing a transport policy in the case of Hualien.

Despite the efficacy of the proposing MCDM approach, the limitations of the current work suggest some directions for future research. This study was limited to a Taiwanese context using a sample of specific experts, and thus the findings may not be directly applicable to other extents. Larger and more diverse groups of samples are thus suggested to enhance the robustness of the proposed method in the following study. For example, the construction of an island-wide freeway network may be an interesting issue for future research by taking national defense into consideration. In addition, the combinations of transport modes (e.g. rail and highway, marine and highway) may be the alternatives in order to examine the policy of Ministry of Transportation and Communications. The evaluation criteria used in this work were selected from a review of the literature on public policy making, especially in transport domain, and other methodologies, such as in-depth interviews or the Delphi method, may be applied to seek other effective criteria.

REFERENCES

1. Tourism Bureau, MOTC, "Discover Taiwan, Suao-Hualien Highway", http://eng.taiwan.net.tw/, 2012.
2. Directorate General of Highways, MOTC, "Highway Networks", http://www.thb.gov.tw/, 2012.
3. Environment Protection Administration, "Environment Impact Analysis", http://www.epa.gov.tw/, 2012.
4. Ministry of Transportation and Communications, "Transportation Policy", http://www.motc.gov.tw/, 2012.
5. Taiwan Railways Administration, MOTC, "Railway Network", http://www.railway.gov.tw/, 2012.
6. Civil Aeronautics Administration, MOTC, "Hualien Airport", http://www.caa.gov.tw/, 2012.
7. Maritime and Port Bureau, MOTC, "Hualien Ship, Passenger Volume", http://www.motcmpb.gov.tw/, 2012.
8. Taiwan Area National Freeway Bureau, MOTC, "Freeway Networks", http://www.freeway.gov.tw/, 2012.
9. Easton, D., *The Political System: An Inquiry into the State of Political Science*, Alfred A. Knopf, New York, 1953.
10. Cohen, M. D., March, J. G., and Olsen, J. P., "A Garbage Can Model of Organizational Choice", *Administrative Science Quarterly*, Vol. 17, 1972, pp. 1-26.

11. Pawlak, Z., *Rough Sets: Theoretical Aspects of Reasoning about Data*, Kluwer Academic Publishing, Dordrecht, 1991.
12. Institute of Transportation, MOTC, "Suao-Hualien Highway", http://www.iot.gov.tw/, 2012.
13. Yedla, S. and Shrestha, R. M., "Multi-Criteria Approach for the Selection of Alternative Options for Environmentally Sustainable Transport System in Delhi", *Transportation Research Part A*, Vol. 37, No. 8, 2003, pp. 717-729.
14. Tudela, A., Akiki, N., and Cisternas, R., "Comparing the Output of Cost Benefit and Multi-Criteria Analysis: An Application to Urban Transport Investments", *Transportation Research Part A*, Vol. 40, No. 5, 2006, pp. 414-423.
15. Zeleny, M., *Multiple Criteria Decision Making*, Mc-Graw-Hill, New York, 1982.
16. Tzeng, G. H., Chiang, C. H., and Li, C. W., "Evaluating Intertwined Effects in E-learning Programs: A Novel Hybrid MCDM Model Based on Factor Analysis and DEMATEL", *Expert Systems with Applications*, Vol. 32, No. 4, 2007, pp. 1028-1044.
17. Liou, J. J. H., Yen, L., and Tzeng, G. H., "Building an Effective Safety Management System for Airlines", *Journal of Air Transport Management*, Vol. 14, No. 1, 2008, pp. 20-26.
18. Liu, C. H., Tzeng, G. H., and Lee, M. H., "Improving Tourism Policy Implementation – The Use of Hybrid MCDM Model", *Tourism Management*, Vol. 33, No. 2, 2012, pp. 413-426.
19. Shieh, J. I., Wu, H. H., and Huang, K. K., "A DEMATEL Method in Identifying Key Success Factors of Hospital Service Quality", *Knowledge-Based Systems*, Vol. 23, No. 3, 2010, pp. 277-282.
20. Wei, P. L., Huang, J. H., Tzeng, G. H., and Wu, S. I., "Causal Modeling of Web-Advertising Effects by Improving SEM Based on DEMATEL Technique", *International Journal of Information Technology & Decision Making*, Vol. 9, No. 5, 2010, pp. 799-829.
21. Saaty, T. L., "Fundamentals of the Analytic Network Process", The International Symposium on the Analytic Hierarchy Process, Kobe, Japan, 1999.
22. Saaty, T. L., *Decision Making with Dependence and Feedback: Analytic Network Process*, RWS Publications, Pittsburgh, 1996.
23. Huang, J. J., Tzeng, G. H., and Ong, C. S., "Multidimensional Data in Multidimensional Scaling Using the Analytic Network Process", *Pattern Recognition Letters*, Vol. 26, No. 6, 2005, pp. 755-767.
24. Opricovic, S., *Multicriteria Optimization of Civil Engineering Systems*, Faculty of Civil Engineering, Belgrade, 1998.
25. Opricovic, S. and Tzeng, G. H., "Compromise Solution by MCDM Methods: A Comparative Analysis of VIKOR and TOPSIS", *European Journal of Operation Research*, Vol. 156, No. 2, 2004, pp. 445-455.
26. Opricovic, S. and Tzeng, G. H., "Extended VIKOR Method in Comparison with Outranking Methods", *European Journal of Operational Research*, Vol. 178, No. 2, 2007, pp. 514-529.
27. Liou, J. J. H., Tzeng, G. H., and Chang, H. C., "Airline Safety Measurement Using a Hybrid Model", *Journal of Air Transport Management*, Vol. 13, No. 4, 2007, pp. 243-249.
28. Hsu, Y. L., Li, W. C., and Chen, K. W., "Structuring Critical Success Factors of Airline

Safety Management System Using a Hybrid Model", *Transportation Research Part E*, Vol. 46, No. 2, 2010, pp. 222-235.

29. Tzeng, G. H., Teng, M. H., Chen, J. J., and Opricovic, S., "Multicriteria Selection for a Restaurant Location in Taipei", *International Journal of Hospitality Management*, Vol. 21, No. 2, 2002, pp. 171-187.

30. Liou, J. J. H. and Chuang, Y. T., "Developing a Hybrid Multi-Criteria Model for Selection of Outsourcing Providers", *Expert Systems with Applications*, Vol. 37, No. 5, 2010, pp. 3755-3761.

31. Yeh, M. S., Hsiao, Y. L., and Liu, H. H., "An Study on Different Decision-Making Models Applying for Transportation Policy Using Su-Hau Highway as an Example", International Conference and Annual Meeting of Chinese Institute of Transportation, Taoyuan, Taiwan, 2009.