A Novel Evaluation Model for the Vehicle Navigation Device Market Using Hybrid MCDM Techniques

Chia-Li Lin[1], Meng-Shu Hsieh[1], and Gwo-Hshiung Tzeng[1,2]

[1] Institute of Management of Technology, National Chiao Tung University, 1001 Ta-Hsueh Road, Hsinchu 300, Taiwan
linchiali0704@yahoo.com.tw
[2] Department of Business and Entrepreneurial Administration, Kainan University, No. 1 Kainan Road, Luchu, Taoyuan County 338, Taiwan
ghtzeng@mail.knu.edu.tw

Abstract. The developing strategy of ND is also presented to initiate the product roadmap. Criteria for evaluation are constructed via reviewing papers, interviewing experts and brain-storming. The ISM (interpretive structural modeling) method was used to construct the relationship between each criterion. The existing NDs were sampled to benchmark the gap between the consumer's aspired/desired utilities with respect to the utilities of existing/developing NDs. The VIKOR method was applied to rank the sampled NDs. This paper will propose the key driving criteria of purchasing new ND and compare the consumer behavior of various characters. Those conclusions can be served as a reference for ND producers for improving existing functions or planning further utilities in the next e-era ND generation.

Keywords: Vehicle navigation device, consumer behavior, ANP(Analytic Network Process), Network Relationship-Map (NRM), ISM (interpretive structural modeling), VIKOR.

1 Introduction

Portable navigation devices (PND), personal digital assistants (PDA) and smart phones. embedded navigation devices [1] is proposed to be equipped in high class cars as a luxury good by automobile producers. END is a highly system-integrated device and controls the air conditioner, vehicle body, telematics, vehicle safety, communication and entertainment utilities. It is mainly promoted as a value-added device by automobile producers and, therefore, its price is higher than other devices. PND is equipped with a car cradle attached to the windscreen or placed upon the instrument board. Navigation is the main utility of a PND, and, however, entertainment utility is also integrated inside in recent years. PND can be easily demounted and installed into different cars. Therefore, consumers can apply it to unequipped cars, such as the automobile. PND is positioned into the consumer market and is developed by GPS, or telematics enterprises.

The remainder of this paper is organized as follows. In section 2, demand model for ND based on consumers' requirements/needs. In section 3, building a novel

Y. Shi et al. (Eds.): MCDM 2009, CCIS 35, pp. 769–779, 2009.

evaluation model for the best ND; In section 4, A novel evaluation model for the vehicle navigation device market using hybrid MCDM techniques. Finally, in section 5, the conclusions and further planning strategies for the next e-Era generation ND are presented.

2 Demand Model for ND Based on Consumers' Requirements/Needs

In the ND industry, system service providers and electronic providers co-play the role of system integration and provide various vehicle-related navigation services and applications. Four commercial ND products in Taiwan are used to discuss aspired/desired functions/utilities of the ideal ND. This research organizes services and utilities into four dimensions: (1) Navigation and mobile information services, (2) Information system services, (3) Fee Rate & Payment Methods, and (4) Product Image and Customer relationships. (1) Navigation and mobile information services: With the rapid growth of road networks and total numbers of cars on the road in Taiwan, traffic problems seem inevitable. With the advanced development of information and communications technologies, people do not need to find roads via traditional maps, rather they just enter their desired destination into a navigation system, and the location services of the ND will map the routes with vocal instructions to help people reach the desired location. But, in addition to directions to the destination, consumers are concerned about real-time traffic situations for route planning, in order to avoid areas of congested traffic [2]. In this paper, four commercial ND products are analyzed and benchmarked to discuss the required utilities/functions and services of the next e-era generation ND. The dimension of navigation & mobile information services (NM) contains four criteria: voice-guided navigation services (NM1), traffic information (NM2), electronic map information (NM3) and mobile information services (NM4) to determine the required utilities/functions for the next e-era generation VTS regarding Navigation and Location Services. The traditional automobile multimedia entertainment was a closed system; people could choose their favorite form of multimedia storage and its corresponding hardware players, such as cassette tapes, compact discs, DVDs, and MP3s. With the advances in the development of technologies, the integrated player supporting different audio-video formats has been created. It eases the inconvenience of converting different systems, but it cannot satisfy the needs of fashion, real-time, and preferences between people. With the advances in technologies, consumers can search and download videos, music, and other multimedia information in real-time via the ND[3]. (2) Information & system services (IS): The core of VTS is communications and information services. The transmission, reception, and communication of information are needed for the operation of various communications and information technologies, particularly wireless technologies. Accordingly, automobile users can obtain various information of real-time and precise when they have different needs on moving, such as personal e-commerce [3, 4]. In this paper, four commercial ND products will be analyzed and benchmarked to discuss the required utilities/functions and services for the next e-era generation ND. The dimension of information system services contains four criteria: user interface (IS1), platform integration services (IS2), information security protection (IS3), and information update frequency (IS4), to determine the required utilities/functions of the next e-era generation ND regarding and Information system services. (3) Fee Rate & Payment Method: In this paper, four commercial ND products will be analyzed and benchmarked to discuss the required utilities/functions and services for the next e-era generation ND. The dimension of fee rate & payment method (FP) contains four criteria: service fee rate (FP1), pricing (FP2), payment method (FP3), and payment channel (FP4), to determine the required utilities/functions of the next e-era generation ND regarding the fee rate & payment method. (4) Product Image and Customer Relationship: The dimension of Product image (PI) contains four criteria that will be analyzed in this paper: product design (PI1), brand image (PI2), after-sales services (PI3), and privacy policy (P4I) to determine the required utilities/functions of the next e-era generation ND regarding product image and customer relationships.

3 Building a Novel Evaluation Model for the Best ND

In this section, the general concept of the evaluation model is proposed for the purpose of building the best ND model using MCDM techniques for evaluating and improving the existing ND products. The study is divided into three subsections. In subsection 3.1, survey for VTS functions and consumer preference, and building the ISM model in section 3.2. In section 3.3, the analytical network procedure (ANP) model, and The VIKOR model in the 3.4 section.

3.1 Survey for VTS Functions and Consumer Preference

Therefore, a suitable value created system should integrate the price and the value of the product by mass customization for a good fit in a custom-made and low cost product in mass production to satisfy the customers' needs. Our research provides an innovation strategy map to show the innovation strategy of enterprises. Figure 1 shows the decision problem of the purchase behavior and research idea map. Although the cost-effective method can help the purchaser to make a decision, a purchaser cannot measure the effective items. A purchaser often only uses the concept of satisfaction degree, as the research can show with a two axis decision map. The cross axis (*X*-axis) is valued by satisfaction degree and the value is organized by three aspects. Therefore, value satisfaction degree can be increased by the improvement of functions and services. The vertical axis (*Y*-axis) represents the price satisfaction degree, and the value is organized by the product price. Price satisfaction degree can be increased by the reduction of the function and service fee rate.

Manufacturers can use four innovation strategies: (1) fix the value satisfaction degree and increase the price satisfaction degree (Low price strategy, S_1), (2) fix the price satisfaction degree and increase the value satisfaction degree (High value strategy, S_2), (3) create the diverse products in the same satisfaction level (Strategy of diverse product portfolios, S_3), and (4) increase the value satisfaction degree and price satisfaction degree by mass customization (Mass customization strategy, S_4). From point *A* of Figure 1, the low price strategy (S_1) is to fix the value satisfaction degree and to increase the price satisfaction degree. This moves the direction of the product point from *A* to *B*. Low price strategy is reached by the mass manufacture and scale economy. From point *B* of Figure 1, we can see the high value strategy (S_2) is to fix the price satisfaction degree and increase the value satisfaction degree. If this happens, the direction of the product point moves from *B* to *C*. The low price strategy is reached by reducing the surplus function and increasing the insufficient function. From point *C* of Figure 1, we can see the strategy of diverse product portfolios (S_3) is to create diverse products in the same satisfaction level, and move the direction of the product point from *C* to *D*. The strategy of diverse product portfolios is reached by increasing the opportunity of product choice. From point *D* of Figure 1, we can see that the mass customization strategy (S_4) is to increase the value satisfaction degree by mass customization. When this is conducted, the direction of the product point moves from *D* to *E*. The mass customization strategy is most difficult, because it integrates the customization product and mass manufacture at the same time.

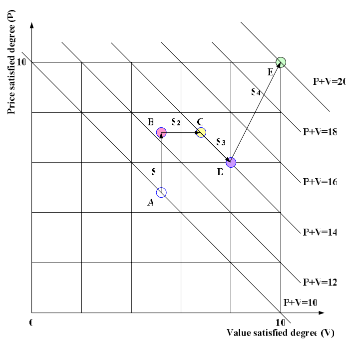

Fig. 1. The explanation of the research concept

3.2 Building the ISM Model

ISM (Interpretive structural modeling) was proposed by Warfield as a computer assistant methodology [5, 6]. It was used to derive and understand the interrelationship among the complex elements and a set of different and directly related elements can be structured into a comprehensive systemic model [7]. The first step of the ISM was to identify the variables relevant to the problem or issue. It extends with a group of problem-solving techniques. A structural self-interaction matrix (SSIM) was developed based on the pair-wise comparison of variables. The SSIM was formed by asking questions such as "will element e_i affect element e_j?" If the answer was yes, then π_{ij}=1. If the answer was no, then π_{ij}=0. SSIM can be described as below:

$$\boldsymbol{D} = \begin{array}{c} \\ e_1 \\ e_1 \\ \vdots \\ e_m \end{array} \begin{array}{c} \begin{array}{cccc} e_1 & e_2 & \cdots & e_n \end{array} \\ \begin{bmatrix} 0 & \pi_{12} & \cdots & \pi_{1n} \\ \pi_{21} & 0 & \cdots & \pi_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \pi_{m1} & \pi_{m2} & \cdots & 0 \end{bmatrix} \end{array} \quad (1)$$

where: e_i means the *i*th element. The π_{ij} means the interrelationship between the *i*th and *j*th elements. ***D*** is an SSIM. After we established the SSIM, we can convert it into a reach ability matrix and its transitivity is checked, such as formula (2) and (3) [8]:

$$\boldsymbol{M} = \boldsymbol{D} + \boldsymbol{I} \tag{2}$$

$$\boldsymbol{M}^* = \boldsymbol{M}^k = \boldsymbol{M}^{k+1} \quad k > 1 \tag{3}$$

where ***I*** is the unit matrix, *k* denotes the powers, and *M** is the reachability matrix. Note that the reach ability matrix is under the operators of the Boolean multiplication and addition (i.e. 1 · 1 = 1, 1 + 1 = 1, 1·0=0, 1+0=0+1=1, 1·0=0·1=0).

3.3 The Analytical Network Procedure (ANP) Model

The ANP method is expressed by a unidirectional hierarchical relationship among decision levels [9-11]. The top element of the hierarchy is the overall goal for the decision model. The hierarchy decomposes to a more specific criterion, until a level of manageable decision criteria is met [12]. Under each criterion, sub-criteria elements relative to the criterion can be constructed. The ANP separates complex decision problems into elements within a simplified hierarchical system. The steps of the ANP method are described as follows: (1) clarifies the questions and constructs the framework, (2) designs the questionnaires and the survey, (3) determines the relative importance of factors by pair-wise comparison to calculate factor weights by dependence and feedback, and checks the consistency of logical judgment, (4) calculates the super matrix, and (5) determines the factor weights [13, 14].

3.4 The VIKOR Model

After establishing the evaluation model, including criteria and given weights in each criterion, the next step is to evaluate the performance of benchmarked alternatives. The more utilities/functions of the ND, the more expensive the ND is. Thus, among the evaluation model of ND, the functional criteria are mutually conflicted with the cost criteria. The VIKOR method is used to evaluate and rank the performance of benchmarked alternatives. The VIKOR method is a MCDM method, and applies to solve a discrete decision problem with non-commensurable and conflicting criteria [15-21]. This method focuses on ranking and selecting from a set of alternatives, and determines compromise solutions for a problem with conflicting criteria, which can help the decision makers to reach a final decision. Here, the compromise solution is a feasible solution closest to the ideal one, and a compromise means an agreement established by mutual concessions. Thus, the VIKOR method would be applied to rank and evaluate the performance of proposed GPS alternatives. The basic concept of VIKOR is to identify the positive-ideal solution and the negative-ideal solution. The positive solution is the best solution that satisfies the most required criteria, and the opposite is the negative-ideal solution. The VIKOR method could rank and determine the difference of negative and positive ideal solutions between services/utilities of the existing NDs. When calculating the distance between the ideal solution and the proposed NDs, the score of every criterion should be summarized. The gap between the consumers' most satisfied one and most unsatisfied one is also analyzed, with respect to services/utilities of the existing NDs. The VIKOR method was started with the form of the $L_p - metric$, which was used as an aggregating function in a compromise programming method and it developed the multi-criteria measure for compromise ranking [22, 23]. VIKOR provided a maximum group utility of the "majority" and a minimum individual regret of the "opponent". The compromise solutions could be the base for negotiation, involving the decision makers' preferences by criteria weights. where: F^* is the ideal solution. F_1^* represents the ideal value of criterion 1. F_2^* represents the ideal value of criterion 2. The compromise solution, F^c, is a feasible solution that is "closest" to the ideal F^*. A compromise means an agreement established by mutual concessions. The VIKOR method is presented with the following steps

Determine the best f_j^* and the worst f_j^- values.

$$f_j^* = \left\{ \left(\max_i f_{ij} \mid i \in I_1 \right), \left(\min_i f_{ij} \mid i \in I_2 \right) \right\} \quad \forall j \tag{4}$$

$$f_i^- = \left\{ \left(\min_j f_{ij} \mid i \in I_1 \right), \left(\max_j f_{ij} \mid i \in I_2 \right) \right\} \forall i \tag{5}$$

Where *j* is the number of feasible alternatives; *i* is the criterion; f_{ij} is the value of the *i*th criterion function; I_1 is the cluster of utility-oriented criteria; I_2 is the cluster of cost-oriented criteria; f_j^* is the positive-ideal solution (or setting the aspired level); and f_j^- is the positive-ideal solution (or setting the worst level). Compute the values S_i and Q_i, $i = 1, 2, ..., m$. The functions are:

$$S_i = \sum_{j=1}^{n_i} w_j^i r_{ij}, \quad i = 1, 2, ..., m \tag{6}$$

$$Q_i = w_j^i \max_j \{ r_{ij} \mid j = 1, 2, ..., n \}, \quad i = 1, 2, ..., m \tag{7}$$

Where: w_j are the weights of the criteria, expressing the relative importance value of the criteria gained via the application of the ANP method, based on NRM. Compute the values: Q_j, *j* = 1,2,. . . ,*J*, by the relationship:

$$Q_j = v\left(S_j - S^*\right) / \left(S^- - S^*\right) + (1 - v)\left(R_j - R^*\right) / \left(R^- - R^*\right) \quad \forall i \tag{8}$$

where $S^* = \underset{j}{Min}\, S_j$; $S^- = \underset{j}{Max}\, S_j$, $R^* = \underset{j}{Min}\, R_j$; $R^- = \underset{j}{Max}\, R_j$ v is introduced as the weight of the strategy of "the majority of criteria" (or "the maximum group utility"), here, v =0.5.; $\underset{i}{Min}\, S_i$ is with a maximum group utility (majority rule), $\underset{i}{Min}\, R_i$ is with a minimum individual regret/gap of the "opponent" for first taking improvement action. Q_{vj} and Q_{pj} are the compromise performance of alternative *i*. Rank the alternatives: In this paper, Q_{vj} and Q_{pj} (here, v =0.5) are applied to determine the value satisfaction index(VSI) and price satisfaction index (PSI). Q_{vj} and Q_{pj} could also consider the index of the maximum group utility and the minimum individual regret of the "opponent", where Q_{vj} and Q_{pj} smaller are better and $0 \leqq Q_{vj}$ or $Q_{pj} \leqq 1$. However, this research prefers to use 1-Q_i for evaluation, which means 1-Q_i bigger is better. When the v value of value satisfaction is 0.5, then v=Q_{vj} and VSI=1-Q_{vj} . When the v value of price satisfaction is 0.5, then p=Q_{pj} and PSI=$1-Q_{pj}$. Therefore, VSI and PSI of different alternatives could be gained.

4 A Novel Evaluation Model for the Vehicle Navigation Device Market Using Hybrid MCDM Techniques

4.1 Empirical Study in ISM Techniques

The real practice is illustrated by using the ISM method to obtain a reach ability matrix. This is demonstrated here. The selected criteria of ND includes: (1) navigation and location services (N), (2) communications and information services (I), (3) fee rate and payment methods (F), and (4) product image. The original interrelationship data among all dimensions is listed in the I column of Table 1. Setting the threshold value=0.73, if the value of the element inside the matrix is more than 0.73, the value would be counted as 1. If the value of the element is lesser than 0.73, the value would be counted as 0. Then, the interrelationship matrix (D) could be created and matrix (M) could create using formula (1). The results are presented in the D and M column of Table 1.

Table 1. The original interrelationship (I), interrelationship matrix (D) and (M) matrix

	I					D					M			
	NM	IS	FP	PI		NM	IS	FP	PI		NM	IS	FP	PI
Navigation & mobile information services (NM)	0.00	0.92	0.53	0.71		0.00	1.00	0.00	0.00		1.00	1.00	0.00	0.00
Information & system services (IS)	0.89	0.00	0.63	0.74		1.00	0.00	0.00	1.00		1.00	1.00	0.00	1.00
Fee rate & payment method (FP)	0.61	0.71	0.00	0.63		0.00	0.00	0.00	0.00		0.00	0.00	1.00	0.00
Product image (PI)	0.74	0.71	0.50	0.00		1.00	0.00	0.00	0.00		1.00	0.00	0.00	1.00

Table 2. Reach ability matrix (M*) of all the dimensions

M*	NM	IS	FP	PI
Navigation & mobile information services (NM)	1	1	0	**1***
Information & system services (IS)	1	1	0	1
Fee rate & payment method (FP)	0	0	1	0
Product image (PI)	1	**1***	0	1

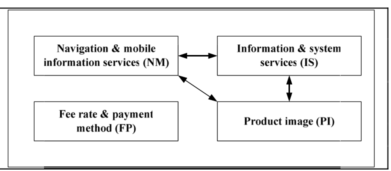

Fig. 2. Dimension interrelationship structure

Finally, the reach ability matrix can be obtained by using formula (2). The star (*) indicates the derivative relationship, which does not emerge in the original relationship matrix. The correlation between every aspect is shown in Table 2 and Figure 2.

4.2 Computing the Weights of Criteria - the ANP Method

The weights could be gained by using the ANP method. In the process of limitation, the multiples of the super matrix M, for 16 squares, and the weights of the dimensions and the criteria could be obtained. The results are presented in Table 3. FP is the only price-oriented dimension. The largest value of factor weights of the price-oriented criterion is FP1 (w=28.6%), the next is FP2 (w=26.2%), FP4 (w=23.8%), and FP3 (w=21.4%). NM, IS, and PI are the value-oriented dimensions. The largest value of factor weights of the value-oriented dimension is NM (w=43.9%), the next is IS (w=33.3%), and finally PI (w=22.8%). The largest value of weights of the value-oriented criterion is NM3 (w=11.8%) and the lowest one is PI1 (w=3.9%). As a result of using ANP method, we determine that the key decision consideration factor that affects the consumer's purchasing of VTS is the communication and information services.

Table 3. Weight of dimensions and criteria

Value-oriented dimensions	Weight of dimension	Criteria	Weigh of criteria		Price-oriented dimensions	Weight of dimension	Criteria	Weight of criteria
Navigation & mobile information services (NM)	43.9%	NM1	11.6%		Fee rate & payment method (FP)	100%	FP1	28.6%
		NM2	10.6%				FP2	26.2%
		NM3	11.8%				FP3	21.4%
		NM4	9.9%				FP3	23.8%
Information & system services (IS)	33.3%	IS1	9.0%					
		IS2	7.2%					
		IS3	7.7%					
		IS4	9.5%					
Product image (PI)	22.8%	PI1	3.9%					
		PI2	5.3%					
		PI3	6.9%					
		PI4	6.7%					

4.3 The VIKOR Model

The compromised solution is stable within a decision making process, which could be the strategy to achieve maximum group utility (when $v > 0.5$ is needed), "by consensus" $v = 0.5$, or with veto" ($v < 0.5$). Here, v is the weight of the decision making strategy of maximum group utility. The v would be assumed to be 0.5 for considering a maximum group utility of the "majority", and a minimum individual regret of the "opponent". $\underset{j}{Min} S_j$ is with a maximum group utility ("majority" rule) and $\underset{j}{Min} R_j$ is with a minimum individual regret of the "opponent". Q_{vj} is the benefit of alternative j. As shown in Figure 3, the Q_{vj} of VSI would not change the Q_{vj} of G Company nüvi 200W (Q_j =0) under different v. However, the Q_{vj} of M company Leap K1 would be reduced as v rises and the Q_{vj} of T company MVC 8100 would be changed slightly. As shown in Figure 3, the Q_{pj} of the PSI would not change the Q_{pj} of M company Leap K1 (Q_{pj}=0) under different v. However, the Q_{vj} of T company MVC 8100 would be reduced as v rises and the Q_{pj} of T company MVC 8100 would be changed slightly.

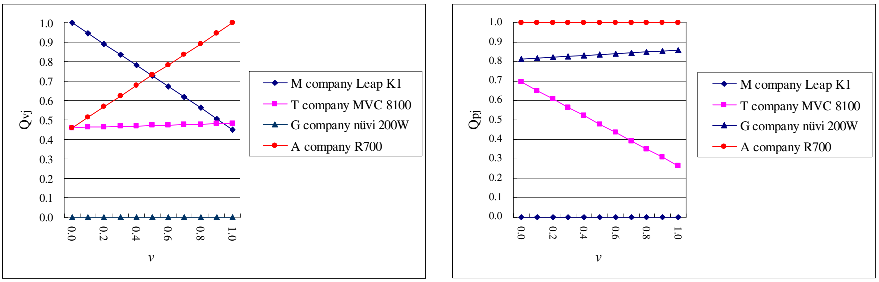

Fig. 3. Q_{vj} and Q_{pj} under different v

Therefore, VSI and PSI of different alternatives could be gained. As shown in Table 4, under v=0.5, Q_{vj} of V=0.726, VSI=0.274 of M company Leap K1, Q_{pj} of P=0, and PSI=1 of M company Leap K1. As shown in Figure 4, the distribution of VSI and PSI are best represented as a two-dimensional-axis graph. The 45 degree slope line means equal utility, which, in turn, means that the sum of VSI and PSI is fixed (i.e. VSI=PSI). The total satisfaction degree is higher rightward and is lower leftward. Thus, the value of total satisfaction from high to low is M company Leap K1(0.274, 1.000), G company nüvi 200W (1.000, 0.162), T company MVC 8100 (0.529, 0.521) and A company R700. The competition strategies could be proposed in the following four types: G company adopts the high value strategy of raising the VSI, M company adopts the low price strategy of raising the PSI, T company adopts the value-price balanced strategy, and A company is relatively weak at PSI and VSI. A company is suggested to consider a balanced strategy when they need to raise the PSI and VSI. The next logical step would be to adopt those strategies, such as what G company and M company does.

Table 4. VSI and PSI under v=0.5

v=0.5	M company Leap K1	T company MVC 8100	G company nüvi 200W	A company R700
V= Q_{vj}	0.726	0.471	0.000	0.730
VSI = $1-Q_{vj}$	**0.274**	**0.529**	**1.000**	**0.270**
P = Q_{pj}	0.000	0.479	0.838	1.000
PSI = $1-Q_{pj}$	**1.000**	**0.521**	**0.162**	**0.000**

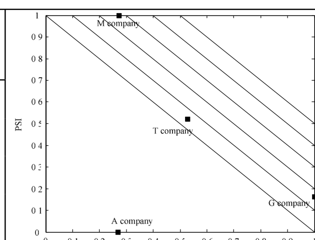

Fig. 4. The strategy under the consideration of VSI & PSI

5 Conclusions

In this paper, we applied the concept of customer satisfaction into the development of products, built the evaluation model of products under the thorough consideration of both VSI and PSI, applied the model to position the product, and proposed the strategy of product development. In the analysis of preferred alternatives, four commercial NDs are benchmarked. Therefore, the competition strategies could be proposed as the following three types: G company adopts the high value strategy of raising the VSI, M company adopts the low price strategy of raising the PSI, and T company adopts the value-price balanced strategy. There are few commercial NDs benchmarked and discussed in this paper. We recommend in the future that different NDs be added to discuss the product development strategy of the same producer in different periods, and the consumers' preferences of different characterizations.

References

1. Gonzalez-Perez, C., Henderson-Sellers, B.: Modelling software development methodologies: A conceptual foundation. Journal of Systems and Software 80(11), 1778–1796 (2007)
2. Chen, Q., Stauss, H.J.: Evaluating traffic effects of a route guidance system by dynamic simulation. Simulation Practice and Theory 5(7-8), 793–804 (1997)
3. Golob, T.F., Regan, A.C.: Impacts of information technology on personal travel and commercial vehicle operations: research challenges and opportunities. Transportation Research Part C: Emerging Technologies 9(2), 87–121 (2001)
4. Anker, F.W.G., Arnold, A.G.: The usefulness of mobile multimedia communications: a case study. Displays 18(4), 193–197 (1998)
5. Agarwal, A., Shankar, R., Tiwari, M.K.: Modeling agility of supply chain. Industrial Marketing Management 36(4), 443–457 (2007)
6. Sharma, H.D., Gupta, A.D., Sushil: The objectives of waste management in India: A futures inquiry. Technological Forecasting and Social Change 48(3), 285–309 (1995)
7. Fontela, E.: The future societal bill: methodological alternatives. Futures 35(1), 25–36 (2003)
8. Huang, J.J., Tzeng, G.H., Ong, C.S.: Multidimensional data in multidimensional scaling using the analytic network process. Pattern Recognition Letters 26(6), 755–767 (2005)
9. Nachtmann, A.R.R., Saaty, T.L., et al.: Forecasting the resurgence of the US economy in 2001: an expert judgment approach. Socio-Economic Planning Sciences 36(2), 77–91 (2002)
10. Niemira, M.P., Saaty, T.L.: An Analytic Network Process model for financial-crisis forecasting. International Journal of Forecasting 20(4), 573–587 (2004)
11. Saaty, T.L.: Rank from comparisons and from ratings in the analytic hierarchy/network processes. European Journal of Operational Research 168(2), 557–570 (2006)
12. Meade, L.M., Presley, A.: R&D project selection using the analytic network process. IEEE Transactions on Engineering Management 49(1), 59–66 (2002)
13. Shyur, H.J.: COTS evaluation using modified TOPSIS and ANP. Applied Mathematics and Computation 177(1), 251–259 (2006)
14. Shyur, H.J., Shih, H.S.: A hybrid MCDM model for strategic vendor selection. Mathematical and Computer Modelling 44(7-8), 749–761 (2006)
15. Opricovic, S., Tzeng, G.H.: Multicriteria planning of post-earthquake sustainable reconstruction. Computer-Aided Civil and Infrastructure Engineering 17(3), 211–220 (2002)

16. Opricovic, S., Tzeng, G.H.: Defuzzification within a multicriteria decision model. International Journal of Uncertainty Fuzziness and Knowledge-Based Systems 11(5), 635–652 (2003)
17. Opricovic, S., Tzeng, G.H.: Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. European Journal of Operational Research 156(2), 445–455 (2004)
18. Opricovic, S., Tzeng, G.H.: Extended VIKOR method in comparison with outranking methods. European Journal of Operational Research 178(2), 514–529 (2007)
19. Tzeng, G.H., Lin, W.C., Opricovic, S.: Multi-criteria analysis of alternative-fuel buses for public transportation. Energy Policy 33(11), 1373–1383 (2005)
20. Tzeng, G.H., Teng, M.H., Chen, J.J., et al.: Multicriteria selection for a restaurant location in Taipei. International Journal of Hospitality Management 21(2), 171–187 (2002)
21. Tzeng, G.H., Tsaur, S.H., Laiw, Y.D., et al.: Multicriteria analysis of environmental quality in Taipei: public preferences and improvement strategies. Journal of Environmental Management 65(2), 109–120 (2002)
22. Yu, P.L.: A class of solutions for group decision problems. Management Science 19(8), 936 (1973) (pre-1986)
23. Zeleny, M.: Multiple Criteria Decision Making. McGraw-Hill, New York (1982)