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A Product Development for Green Logistics Model by Integrated Evaluation of Design and Manufacturing and Green Supply Chain

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***Abstract*—**A product development for green logistics model using the fuzzy analytic network process method is presented for evaluating the relationships among the product design, the manufacturing activities, and the green supply chain. In the product development stage, there can be alternative ways to design the detailed components to satisfy the design concept and product requirement. In different design alternative cases, the manufacturing activities can be different. In addition, the manufacturing activities can affect the green supply chain of the components and product. In this research, a fuzzy analytic network process evaluation model is presented for evaluating the criteria in product design, manufacturing activities, and green supply chain. The comparison matrices for evaluating the criteria among the three groups are established. The total relational values between the three groups represent the relationships and effects. In application, the total relational values can be used to evaluate the design alternative cases for decision-making to select a suitable design case and the green supply chain. In this presentation, an example product is illustrated. It shows that the model is useful for integrated evaluation of design and manufacturing and green supply chain for the purpose of product development for green logistics.

***Keywords*—**Supply chain management, green supply chain, product development for logistics, fuzzy analytic network process.

I. Introduction

To produce a product, in the product development stage, with a given product requirement and conceptual design, there may be different ways to design the detailed components and product. If the detailed specifications are different, the components and product may need to be produced with different manufacturing processes and operations. In this way, the manufacturing processes and operations will affect the supply chain. Therefore, the decision-making of supplier selection can be affected by the different design alternative cases. It is necessary to evaluate the effects of using the different design alternative cases and to analyze how the different designs affect the supply chain.

In a typical supply chain, the supplier evaluation is mainly determined based on the criteria of time, cost, and quality. However, due to the increasing ecological impact and the emerging environmental regulations, the concept of green supply chain is presented. In a green supply chain, the criteria of energy usage and environment impact are essential factors to be added.

Therefore, in a green supply chain, the criteria should include energy and environment, in addition to the traditional criteria of time, cost, and quality. As a result, the decisions in manufacturing activities will affect the decisions in a green supply chain. For example, a low cost in the manufacturing activities may result in a high cost in the green supply chain. In contrast, a low cost in the green supply chain may require a high cost in the manufacturing activities. Therefore, it is necessary to analyze the relationship between the three and integrate the evaluation.

If several design alternative cases are available, the different design alternative cases can affect the decisions of manufacturing activities and green supply chain activities. A product design decision not only changes a portion of the components or product, but also affects the activities in manufacturing and the green supply chain. Therefore, it is necessary to consider the design alternative cases prior to the actual production of the product. In a green product life cycle, it is important to plan how a product can be manufactured in the green supply chain. To avoid a high cost in the green supply chain, the key is to consider the manufacturing activities and the green supply chain in a concurrent way. With the above concept, a product development for green logistics model is presented in this research.

In this research, a product development for green logistics model using the fuzzy analytic network process (FANP) method is presented for evaluating the relationships among the design alternative cases, the manufacturing activities, and the activities in the green supply chain. The product development evaluation model can be used to analyze the relationships and interactions among the activities in the three groups. In applications, the evaluation model can be applied to decision-makings for design case selection and supplier selection.

The presented fuzzy analytic network process models and methods have been implemented and tested with example products. The main contribution lies in the new concept of integrated evaluation of the relationships among the design alternative cases, the manufacturing activities, and the activities in the green supply chain. The test results show that the presented model and method is feasible and efficient for modeling the integrated evaluation problem. In this paper, the

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test result of an example product is illustrated and demonstrated.

This paper is organized as follows. In this paper, Section I presents an introduction. Section II presents a literature review. Section III describes the models and the methods. In Section IV, the application of the model is demonstrated. Finally, a conclusion is presented in Section V.

II. Literature Review

In the previous research, the problems of supplier selection in supply chains have been presented and modeled [1]-[3]. In the recent research, a literature review of supply chain performance measurement was presented [4]. The topics of forward and reverse logics and green supply chains have been presented in [5] and [6]. In [7] and [8], the problems of close-loop supply chain were investigated and modeled. In [9] and [10], the models of close-loop supply chain were developed and solved with optimized methods. In [11] and [12], the methods of fuzzy number applications and analytic network process methods were presented and discussed.

In the previous literature, many of the previous papers presented models for investigating green supply chains and closed-loop supply chains. Many solution methods for solving the supplier selection problems have been developed. Several papers presented models and optimization methods for integrating the manufacturing activities and forward and reverse supply chains. However, the issue that the product design and development can affect the green supply chain has not been discussed. Moreover, the relationships among product design activities, manufacturing activities, and their associated green supply chain have not been evaluated in an integrated way. Therefore, in this research, a model for integrated evaluation of product development and design, manufacturing, and the related green supply chain is developed. A new product development for green logistics model using the fuzzy analytic network process method is presented in this research.

III. Research Models and Methods

In this chapter, the model using the fuzzy analytic network process approach is presented. To represent the relationships between the components of a product, a component relational matrix for the product is modeled. A component relational value is assigned to each pair of components. A higher component relational value indicates that the two components have a higher degree of relationship and interaction. The format of the component relational matrix is shown in Table I. The matrix can be used to represent the relationships between the components of a product in the design stage.

To evaluate the relationships among design, manufacturing, and green supply chain, the fuzzy analytic network process evaluation model is presented. A network hierarchical structure is established to represent the relationships among the criteria in the three groups.

In the product development and design group, the criteria for evaluating a design include material, shape, dimension, number of components, and weight. In the manufacturing group, the criteria for evaluating the manufacturing activities include operation, process, tool, machine, and assembly. In the green supply chain group, the criteria for evaluating the green supply chain activities include time, cost, quality, energy, and environment. The relationships of the criteria in the three groups are shown in Fig. 1.

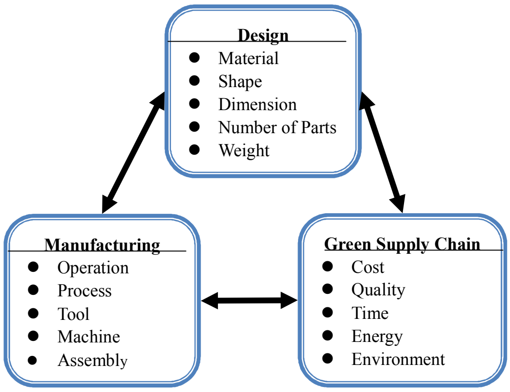

Fig. 1 The relationships of the criteria in the three groups

A network hierarchical structure is development to link the criteria in the three groups as shown in Fig. 2. Given the network hierarchical structure, the comparison matrices for evaluating the relationships between each of the pairs of the criteria among the three groups are established. The comparison matrices are modeled as fuzzy relational matrices. After the relational values of the pairs of the three groups are evaluated and graded, a defuzzication process is utilized. The relational values of the different criteria in the three groups can be calculated. The relational values of the criteria are checked for consistency. A higher relational value indicates that a pair of the criteria has a higher relationship and a higher interactive effect. For example, in a design, the material in the design can have a higher effect on the process in the manufacturing and a higher impact on the environment of the green supply chain.

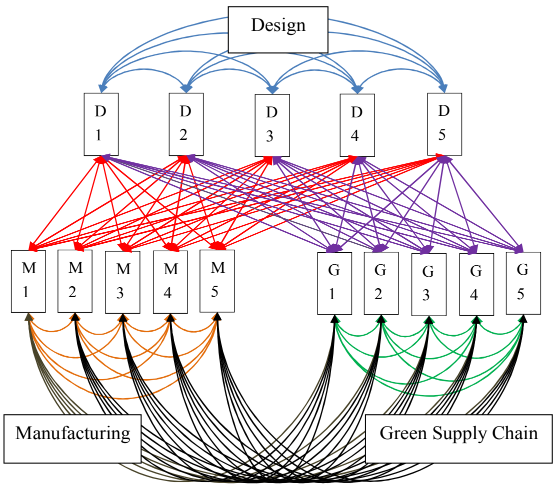

Fig. 2 The network hierarchical structure of criteria of design, manufacturing, and green supply chain

The fuzzy analytic network process model is described as follows:

1) Build component relational matrices of the components of the product. The component relational matrix of the components of the product is modeled to represent the relationships between each of the pairs of components as shown in Table I.
2) Build relational matrices of the design criteria for the design alternative cases. The relational matrix of each of the design criteria is built for the design cases. The design criteria are listed in Table II. This step builds relational matrix of all design criteria of the design cases as shown in Table III.
3) Build relational matrix of the manufacturing criteria for the manufacturing activities. The manufacturing criteria are listed in Table IV. This step builds relational matrix of all manufacturing criteria of the design cases as shown in Table V.
4) Build relational matrix of the green supply chain criteria for the green supply chain activities. The green supply chain criteria are listed in Table VI. This step builds relational matrix of all green supply chain criteria of the design cases as shown in Table VII.
5) Build network relational structure. The network hierarchical relational structure of the three groups of design, manufacturing, and green supply chain is shown in Fig. 2 and Table IV to VII.
6) Build comparison matrix between the criteria of the three groups of design, manufacturing, and green supply chain, as shown in Table VIII. In the design group, the criteria for evaluating a design include material, shape, dimension, number of components, and weight. In the manufacturing group, the criteria for evaluating the manufacturing activities include operation, process, tool, machine, and assembly. In the green supply chain group, the criteria for evaluating the green activities include cost, quality, time, energy, and environment.
7) Evaluate pair-wise comparison with evaluation and grading values provided by decision makers.

$$A_{ij} = \begin{bmatrix} 1 & a_{12} & a_{13} & \cdots & a_{1p} \\ a_{21} & 1 & a_{23} & \cdots & a_{2p} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a_{p1} & a_{p2} & a_{p3} & \cdots & 1 \end{bmatrix} \quad (1)$$

where A_{ij}: The matrix of j criterion in i group. a_{mn}: The n evaluation value of m criterion. P: number of criteria. $a_{nm} = 1/a_{mn}$, $\forall \; m,n = 1,2,..., p.$

8) Check consistency of the evaluation and grading. Check consistency using consistency index (C.I.). If C.I. is equal to 0, it indicates that the evaluation and judgment is consistent. If C.I. is greater than 0, then it is inconsistent. If C.I. is equal to or smaller than 0.1, it can be decided as consistent.

$$C.I. = \frac{(\lambda_{\max} - p)}{(p-1)} \quad (2)$$

If $C.I. \le 0.1$, it is consistent.

$$C.R. = \frac{C.I.}{R.I.}$$

If $C.R. \le 0.1$, it is consistent. Where R.I.: Random index.

9) Construct the fuzzy relational matrix.

$$\tilde{a}_{mn} = (l_{mn}, a_{mn}, u_{mn}) \quad (3)$$

where l_{mn} : the left value of the fuzzy number of the n evaluation value of m criterion. a_{mn} : the middle value of the fuzzy number of the n evaluation value of m criterion. u_{mn} : the right value of the fuzzy number of the n evaluation value of m criterion.

$$\tilde{A}_{ij} = \left[\tilde{a}_{mn}\right] = \begin{bmatrix} 1 & \tilde{a}_{12} & \tilde{a}_{13} & \cdots & \tilde{a}_{1p} \\ \tilde{a}_{21} & 1 & \tilde{a}_{23} & \cdots & \tilde{a}_{2p} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{p1} & \tilde{a}_{p2} & \tilde{a}_{p3} & \cdots & 1 \end{bmatrix} \quad (4)$$

10) Perform defuzzication according the center of gravity defuzzication method.

$$DF_{mn} = \frac{(l_{mn} + a_{mn} + u_{mn})}{3} \quad (5)$$

where DF_{mn}: De fuzzy weighted value.

$$H_{ij} = \begin{bmatrix} 1 & DF_{12} & DF_{13} & \cdots & DF_{1p} \\ DF_{21} & 1 & DF_{23} & \cdots & DF_{2p} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ DF_{p1} & DF_{p2} & DF_{p3} & \cdots & 1 \end{bmatrix} \quad (6)$$

11) Perform comparison between the criteria of the three groups and calculate the final relational values.

$$PV_{[j]m} = \sum_{n=1}^{N} \left(\frac{DF_{[j]mn}}{\sum_{m=1}^{M} DF_{[j]mn}} \right) \Bigg/ N \quad (7)$$

12) Calculate the final relational values of the criteria of the three groups and build a super matrix of the three groups.

A super matrix as shown in (8) can be build to represent the relational values between the criteria of the three groups. The FANP model and the evaluation method can be executed using the above steps. The presented FANP model can be used to analyze and evaluate the designed product and its associated manufacturing activities and green supply chain activities.

$$W = \begin{array}{c} \\ Group1^{Criterion} \\ \cdots \\ Group2^{Criterion} \\ \cdots \\ Group3^{Criterion} \\ \cdots \\ \vdots \end{array} \begin{array}{c} \begin{array}{cccc} \underset{Criterion1,2,...p}{Group1} & \underset{Criterion1,2,...p}{Group2} & \underset{Criterion1,2,...p}{Group3} & \cdots \end{array} \\ \begin{bmatrix} PV_{[1]1} & PV_{[1]2} & PV_{[1]3} & \cdots \\ PV_{[2]1} & PV_{[2]2} & PV_{[2]3} & \cdots \\ PV_{[3]1} & PV_{[3]2} & PV_{[3]2} & \cdots \\ \vdots & \vdots & \vdots & \vdots \end{bmatrix} \end{array} \quad (8)$$

TABLE I
COMPONENT RELATIONAL MATRIX

		n		β	
		$p_{\beta 1}$	$p_{\beta 2}$	$p_{\beta 3}$	$p_{\beta i}$
α	$p_{\alpha 1}$	$k_{11[n]}$	$k_{12[n]}$	...	$k_{1i[n]}$
	$p_{\alpha 2}$	$k_{21[n]}$	$k_{22[n]}$	...	$k_{2i[n]}$
	$p_{\alpha 3}$	$k_{31[n]}$	$k_{32[n]}$	...	$k_{3i[n]}$
	$p_{\alpha i}$	$k_{i1[n]}$	$k_{i2[n]}$	...	$k_{\alpha\beta[n]}$

α : Set of components in design cases. β : Set of components in design cases. $p_{\alpha i}$: Components in design cases. $p_{\beta i}$: Components in design cases. $k_{\alpha\beta[n]}$: Relational value of n criterion.

TABLE II
DESIGN CRITERIA FOR EVALUATING DESIGN ACTIVITIES

D_1	D_2	D_3	D_4	D_5
Material	Shape	Dimension	Number of Components	Weight

TABLE III
RELATIONAL MATRIX OF ALL DESIGN CRITERIA

	α	β	Relational value				
			D_1	D_2	D_3	D_4	D_5
Design Case	$p_{\alpha i}$	$p_{\beta 1}$					
		$p_{\beta 2}$					
		⋮					
		$p_{\beta i}$					
		Sum and Average					

TABLE IV
MANUFACTURING CRITERIA FOR MANUFACTURING ACTIVITIES

M_1	M_2	M_3	M_4	M_5
Operation	Process	Tool	Machine	Assembly

TABLE V
RELATIONAL MATRIX OF ALL MANUFACTURING CRITERIA

	α		Relational value				
		β	M_1	M_2	M_3	M_4	M_5
Design Case	$p_{\alpha i}$	$p_{\beta 1}$					
		$p_{\beta 2}$					
		⋮					
		$p_{\beta i}$					
		Sum and Average					

TABLE VI
GREEN SUPPLY CHAIN CRITERIA

G_1	G_2	G_3	G_4	G_5
Cost	Quality	Time	Energy	Environment

TABLE VII
RELATIONAL MATRIX OF ALL GREEN SUPPLY CHAIN CRITERIA

	α	β	Relational value				
			G_1	G_2	G_3	G_4	G_5
Design Case	$p_{\alpha i}$	$p_{\beta 1}$					
		$p_{\beta 2}$					
		⋮					
		$p_{\beta i}$					
		Sum and Average					

TABLE VIII
THE SUPER MATRIX OF FANP MODELS FOR THE CRITERIA OF DESIGN, MANUFACTURING, AND GREEN SUPPLY CHAIN

		Design					Manufacturing					Green Supply Chain				
		D_1	..			D_5	M_1	..			M_5	G_1	..			G_5
Design	D_1															
	D_2															
	…															
	D_5															
Manufacturing	M_1															
	M_2															
	…															
	M_5															
Green Supply Chain	G_1															
	G_2															
	…															
	G_5															

IV. Application to Evaluation of Design Cases and Supply Chain Selections D

In this research, the methods and models were implemented using the Excel VBA software on a personal computer. An example product is used for demonstration. The final super matrix for evaluating the different design cases is shown in Table IX. An example product is shown Fig. 3. In Fig. 3, a mobile phone is used as an example. The modeling of parts is simplified for demonstration. After executing the developed models and methods, the final super matrix is shown in Table X. As shown in Table X, the values represent the weighted relational value of the criteria for design cases 1 to t. The sum of the evaluated scores of the relational values can be used in the selection of design cases and green supply chain decisions.

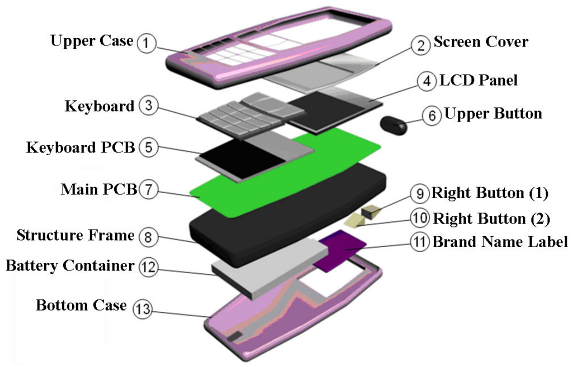

Fig. 3 The example product used for testing

TABLE IX
The Final Super Matrix of FANP Models for Evaluation of Design Cases using the Criteria of the Three Groups

			Design Case t					
	Relational Value Evaluation Score		1	2	3	4	5	Sum
Design	Material	$PV_{[1]m}$	$\sum_{i=1}^{I} k_{1i[n_s]} / I \times PV_{[1]m}$					W_{D1}
	Shape							W_{D2}
	Dimension							W_{D3}
	Number of Components							W_{D4}
	Weight							W_{D5}
Manufacturing	Raw Material	$PV_{[2]m}$	$\sum_{i=1}^{I} k_{1i[n_s]} / I \times PV_{[2]m}$					W_{M1}
	Operations							W_{M2}
	Processes							W_{M3}
	Tools							W_{M4}
	Machines							W_{M5}
Green Supply Chain	Cost	$PV_{[3]m}$	$\sum_{i=1}^{I} k_{1i[n_s]} / I \times PV_{[3]m}$					W_{G1}
	Time							W_{s2}
	Quality							W_{s3}
	Energy							W_{s4}
	Environment							W_{s5}

TABLE X
The Super Matrix of an Example Product using the FANP Models and Methods

Supply Selection Criteria		Design Case 1	Design Case 2	Design Case 3	Design Case 4	Design Case 5
Design	Material	Values	…			
	Shape	…				
	Dimension					
	Number of Componentts					
	Weight					
Manufacturing	Operation	Values	…			
	Process	…				
	Tool					
	Machine					
	Assembly					
Green Supply Chain	Cost	Values	…			
	Quality	…				
	Time					
	Energy					
	Environment					

V. Conclusions

In the product development stage, a product and its components can be designed with different specifications to satisfy the same product requirement and design concept. The different design cases can affect the manufacturing activities and the green supply chain activities. In this research, a product design evaluation model using the fuzzy analytic network process (FANP) method is presented for evaluating the relationships among the design activities, the manufacturing activities, and the green supply chain activities. A network hierarchical structure is established to represent the relationships among the criteria in the three groups. In the design group, the criteria include material, shape, dimension, number of components, and weight. In the manufacturing group, the criteria include operation, process, tool, machine, and assembly. In the green supply chain group, the criteria for evaluating a green supply chain include cost, quality, time, energy, and environment. The relational values of the different criteria in the three groups can be calculated. A super matrix can be modeled to represent the relationship between the criteria in the three groups of the network structure. The total relational values of different design cases can be compared to select the most suitable design case and the most suitable green supply chain. The presented models and methods can be applied in the design alternative decisions and the supplier selection decisions. The application and test show that the model is feasible and useful for integrated evaluation of design and manufacturing and green supply chain for the purpose of product development for green logistics. Future research can be directed to investigate more detailed cost evaluation methods and more practical evaluation criteria.

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