ESTABLISHING THE EVALUATION ANALYSIS MODEL FOR CARGO TRANSPORTATION SYSTEM

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Abstract

Concerning the design of engineering systems, especially at the conceptual design stage, it is difficult to predict the technical and socio-economic environmental implication of the design objects. As a result, the decision-making is to be done without sufficiently quantifying the design factors. Also, the initial planning stage, the project design, design specification, machinery selection, and their layout are generally made out of a number of possible alterative plans which have uncertain design factors. It is important that the final decision of plans is balanced in an overall perspective and be able to distinguish between conflicting objects. Moreover, in such problems, which are extremely subjective to personal likes and dislikes or depend on conceptual variations, an element of ambiguousness exists in the process of design making. Thus, the evaluation and decision making tends to be dependent upon the experience and ingenuity of engineers and specialists. Cargo transportation system is important to develop a prosperous country and establishing the evaluation analysis method for it is needed in the planning stage. As a practical example for the proposed method, the evaluation analytical model of inter-city material transportation systems between two metropolises is presented. The road transportation is the main type of domestic material distribution system in Japan. But modal shift concept is needed to reduce the load due to the growing demand of transportation volume. Accordingly, the proposed evaluation method is applied to some typical transportation systems that are in operation between the metropolises of Tokyo and Osaka including road transportation and marine transportation, as an example.

Keywords: *Multi-criteria Analysis, Evaluation Methodology, Material Transportation*

1. Introduction

Concerning the design of engineering systems, especially at the conceptual design stage, it is difficult to predict the technical and socioeconomic environmental implication of the design objects. As a result, the decision making is to be done without sufficiently quantifying the design factors. Also, athe initial planning stage, the project design, design specification, machinery selection, and their layout are generally made out of a number of possible alternative plans which have uncertain design factors. It is important that the final decision of plans is balanced in an overall perspective and be able to distinguish between conflicting objects. Moreover, in such problems, which are extremely subjective to personal likes and dislikes or depend on conceptual variations, an element of fuzziness exists in the process of design making. Thus, the evaluation and decision making tends to be dependent upon experience and ingenuity of engineers and specialist. As a practical example for the application of proposed method, the evaluation and decision making of inter island cargo transportation system is presented here.

2. Analytical Process of Evaluation Model

The analytical model is broken down into three parts, i.e.: structural evaluation model, grading analysis model, and evaluation-decision model.

2.1. A Structural Evaluation Model

At the formation of structural evaluation model, the whole problem under evaluation has to be grasped and items and criteria are to be selected using the brain-storming method. Range of problem also needs to be defined. Details of components of structural evaluation model are described as follows:

(1) Hierarchy analysis model

Hierarchy analysis model is composed of problems, objects and intems under evaluation. To show the relationship between objects clearly, the higher part of the hierarchy levels are more general designation of the items under evaluation.

(2**)** Weighting values under evaluation

The consistency condition is not strict when estimating the weighting under evaltion by a subjective scale because of its difficulty to keep consistency between items. Here, the pair test method called AHP (Analytical Hierarchy Process) is used. This method introduces the consistency index to avoid the consistency between the items under evaluation in the hierarchy model (Satty, 1988). Some fuzziness also to be added based on proposed method by Shinoda and Fukuchi (1992) to correct the weighting values.

(3) Items under independent evaluation
To avoid making imperfect estimation, the items under evaluation need to be carefully checked by calculating interdependence correction parameters. In this case, checking methodology proposed by Shinoda and Fukuchi (1992) is used to evaluate the items.

2.2. A Grading Analysis Model

Let p_{ij} defined as a grading estimation to the i-th object ($1 \le i \le n$) about the j-th item ($1 \le j \le m$) under evaluation. Value p_{ij} is determined with the quantifying model and denominated the judgement in words such as 'good' or 'bad' with the linguistic variables that includes fuzziness (Shinoda and Fukuchi, 1991). The p_{ij} is the element of the impact matrix $\mathbf{P}$ which is grading information. When the fuzziness of value p_{ij} is weak, we can assume p_{ij} is a non-fuzzy number and analyze the gradation using the gradation model.

2.3. An Evaluation-decision Model

(1) The Concordance Index
The degree of advance between the i-th and the i'-th objects, which is called the concordance index $c_{ii'}$, is estimatedby the following formula using the impact matrix $\mathbf{P}$.

$$c_{ii'} = \sum_{j \in c_{ii'}} w_j \frac{|p_{ij} - p_{i'j}|}{\max\limits_{1 \le i,i' \le n} |p_{ij} - p_{i'j}|} \qquad (1)$$

where, the symbol $c_{ii'}$ is the preference condition as follow:

$$c_{ii'} = (j | p_{ij} \succ p_{i'j}) \qquad (2)$$

where the symbol $\succ$ shows the reference relationships.

(2) The Concordance Dominance Index
The total evaluation index of the i-th object is called fuzzy concordance dominance index c_i The weighted difference between the concordance indices of advantage and disadvantage of the i-th to the i'-th object $c_{ii'}$ and $c_{i'i}$, is calculated as follows:

$$c_i = \alpha \sum_{i'=1}^{n} c_{ii'} - \beta \sum_{i'=1}^{n} c_{i'i} \qquad (3)$$

where α and β are the weightings for advantage and disadvantage. If $\alpha > \beta$, then the estimation is optimistic, and if equal then the estimation is balance.

3. An Example of a Practical Application – Evaluation of Cargo Transportation Systems

Road transportation is the main type of cargo transportation in most part of the world. But as demand grows, problem arises in the form of man power unavailability and environmental problem that becomes stumbling block on the desired economic pattern, and the need for new transportation system is gradually being felt. Concept of modal shift is introduced as one of political measurement to shift the load of road transport to shipping or rail transport. Here we evaluate the transportation system including the modal shift between modes of transportation.

3.1. Cargo Transportation System Between Cities

The proposed method is applied to a typical transportation system between two metropolitan city of Tokyo and Osaka as an example. Here we consider some alternatives of transportation system as shown in Table 1 with the explanation for each evaluation items is shown in Table 2. The transportation system is evaluated by economic and environmental perspective. Then the quantifying effect of these systems is analyzed as fuzziness.

Table 1 System denomination for cargo transportation system

System Denomination	Explanation of the system
(A) Truck (575km)	This is chosen when the cargo comes from several scattered points of origin and can only be reached by truck. Transportation time will vary depending on the road condition. Transportation cost is moderate.
(B) Truck + railway (10km) (565km)	Two means of transportation are used. This combination will reduce transportation time; however, cargo transported need double-handling process. This process would result in additional handling time and cargo quality reduction.
(C) Truck + airplane (25KM) (500km)	This transportation mode combination will reduce transportation time, but increase transportation cost. Double-handling process will also occur and special attention should be given for the packing. As a result, increase of handling and packing costs is inevitable.
(D) Truck + domestic sea (A) (25km) (720km)	This choice is selected when transportation cost need to be lowered: as a result of the large quantity that can be transported. However, the transportation time will increase. Attention should be given because there will be double-handling process and special packing.
(E) Truck + domestic sea (B) (25km) (720km)	The amount of cargo to be transported is slightly reduced which results in slightly increase of transportation cost. However, transportation time will decrease significantly.
(F) Underground railway (25km) + domestic sea (B) (720km)	This combination will be selected when a large amount of cargo can be consolidated in one place near railway station. The cargo then can be directly transported to a particular port before loaded into a ship. This will reduce transportation time, but slightly increase transportation cost. Double handling process occurs.

Table 2 System denomination for evaluation items for cargo transportation

Evaluation items			Explanation of evaluation items
Transportation and economy	Payload (ton)		The larger the amount of cargo can be transported by a particular mode at one time, the lower the unit cost of transportation; but this would increase transportation time, operating cost, initial investment and environmental problems.
	Transportation time (h)		Transportation time is directly proportional to payload, operating cost, and cost time efficiency.
	Cost-time efficiency (¥/h)		This will reduce transportation time and operating cost, but could increase initial investment.
	Operating cost (¥)		This will increase when transportation time needs to be reduced
	Initial investment (¥)		Large amount of initial investment will be inevitable when several small-size modes of transportation (i.e., with small payload) are used for transporting a particular large amount of cargo (i.e., payload).
	Punctuality		Punctuality will reduce operating cost.
Social problems	Manning		Manning is directly proportional to payload. Deploying several small-size modes of transportation will increase manning and operating cost. Inversely, reduction of manning scale will lower the operating cost and indirectly will decrease initial investment.
	Energy saving		Use of large-size of mode of transportation instead of using several small-size one, will lower energy consumption. Reducing transportation time (e.g., by using high speed mode) will increase the use of energy.
Environmental problems	Urban	Air, noise, vibration pollution	Pollution will directly increase proportionally as the increase use of many small-size mode of transportation to transport a large quantity of cargo.
		Smoothing traffic congestion	This will reduce transportation time and operating cost, improve cost time efficiency, and will save energy.
	Sub-urban	Pollution	Sub-urban region would experience less level of pollution compared to urban area.

Cargo transportation system selection has to consider several aspects, such as, type of cargo, time of arrival, and transportation cost. High value cargo, for example, finished goods, usually has to be transported using moderate-to-fast mode of transportation and this requires high transportation cost. Converesly, low value of cargo, e.g., raw material for industry, can be transported using slow mode of transportation.Truck alone and a combination of truck and railway will give moderate time of transportation and transportation cost. Use of truck and airplane will result in the fastest transportation time and the most expensive transportation cost. The lowest transportation cost is provided by using truck and domestic sea transportation, however, this combination will give the slowest transportation time as shown in Table 1.

The previous considerations also have to pay attention on three factors, each one of which would be conflicted. Fast transportation system will reduce transportation time, but will increase

Table 3 Pair test for individual functional items for cargo transportation

	Pair Test Value						Geometric Mean	Weighting
	(1)	(2)	(3)	(4)	(5)	(6)		
1.Payload	1	1/5	1/5	1/7	1/7	1/3	0.255	0.03
2.Transportation Time	5	1	1/3	1/3	1/3	1	0.755	0.10
3.Cost-time Efficiency	5	3	1	1/3	1	3	1.570	0.20
4.Operating Cost	7	3	3	1	1	5	2.608	0.33
5.Initial Investment	7	3	1	1	1	5	2.172	0.27
6.Punctuality	3	1	1/3	1/5	1/5	1	0.585	0.07

Table 4 Definition of pair test values

Value	Situational case	Value	Situational case
1	Almost equally weighted	7	Former is considerably weighted
3	Former is slightly weighted	9	Former is almost completely weighted
5	Former is more weighted	2,4,6,8	Intermediate weighting other than above

Note : Reciprocal values of the above means Replacing the former with the later

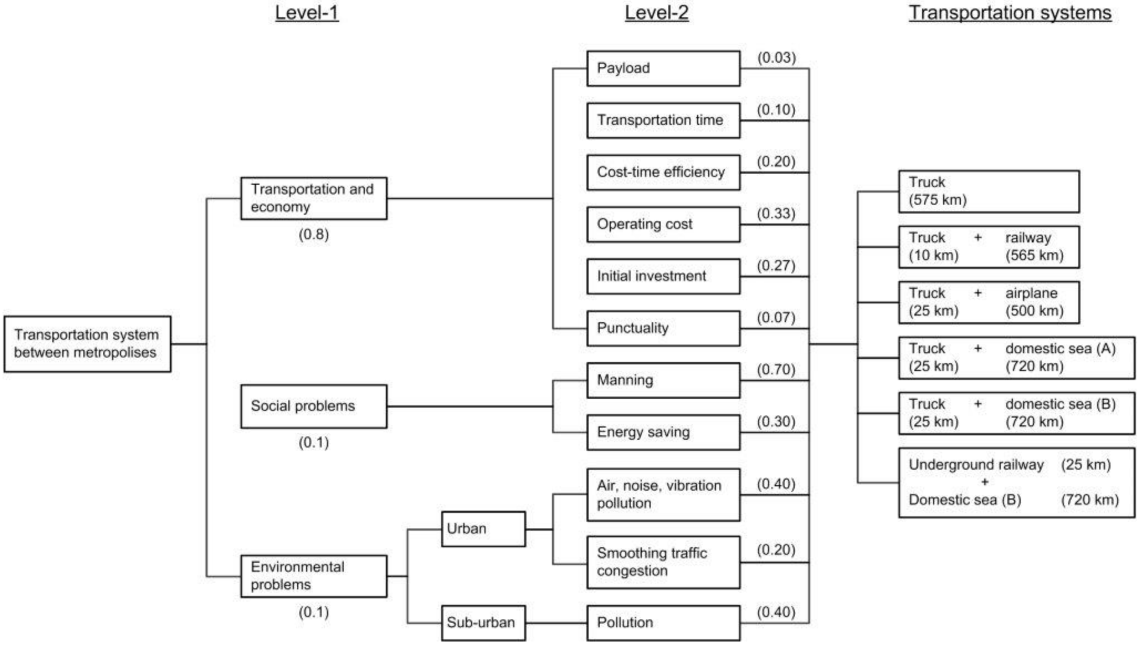

Figure 1 Hierarchy analysis model for evaluation of cargo transportation systems

transportation cost and operating cost. Efficient transportation system will reduce transportation time, operating cost, manning, use of energy, and pollution, but will increase initial investment and punctuality. High efficient transportation system is also as a result of utilising huge payload mode of transportation for transporting large amount of cargo at one time as shown in Table 2.

3.2. Items and Weighting Evaluation

The items under evaluation for appropriate transportation systems are chosen and shown by hierarchy analysis model as illustrated in Figure 1. With this figure, the relationship between objects under evaluation can be understood totally. Since there are many subitems in the model, the pair test method proposed by Shinoda and Fukuchi (1991) is applied. These values are the judgment for the relative advantage and disadvantage. In this example, an estimation of pair test for individual functional items is shown in Table 3 with pair sets referring to Table 4 and is given a positive numerical value for each set. If the item payload for example, is more than the item of payload, the value is estimated as 7 and the opposite pair value is taken as its inverse, 1/7. The consistency index for this case is below 0.1 which is satisfied.

Table 5 Table of goodness gradation for evaluation of transportion system

Transportation Items \ Evaluation Items	Transportation and Economy						Social Problems		Environmental Problems		
	(1). Payload	(2). Transportation time	(3). Cost-time efficiency	(4). Operating cost	(5). Intitial Investment	(6). Punctuality	(7). Manning	(8). Energy Saving	(9). Air, noise, vibration pollution	(10). Smoothing traffic congestion	(11). Pollution
(A). Truck (575km)	V_B	*F*	V_B	*B*	*Ex*	*G*	V_B	V_B	*B*	*B*	V_B
(B).Truck + railway (10km) (565km)	*F*	*F*	*F*	*F*	*B*	*Ex*	*F*	*F*	*G*	*G*	*B*
(C).Truck + airplane (25KM) (500km)	*B*	*Ex*	*G*	V_B	V_B	V_B	*F*	V_B	*B*	*B*	*B*
(D).Truck + domestic sea (A) (25km) (720km)	*Ex*	V_B	*F*	*Ex*	*Ex*	*F*	*Ex*	*Ex*	*B*	*B*	*Ex*
(E).Truck + domestic sea (B) (25km) (720km)	*G*	*F*	*G*	*G*	*G*	*B*	*G*	*G*	*B*	*B*	*G*
(F).Underground railway (25km) + domestic sea (B) (720km)	*G*	*F*	*G*	*G*	*F*	*B*	*G*	*G*	*Ex*	*Ex*	*G*
Weighting — economics	0.03	0.08	0.16	0.26	0.22	0.06	0.06	0.03	0.04	0.02	0.04
Weighting — environment	0.01	0.04	0.08	0.13	0.11	0.03	0.13	0.07	0.16	0.08	0.16

Linguistic variables *Ex : Excellent G : Good F : Fair B : Bad* V_B *: Very Bad*

Table 6 Concordance index of functional items weighted on economics

Evaluation Items	Option A	Option B	Option C	Option D	Option E	Option F	Σcii'
Option A	0	0.164	0.328	0.053	0.084	0.139	0.767
Option B	0.299	0	0.309	0.109	0.086	0.044	0.847
Option C	0.245	0.091	0	0.129	0.038	0.038	0.54
Option D	0.466	0.387	0.625	0	0.176	0.23	1.884
Option E	0.412	0.279	0.449	0.091	0	0.055	1.285
Option F	0.475	0.245	0.457	0.154	0.063	0	1.394
Σci'i	1.897	1.166	2.168	0.535	0.447	0.506	

3.3. Grading Model and Evaluation Indices

An estimation of the grade of each transportation system with respect to the items under evaluation is judged lingustically in Table 5 that designates the impact matrix **P**. When Eq.(3) is adopted as the preference condition, the concordance index $c_{ii'}$ are calculated by Eq.(2) and these indices are shown in Table 6. The concordance dominance indices are calculated by Eq.(4) and the relative advantage of the ith object can be obtained.

3.4. Total Evaluation

System D,F,E,B,A,C are ranked in descending of the concordance indices for the economic judgment to evaluate the preference with truck-domestic sea (type A) is selected as preferred object. On the other hand, according to environment judgment, the preference ranked as F,D,E,B,C,A in descending manner with undergound railway-domestic sea (type B) are selected as preferred object. Finally, total preference object of system F (underground railway-domestic sea type B) has most prominent value based on comparison shown in Table 7.

Table 7 Comparison of concordance dominance index

Evaluation Indices	Preference evaluation indices					
	A	B	C	D	E	F
Economics indices	-1.130	-0.318	-1.628	1.350	0.838	0.888
Preference Ordering	5	4	6	1	3	2
Environment indices	-1.836	0.068	-1.574	1.150	0.458	1.734
Preference Ordering	6	4	5	2	3	1

4. Conclusion

An analytical evaluation and decision making method for the conceptual, qualitative and fuzzy-quantitative elements is proposed through multi-criteria analysis considering the fuzziness, the weighting and the grading under evaluation. As an example, inter-city cargo transportation is analyzed. This evaluation process by the developed method reveals preferenced system for future operation or feed back in design and conceptual evolution of a transportation system.

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