Improving the method of alternatives analysis: principal component analysis

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Abstract: The discussion of alternatives is called as the heart of the environmental impact statement, but yet little progress on alternative considerations has been observed over the years. Despite its importance, such discussion has not generally been encouraged. The multiple criteria analysis (MCA) method could help stakeholders make group decisions. However, a complex comparison table with detailed ratings could be one obstacle to better understanding of alternatives, as limits on our capacity to process information presented in complex formats and can exclude the public from effective participation. In addition commonly used MCA methods fail to address correlations between some criteria, which may result in an incorrect alternative being selected. The principal component analysis (PCA) is one potential solution for dealing with high correlation, and the 10 to 20 correlated variables may be reduced to two or three principle components, allowing for visualization of the merits and demerits of alternatives on a scatter diagram. The PCA is expected to make the distinctions between alternatives easier to understand and encourage the discussion of alternatives. Further research is needed to verify the effectiveness of PCA as a method for alternatives analysis on case studies.

Key Words: alternatives analysis, multiple criteria analysis, principle component analysis, discussion of alternatives

Introduction

The US Council on Environmental Quality (CEQ 1978) calls the discussion of alternatives "the heart of the environmental impact statement." The objective of comparative analysis is to sharply define the merits and demerits of realistic alternatives, thereby providing decision makers and the public with a clear basis for choosing between options (World Bank 1996).

The multiple criteria analysis (MCA) method including an analytic hierarchy process (AHP) and a weighted summation (WS) can help stakeholders make group decisions, even when they hold strongly conflicting preferences. A simple, and understandable MCA methodology is most appropriate (Hajkowicz 2008). Several case studies for comparing alternatives using MCA methods have been reported including large industrial development alternatives using AHP (Sólnes 2003), site selection for limestone quarry expansion using AHP (Dey and Ramcharan 2008), and road corridor selection using WS (Geneletti 2005). Previous reseach showed the decision-making process using MCA but did not examine discussions taking place in meetings. Despite its importance, little progress on alternative considerations has been observed (Geneletti 2014).

This study aimed at a better understanding of the actual discussion of alternatives using a case study as well as improving the analysis method of alternatives to encourage discussion of key issues.

1. Data and methods

1.1 Second Mekong Bridge Project in Cambodia

The Japan International Cooperation Agency (JICA), which assists and supports developing countries as the executing agency of Japan's

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official development assistance (ODA), conducted a feasibility study on the Second Mekong Bridge Project in Cambodia from April 2004 to March 2006 (JICA 2006). Prior to the construction of the bridge, a ferry service was the only available method for crossing the Mekong River at Neak Loeung, about 50 kilometers south-east of Phnom Penh. The project proponent, the Ministry of Public Works and Transport (MPWT), and consultants analyzed four alternatives for improving transportation included bridge construction, no action, ferry improvement, and ferry improvement plus bridge construction. The alternatives analysis technique was an AHP that compared 13 evaluation criteria: stability, safety, sustainability, traffic demand, investment efficiency, regional economy, noise and vibration, traffic accident, other environmental impacts, resettlement, land use, local livelihood, and other social impacts. The option of ferry improvement plus bridge construction was selected after public consultation and an AHP score of .480. The second, third and fourth option were a bridge, ferry improvement, and no action, with AHP scores of .234, .191, and, .095 respectively (Table 1).

Stakeholder meetings were held 15 times in total from May 2004 to January 2006 in Phnom Penh and Neak Loeung (project site) with a total of more than 1,595 participants representing many stakeholder groups. The meetings were prepared and executed in collaboration with JICA. Materials were prepared in the local language, and disseminated near the project site and through a website. MPWT arranged a facilitator and encouraged local people to participate by sending invitation letters.

MPWT and consultants explained four alternatives, 13 evaluation criteria, and AHP including the best option and the rationale. They provided local people with a briefing session on AHP for deeper comprehension of the process. However, local people did not ask any questions about alternatives, the selected option or the reasons for its selection. They appeared to show little interest in alternatives to the project although they actively participated in meetings.

1.2 Principal component analysis

The principal component analysis (PCA) was applied to the scores of four alternatives and 13 evaluation criteria. The PCA is a popular multi-variable analysis that transforms a number of correlated variables into a smaller number of uncorrelated variables, called principal components (PCs). Ten to twenty correlated variables are generally reduced to two or three PCs, and the merits and demerits of alternatives are visually depicted on a scatter diagram, thereby showing a preferable option. It can reduce the number of variables and avoid correlation.

In this study, PCA was performed from the correlation coefficient matrix. Procedures were: normalization of scores, calculation of correlation coefficient matrix, calculation of eigenvalue and eigenvector, calculation of PC loading, and calculation of PC score. The PC score was a weighted summation of normalized scores and eigenvectors regarding all the evaluation criteria. The PC score of four alternatives was shown on a scatter diagram with the first PC on the X axis and the second PC on the Y axis, following which a preferable option was easily selected.

Table 1. Results of AHP for the Second Mekong Bridge Project in Cambodia

Evaluation criteria	Engineering criteria 0.35			Economic criteria 0.47			Environmental criteria 0.18							AHP score
							Natural environment 0.30			Social environment 0.70				
	Stability 0.26	Safety 0.45	Sustainability 0.29	Traffic demand 0.39	Investment efficiency 0.31	Regional economy 0.30	Noise vibration 0.14	Traffic accident 0.63	Other impacts 0.23	Resettlement 0.48	Land use 0.17	Local livelihood 0.25	Other impacts 0.13	
Weight	0.09	0.16	0.10	0.18	0.14	0.14	0.01	0.04	0.01	0.06	0.02	0.03	0.02	
Bridge	0.20	0.32	0.31	0.17	0.14	0.28	0.25	0.26	0.17	0.17	0.33	0.26	0.27	0.234
No action	0.05	0.06	0.06	0.05	0.06	0.05	0.11	0.14	0.35	0.54	0.07	0.10	0.11	0.095
Ferry improve	0.21	0.12	0.14	0.27	0.26	0.17	0.23	0.14	0.35	0.09	0.11	0.22	0.26	0.191
Ferry+bridge	0.55	0.49	0.49	0.51	0.54	0.51	0.42	0.46	0.12	0.20	0.49	0.41	0.36	0.480

Source: Data from JICA 2006.

2. Results

2.1 Result of PCA

The PCA was applied to the scores of four alternatives and 13 evaluation criteria, and transformed into two PCs. The contribution rate (CR) of the first and the second PC was .87 and .08 and the cumulative CR (CCR) of two PCs was .95, which was judged to be a satisfactory level. The first PC was interpreted as an index of development based on the eigenvector, and the second PC was interpreted as index of resettlement (Table 2). The PC scores, which represent the results of overall evaluation, showed the merits and demerits of each alternative on a scatter diagram. The PC scores showed that the option of ferry plus bridge construction had greater merits in respect to development and resettlement compared to other two options of bridge and ferry improvement (Figure 1).

Table 2. Eigenvalue, eigenvector and PC score

	1st PC	2nd PC
Eigenvalue	11.32	1.06
Contribution rate (CR)	0.87	0.08
Cumulative CR (CCR)	0.87	0.95
Eigenvector	**1st PC**	**2nd PC**
Stability	0.29	-0.05
Safety	0.29	0.21
Sustainability	0.29	0.15
Traffic demand	0.27	-0.22
Investment efficiency	0.27	-0.19
Regional economy	0.30	0.07
Noise and vibration	0.30	-0.08
Traffic accident	0.28	0.29
Other impacts	-0.26	-0.34
Resettlement	-0.17	0.71
Land use	0.28	0.24
Local livelihood	0.30	-0.08
Other impacts	0.28	-0.26
PC score	**1st PC**	**2nd PC**
Bridge	0.45	0.38
No action	-4.22	1.00
Ferry improvement	-1.29	-1.73
Ferry+bridge	5.06	0.36

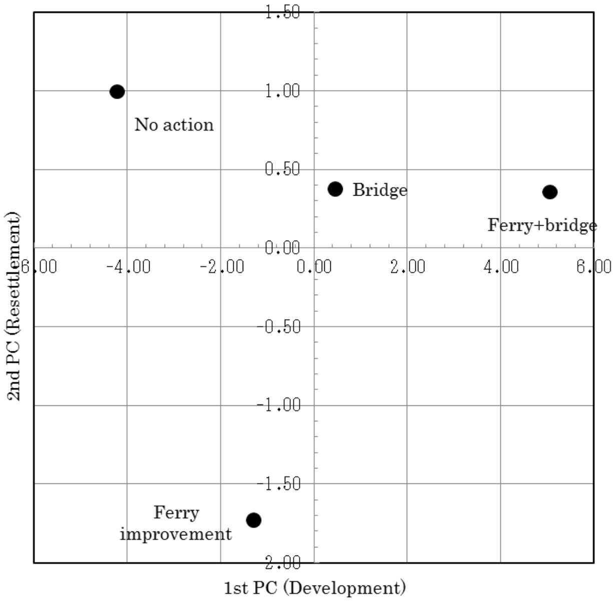

Figure 1. Plot of principle component score

2.2 High correlation between criteria

The correlation between 12 criteria, with the exception of resettlement, was very high. This showed the large contribution rate and absolute value of eigenvector of the first PC. These twelve criteria seemed to be transformed into the first PC. The AHP did not deal with the high correlation so that the AHP score of the option of ferry plus bridge construction was likely to be overestimated. A large difference between the first and second options for the bridge project means that the preferable option was the same even after avoidance of high correlation. However, when there is a small difference between options, the AHP can result in the incorrect selection of an alternative as a result of no addressing the high correlation.

3. Discussion

3.1 Comparison of AHP and PCA

The AHP showed an order of four options with AHP scores calculated by weighted summation of the weight and scores according to pair-wise comparison. However, it was difficult to show the merits and demerits of alternatives in a simple manner and avoid high correlations between criteria. Due to limits on our capacity to process information, it is possible that local people could not clearly understand the complicated comparison table with detailed ratings of the four alternatives and use of 13 evaluation criteria. The pair-wise comparison also might be difficult for them to understand. A possible difficulty of AHP is that more complex algorithms and procedures can present a 'black box' analysis to stakeholders (Hajkowicz 2008). For example, Bojórquez-Tapia et al. (2005) encountered problems of stakeholder acceptance with the AHP to evaluate airport sites in Mexico City as part of an environmental impact assessment (EIA). They found some experts perceived the AHP software as a 'black box'.

The PCA reduced 13 evaluation criteria to only two PCs with CCR of .95 and avoided high correlations. A table of two variables in comparison to 13 variables may be easier to understand. Two PC scores clearly showed the merits and demerits of alternatives and reasons for selecting the preferable option on a scatter diagram. Furthermore, the PCA represents a simple and understandable method to compare alternatives. The scores of PCA are any scale, such as the ratio scale, like square measure or cost, as well as the interval scale, like a scale of one to five, the ordinal scale, like rank score, and a mixture of three kinds of scale because those scores are normalized. It is a method convenient for EIA practitioners as well.

3.2 Setting suitable alternatives and criteria

While it can be challenging to set and verify suitable alternatives and criteria, PCA can facilitate setting as well as provide verification. When PCA is applied to a tentative comparison table of alternatives and criteria with scores, it shows the correlation, the number of PC, and PC scores of options. While looking at a result, alternatives and criteria can be improved by adding and revising the original ones. For example, it is possible to lower the correlation by reducing engineering and economic criteria and adding new environmental and social criteria while looking at Table 1 and Table 2. In addition, it is easy to incorporate new alternatives and criteria requested by stakeholders through the consultation process. As a result it is possible to set more suitable alternatives and criteria as well as to select a more preferable option.

Conclusions

It may be the only time in their lives of local people that they can participate in a public consultation. A simple and understandable alternatives analysis method is the key to facilitating discussion on alternatives. The PCA proposed in this study is a recommendable approach for promoting discussion. The PCA is a very standard statistical method utilizing inexpensive and widely available software. Practical uses of PCA in the field are warranted and will add to our understanding of the approach. Further research is needed to verify the effectiveness of PCA and explore the discussion of alternatives on case studies.

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