A Verification of Alternative Assessment using Principal Component Analysis based on Case Studies of the Japan International Cooperation Agency

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Abstract: Prior research suggested that principal component analysis was effective as an alternative assessment technique in terms of clarity of reasons for selecting the most suitable option, low arbitrariness, verification of analysis results and easiness of technique. This study aimed to apply this analysis to the 15 cases of alternative assessment that the Japan International Cooperation Agency prepared, in order to verify the adequacy of a regular assessment methodology. Some options selected were the same as options selected by regular techniques and other options were different. The reasons would be criteria setting with a high correlation, arbitrary weighting and evaluation, and summation using scores not normalized. The principal component analysis could deal with the above-mentioned problems and be a recommended alternative assessment technique and a preferable number of alternatives and criteria could be six and ten at the minimum. Finally, this paper proposed to use this analysis as a second assessment technique to verify the result of an alternative analysis with summation using normalized scores. Further case studies are required to find an appropriate alternative assessment methodology including public involvement and establishing correct criteria and right alternatives.

Key Words: alternative assessment, principal component analysis, case studies, Japan International Cooperation Agency, public involvement

INTRODUCTION

The analysis of alternatives is at the heart of the environmental impact assessment (EIA) process and methodology, and helps to determine the best method of achieving project objectives while minimizing environmental impacts (UNEP, 2002). A review of alternatives to a proposed action is a basis for EIA good practice. The overall effectiveness of EIA can be improved by applying the process; in particilar, better delivery of substantive environmental and social benefits can be promoted by the systematic analysis of reasonable alternatives (UNEP, 2004). 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. The key challenge to EIA practitioners in comparative assessment is to show distinctions objectively, and as simply as possible. The adoption of unnecessarily complicated techniques can confuse decision-makers and exclude the public from effective participation (World Bank, 1996)[1].

Steinemann, A. (2001) proposed ways to improve alternatives based on a study of EIAs in the US. The four recommendations were: 1) the use of strategic environmental assessment (SEA) at the early stages of planning; 2) explicit criteria for screening alternatives; 3) substantive public involvement in the development of alternatives; and 4) more environmentally sound approaches before proposing action.

Hajkowicz, S.A. (2008) showed that the multiple criteria analysis (MCA) method could help stakeholders make group decisions, even when they held strongly conflicting preferences. Janssen, R. (2001) noted that although computationally

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simple, weighted summation (WS) provided a reasonable solution in many applications and the most important issue was selecting the correct criteria and right options in the first place.

The comparative assessment of alternatives using principle component analysis (PCA) could be confirmed to be a reasonable and easy-to-use way and showed the validity of zero option and mitigation measures by analysis of alternatives (Kamijo, 2012). It was suggested that PCA was effective as an alternative assessment technique in terms of clarity of reasons for selecting the most suitable option, low arbitrariness, verification of analysis results and easiness of technique, compared with an analytic hierarchy process (AHP) and WS (Kamijo, 2013).

This study aimed at finding a suitable way of using alternative assessment methodology through case studies using PCA as well as showing the further effectiveness of PCA as an alternative assessment technique.

1. METHODS

The 15 cases of environmental assessment reports prepared by the Japan International Cooperation Agency were targets of this study, which had more than four alternatives. First the results of alternative analysis using regular techniques and the PCA method were summarized in a table regarding a number of alternatives and criteria, assessment technique and scale of measurement, a selected option by regular technique, the presence of discussion about options, a selected option by PCA, and a number of principal components (PCs) and cumulative contribution ratio (CCR).

The environmental assessment of three (and under) alternatives was excluded from the targets because the qualitative technique would be sufficient and MCA was not needed to apply to select the best option. The discussion about selection of options was confirmed by reading the minutes of meetings about public involvement. When it was confirmed, "Options discussed" was noted. When the minutes of meetings were not available or discussion about options was not recorded, it was judged "No options discussed", even if they were actually discussed.

The PCA was applied to the alternative comparison. In the case of a qualitative technique, an order of alternatives was interpreted in every criterion and the ordinal scale was used for the PCA. The number of PCs was indicated to show a high and low correlation between criteria. One PC means a very high correlation and two mean a relatively high correlation.

The AHP is a tool for dealing with complex decisions and considers a set of evaluation criteria and a set of alternative options among which the best decision is to be made. The AHP generates a weight for each evaluation criterion according to pairwise comparisons of criteria. The total score for a given option is a weighted sum of the score it obtained with respect to all the criteria. The drawback to the AHP is pointed out that the work of pairwise comparisons takes an enormous amount of time.

The WS is a simple MCA. All scores are normalized and the score of each alternative is calculated by multiplying the normalized scores and their weights and then summing the weighted scores for all the criteria. The best alternative is the one that yields the maximum total score. The arbitrary nature of weighting between all the criteria is pointed out to be a drawback of this technique.

The PCA is a procedure that transforms a number of correlated variables into a smaller number of uncorrelated variables (PCs). In this study, PCA was performed from the correlation coefficient matrix. The procedures were: normalization of data, calculation of correlation coefficient matrix, calculation of eigenvalue and eigenvector, calculation of PC loading, and calculation of PC score, which is a weighted sum of normalized data and eigenvector regarding all the criteria. The 10 to 20 correlated variables are generally reduced to two or three PCs, which visualize the merits and demerits of alternatives in scatter diagrams, and show preferable options by interpreting PCs and PC scores.

2. RESULTS

2.1 Overview of alternative analysis

A brief outline of the alternative analysis is shown in Table 1. The EIA level was 11 and the initial environmental examination (IEE) level was four. The average and the median of alternatives and criteria were: 6.1 and 5, and 9.2 and 6, respectively.

The assessment techniques were WS, AHP, summation, score, qualitative, and number and qualitative. Scales of measurement were ordinal, interval and ratio. Nine projects discussed options and the other six projects didn't.

The result using PCA was the same in four projects, different in six projects, modified in five projects (another option added). The number of PCs was one in two projects, two in nine projects and three in four projects. The CCR was more than 0.83, which could be a satisfactory level.

The four projects were excluded from the list of project due to difficulty of evaluation interpretation. Their assessment technique was qualitative and their average and median of alternatives and criteria were: 8.3 and 6, and 9.5 and 6.5. An order of alternatives couldn't be interpreted in accordance with increase in the number of alternatives and/or criteria. They didn't discuss options.

Table 1 Result of alternative analysis

No.	Project and year	EIA or IEE	Alternative and criteria	Assessment technique and scale	Selected option	Public involvement	Option by PCA	PCs	CCR	Result
1	Padma bridge in Bangladesh, 2005	EIA	4 and 8	Score and interval	S1 or S3	Options discussed	S1 or S3	1	0.93	Same
2	Second Mekong bridge in Cambodia, 2006	EIA	4 and 13	AHP and ordinal	Ferry and bridge	Options discussed	Ferry and bridge	2	0.95	Same
3	CALA east-west national road in Philippines, 2006	EIA	4 and 8	Summation and interval	A3	Options discussed	A3	2	0.95	Same
4	Power generation in Sri Lanka, 2006	EIA	5 and 4	Qualitative	A2	No options discussed	A1, A3 or A4	1	0.99	Different
5	Airport improvement in Guatemala, 2006	EIA	19 and 6	WS and interval	A12 or A13	Options discussed	A12 or A13	3	0.83	Same
6	Surabaya metropolitan ports in Indonesia, 2007	EIA	6 and 6	Score and interval	A1	No options discussed	A2	2	0.92	Different
7	Sewerage system in Albania, 2007	IEE	4 and 5	Score and interval	A2	Options discussed	A1 or A2	2	0.94	Option added
8	Tomasina port development in Madagascar, 2009	EIA	5 and 4	Qualitative	E	Options discussed	A or E	2	0.99	Option added
9	Urban development for Lusaka city in Zambia, 2009	IEE	6 and 10	Score and interval	Central	Options discussed	Central, South or NE	3	0.86	Option added
10	Urban development in Great Cairo Region in Egypt, 2009	IEE	8 and 5	Score and interval	A5	No options discussed	A2 or A4	2	0.85	Different
11	Hydropower development in Uganda, 2011	EIA	7 and 32	WS and interval	Ayago	Options discussed	Isimba	3	0.89	Different
12	Mykolaiv bridge construction in Ukraine, 2011	EIA	4 and 7	Score and interval	A2	No options discussed	A4	2	0.96	Different
13	Pampanga river basin management in Philippines, 2011	IEE	4 and 5	Number and Qualitative, and ratio	A1	No options discussed	A3 or A4	2	0.99	Different
14	Multiple-airport development in Indonesia, 2012	EIA	7 and 19	WS and interval	E4	Options discussed	E4 or W2	3	0.88	Option added
15	Reconstruction of Somalia drive in Liberia, 2013	EIA	5 and 6	Summation and interval	PP	No options discussed	PP or A3	2	0.91	Option added

2.2 Assessment technique and public involvement

When the number of alternatives and/or criteria increased, the quantitative techniques such as WS and AHP were used. When the number was small, summation, score and qualitative techniques were used (Fig. 1). When the number of criteria was large, options were discussed, and when it was small, they weren't discussed (Fig. 2).

When the number of criteria was large, the quantitative techniques with overall evaluation such as WS and AHP, as well as discussion of options were needed to select a preferable one. When the number of criteria was small, it is considered that the qualitative or simple quantitative technique was sufficient to select it and discussion of options was unnecessary.

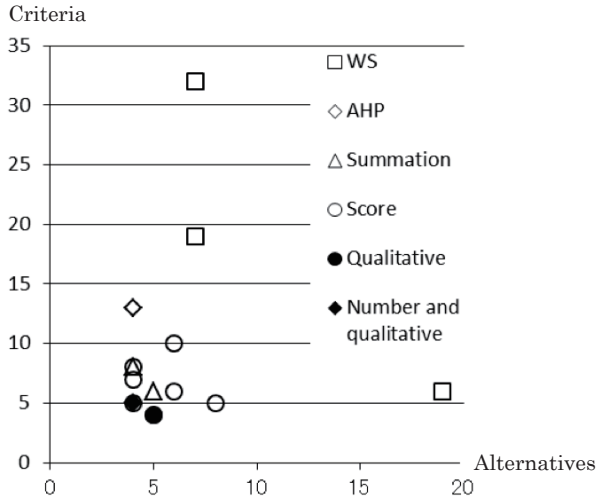

Fig. 1 Assessment technique

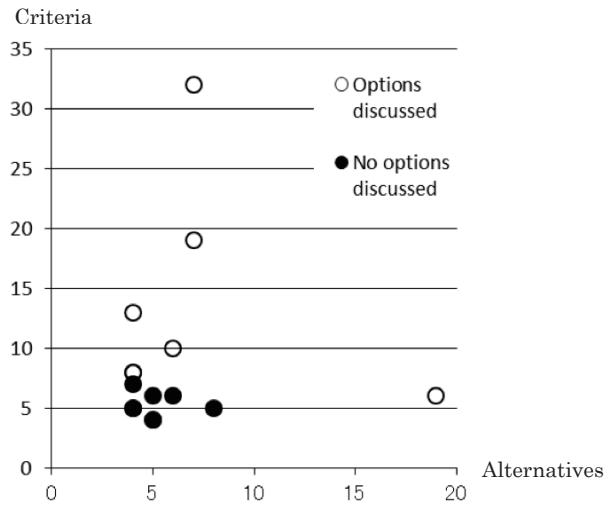

Fig. 2 Discussion of options

2.3 Result of PCA

The selected option by PCA was the same in four cases. Other options were added in five cases. The selected option was different in six cases. One PC showed in two cases, two PCs showed in nine cases and three PCs showed in four cases. The main reason of same or different result was a large or small difference between alternatives. The selected options by PCA were same when the difference was large and they were different when it was small. The reasons of different options were high correlation between criteria, arbitrary overall evaluation and weight setting, and summation using scores not normalized. The regular techniques didn't address these problems so that the selected option could not be a right one.

The relationship between techniques and the selected options by PCA was not observed. On the other hand, one and two PC cases were observed when the number of alternatives and/or criteria was small, and three PC cases were observed when the number increased (Fig. 3). One PC means very high correlation between criteria, resulting in an overlapping of meanings. The correlations between some criteria were nearly one. The two PCs mean there is still a high correlation between some criteria. The three PCs mean the correlation is not high compared with cases of one and two PCs. The correlation was lowered as the number of alternatives and/or criteria increased.

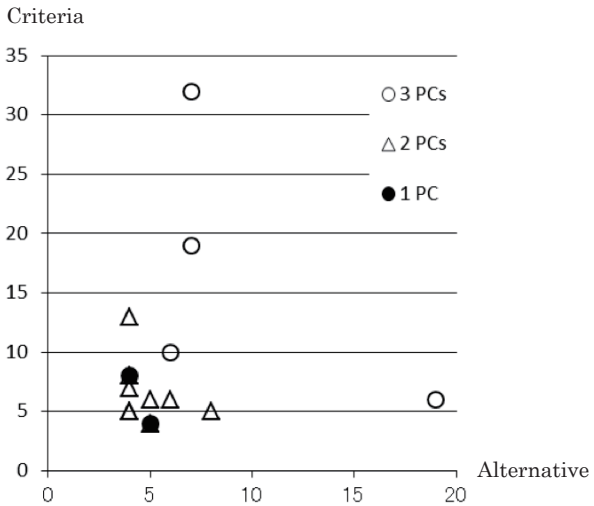

Fig. 3 Number of principle components

A high correlation could cause the wrong selection of an alternative and the PCA is one solution to deal with the high correlation. High correlated criteria are transformed into PCs. The three PCs cases (No. 5, 9, 11 and 14) covered a wide range of alternatives and criteria, and were preferable. But 13 of 19 site alternatives of the case 5 were unsuitable due to reasons such as geographical features and accessibility. The alternatives needed to be set appropriately without excessively increasing the number. The result using PCA of three projects (No. 9, 11 and 14) was different or modified because the regular techniques didn't address a high correlation, arbitrariness and scores not normalized. The PCA dealt with them, and showed merits and demerits of alternatives and the clear reason for choosing between them.

No. 9 (Urban development for Lusaka city in Zambia) showed the smallest number of alternatives and criteria in the cases of three PCs and was judged to be a good example to see the threshold of alternatives and criteria to be transformed into three PCs as well as the practical side of PCA process. The numbers of alternatives and criteria were six and ten and the assessment technique was score, and options were discussed. Besides the selected option, other two options were added after the PCA process.

2.4 Urban development for Lusaka city

The overall urban development potential was evaluated according to four grades. The six site alternatives were Central, North, North East (NE), South, Central East (CE) and Central West (CW). The criteria had two levels and three criteria of the first level were accessibility, land availability and development constraints. The ten sub-criteria were central business district (CBD), international economic corridors (IEC), international airport (IA), national railway network (NRN), steep slope (SS), land availability (LA), preparedness by plan and project (PPP), nature reserve potential (NRP), agriculture potential (AP) and hazard prone area (HPA).

The score was not normalized. The Central was selected as the best option with four points of evaluation (E), but the overall evaluation process was not mentioned and the reason for the choice of Central was not clear. The summation (S) and the WS were added for this time review (Table 2).

The difference of four alternatives (Central, North, NE and South) was small. The normalized score was added for review (Table 3). The difference of three alternatives (Central, NE and South) was small and the order was changed after the WS. The NE was a first option and Central was a second one. The Central and the NE could be almost same.

The PCA was applied to the scores of six alternatives and ten sub-criteria, which were transformed into three PCs. The contribution rate (CR) of the first, the second and the third PC was 0.39, 0.30 and 0.18. The CCR of three PCs was 0.86, which was judged to be a satisfactory level. The first PC was interpreted as an index of business and agriculture based on the eigenvector, and the second and third PCs were interpreted as indexes of railway and land preparation, and topography (Table 4). The PC scores, which meant results of overall evaluation, showed the merits and demerits of each alternative in scatter diagrams. A result of PCA showed that in addition to the Central, the South and the NE would also be options to be selected (Fig. 4).

Table 2 Alternative analysis using score technique

Criteria and weight	Accessibility 3.0				Land availability 5.0			Development constraints 2.0			E	S	WS
	CBD	IEC	IA	NRN	SS	LA	PPP	NRP	AP	HPA			
Central	4	4	3	4	3	1	4	1	1	3	4	28	95
North	3	4	3	4	2	3	2	2	3	1	3	27	89
NE	3	3	4	2	3	3	3	2	3	1	3	27	93
South	3	4	1	4	3	3	2	2	4	1	3	27	90
CE	2	2	3	1	2	2	4	4	3	2	2	25	82
CW	2	1	2	1	3	3	2	2	3	3	2	22	74
Average	2.8	3.0	2.7	2.7	2.7	2.5	2.8	2.2	2.8	1.8			
Standard deviation	0.7	1.2	0.9	1.4	0.5	0.8	0.9	0.9	0.9	0.9			

Table 3 Normalization of score

Normalization	CBD	IEC	IA	NRN	SS	LA	PPP	NRP	AP	HPA	S	WS
Central	1.7	0.9	0.4	1.0	0.7	-2.0	1.3	-1.3	-2.0	1.3	1.9	7.8
North	0.2	0.9	0.4	1.0	-1.4	0.7	-0.9	-0.2	0.2	-0.9	-0.2	-3.0
NE	0.2	0.0	1.4	-0.5	0.7	0.7	0.2	-0.2	0.2	-0.9	1.8	9.4
South	0.2	0.9	-1.8	1.0	0.7	0.7	-0.9	-0.2	1.3	-0.9	0.9	3.5
CE	-1.2	-0.9	0.4	-1.2	-1.4	-0.7	1.3	2.0	0.2	0.2	-1.3	-7.8
CW	-1.2	-1.7	-0.7	-1.2	0.7	0.7	-0.9	-0.2	0.2	1.3	-3.1	-9.8

Table 4 Eigenvalue, eigenvector and PC score

	1st PC	2nd PC	3rd PC
Eigenvalue	3.86	3.02	1.77
CR	0.39	0.30	0.18
CCR	0.39	0.69	0.86

Eigenvector	1st PC	2nd PC	3rd PC
CBD	0.48	0.17	-0.07
IEC	0.34	0.34	-0.32
IA	0.11	-0.26	-0.38
NRN	0.35	0.38	-0.14
SS	0.16	0.11	0.58
LA	-0.36	0.35	0.05
PPP	0.22	-0.45	-0.24
NRP	-0.37	-0.24	-0.35
AP	-0.41	0.31	-0.05
HPA	0.13	-0.39	0.46

PC score	1st PC	2nd PC	3rd PC
Central	4.07	-1.20	0.49
North	0.00	1.56	-1.50
NE	-0.10	0.18	-0.46
South	-0.35	2.71	0.48
CE	-1.78	-2.51	-1.40
CW	-1.84	-0.75	2.39

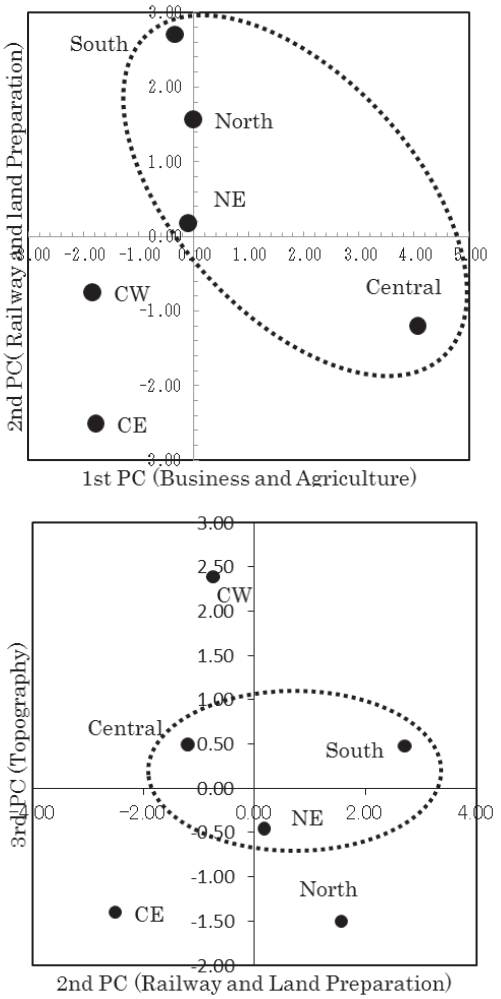

Fig. 4 Principle component score

The Central had a good first PC score, the South had a good second PC score and the NE had average scores of three PCs. The PCA could provide a good basis for discussion. The preferable option should be selected after discussion of the merits and demerits of alternatives. The score, summation and WS couldn't show them and the arbitrary overall evaluation and weight setting, and summation using scores not normalized could cause the wrong selection of an alternative.

3. DISCUSSION

3.1 Number of alternatives and criteria

How many alternatives and criteria are preferable? A number of variables transformed into three PCs could be one answer, to cover a wide range of impacts. In this study, the number of alternatives and criteria were six and ten at the minimum, even if the number of samples was small. It had a tendency to show the correlation between criteria entirely high as a whole. Even the cases of three PCs included a high correlation. Based on the high correlation between criteria, setting alternatives and criteria so as to transform into three PCs could assess three elements of sustainable development such as environment, economy and society. Three PCs showed the merits and demerits of alternatives objectively and simply (Fig. 4). Suitable setting of alternatives and criteria makes the decision process more transparent and enhances the credibility of a selected option for stakeholders.

3.2 Discussion of options

In the case of a qualitative technique or a small number of criteria, no options tended to be discussed. It could be difficult for stakeholders to understand alternative analysis with a qualitative technique due to excess of judgment capacity, especially in the case of a large number of alternatives and/or criteria. When options were discussed with the number of six alternatives and ten criteria, a preferable setting at the minimum in this study, an assessment technique should be a quantitative technique for stakeholders to

understand a difference of options with comparative ease. The quantitative technique was better than the qualitative one for option discussion.

Providing opportunities for stakeholders to express their views during alternative analysis can be beneficial in two ways: to obtain information and to build consensus. The key challenge is to show distinctions objectively and as simply as possible. The adoption of unnecessarily complicated techniques can confuse decision-makers and exclude the public from effective participation (World Bank, 1996)[1]. The PCA could be an answer to this challenge.

3.3 Selection of a preferable option by PCA

The objective of alternative 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)[1].

In the case of Urban development for Lusaka city, the PCA showed that the alternatives of Central, South and NE had their merits (Fig. 4). But the score, summation and WS could not show them sharply and simply (Table 2 and Table 3). Similarly, AHP shows an order of alternatives with scores and their process but it is difficult to show merits and demerits of alternatives simply along with an increase of criteria.

The result of PCA showed the merits and demerits of each alternative with the corresponding reason. It is anticipated for stakeholders to understand the alternative assessment process, discuss merits and demerits of alternatives and select a preferable option by viewing PC scores, which is easier to do than the convenient quantitative techniques.

3.4 Preferable assessment technique

Six techniques including PCA are compared with respect to five criteria, which are: 1) option discussion, 2) definition of merits and demerits of alternatives, 3) arbitrariness of an evaluator, 4) countermeasures for a high correlation between criteria, and 5) easiness of use (Table 5).

Table 5 Comparison of techniques

Criteria	WS	AHP	Summation	Score	Qualitative	PCA
Option discussion	○	○	○	○	×	○
Merits and demerits	×	×	×	×	×	○
Arbitrariness	×	×	○	×	×	○
High correlation	×	×	×	×	×	○
Easiness of use	○	×	○	○	○	○

Note: ○: Good, ×: No Good

It is difficult for stakeholders to understand the differences between alternatives and overall evaluation using a qualitative technique along with an increase of number of alternatives and/or criteria. As a result options couldn't be discussed. It is unsuited for option discussion compared with other techniques. Five techniques, except PCA, couldn't show the merits and demerits of alternatives simply and objectively although they showed a selected option or ranking of options.

The score and qualitative techniques have no overall evaluation process and an evaluator decides an overall result in total consideration of alternatives and criteria impact. The weighting of WS and AHP also reflects the arbitrariness of evaluators. It is quite difficult for stakeholders to reach a consensus about weighting. The WS was affected by subjectivity, bias and error of assumption of evaluators (Canter, 1996). The above four techniques have arbitrariness. The decision is likely to be different by an evaluator. On the other hand, the summation and PCA have an overall evaluation process and don't set weighting, therefore their arbitrariness could decrease compared with the other four techniques.

A high correlation between criteria could select a wrong option and it is necessary to address it. The PCA is a solution to deal with it and has a process to calculate a correlation coefficient matrix, to check it and to improve setting alternatives and criteria. But the other five techniques have no process to see correlation between criteria. The AHP uses the work of pairwise comparisons of criteria, and takes an enormous amount of time.

Besides it is not easy to teach AHP to stakeholders and to get them to understand it. The use of the other five, including PCA, is relatively easy.

The scores of PCA are normalized and the scores are enough for the ratio scale, like square measure or total cost, as well as the interval scale, like a scale of 1 to 5, and the ordinal scale, like rank order (1st, 2nd, 3rd, etc.). It is also possible to cope with a mixture of three kinds of scales. The PCA is a popular multivariate analysis and the program is low-priced. The weight setting is not necessary and it can shorten analysis time in comparison with WS and AHP.

The summation using normalized scores could be better among five regular techniques by reason of low arbitrariness, and it showed the same three options to be selected (the Central, the South and the NE) as PCA in the case of urban development for Lusaka city (Table 3).

CONCLUSIONS

As a result of this study, it can be concluded that the PCA is a recommendable alternative assessment technique compared with five regular techniques, and preferable numbers of alternatives and criteria were six and ten at the minimum. But it has no results in practice at the moment. A realistic approach is to use the PCA as a second assessment technique to verify the results of alternative analysis with the summation using normalized scores, which is a better technique among regular ones.

The cases of more than ten criteria were limited in this study. Further case studies are required to find an appropriate alternative assessment methodology, including the effect of public involvement and setting correct criteria and right alternatives.

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NOTES

[1)] World Bank (06/05/2014 updated) Update No. 17 - Analysis of Alternatives in Environmental Assessment page. <http://siteresources.worldbank.org/INTSAFEPOL/1142947-1116495579739/20507390/Update17AnalysisOfAlternativesInEADecember1996.pdf>, 06/05/2014 referred.

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