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Using Analytic Hierarchy/Network Process (AHP/ANP) in Developing Countries: Shortcomings and Suggestions

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Using Analytic Hierarchy/Network Process (AHP/ANP) in Developing Countries: Shortcomings and Suggestions

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This article intends to shed light on the problems arising in the benefit–cost (BC) analyses through the analytic hierarchy/network process (AHP/ANP) in developing countries when analysts may encounter lack of data, deficient databases, defective information, and, more important, the lack of groups of specialists with considerable expertise. In this article, through a comparison between the AHP/ANP and conventional engineering economy techniques, the major concerns that may be encountered are theoretically addressed. Then, through a real case project appraisal, the specific developing country-related issues that can distort the AHP/ANP results from the BC analysis are demonstrated.

Introduction

Analysis and evaluation of decisions include the process of recognizing, quantifying, and comparing the benefits and costs of decision criteria. Each decision requires an evaluation for determining whether or not it represents an efficient use of resources (e.g., time, money, energy, etc.). For decision problems containing tangible and intangible evaluation criteria, multicriteria decision making (MCDM) methods are employed when the intangible decision criteria are difficult to quantify and monetize. From among the MCDM techniques, the analytic hierarchy process (AHP; Saaty 1980) and its extended version, the analytic network process (ANP; Saaty 2001), have been used by many scientists, researchers, and practitioners.

A quick examination of the literature attests to the fact that few AHP/ANP applications have experienced a postanalysis evaluation after policy makers had followed the AHP/ANP results. Though several adopted approaches in AHP and ANP may improve the quality of analysis such as deploying a more fitting bipolar scale for pairwise comparisons (Beynon 2002), graphical elicitation and presentation of preferences (Millet and Schoner 2005), incorporating negative values in decision making (Millet and Schoner 2005), employing the proper priority vector calculation technique (Ishizaka and Lusti 2006; Saaty 2003; Saaty and Hu, 1998; Srdjevic 2005), and using novel methods for synthesizing the benefits, opportunities, costs, and risk preferences (Wedley et al. 2001; Wijnmalen 2007), these approaches do not guarantee the validity of the results. Furthermore, the AHP/ANP

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validated examples appearing in case studies that were performed in developed countries are mainly situations in which the actual preferences were known beforehand. These case studies were mainly performed by Thomas L. Saaty to indicate how well the AHP and ANP cope with real-world complex situations. As an example, we can refer to the study trying to determine which drink is most often consumed in the United States or which food contains more protein (Saaty and Vargas 2000, p. 7); the study for estimating the relative market share of Walmart, Kmart, and Target (Saaty 2005, p. 397, table 9.22; Whitaker 2007); the study deriving the market share in the U.S. hamburger industry (Saaty 1999); or the one investigating the actual and predicted relative market share of airlines or cell phone providers (Saaty 2004b, tables 10 and 11).

Engineering economy techniques, evaluation theories, and scenario analyses have emerged mainly from the literature published in developed countries and usually require available data on monetary costs and benefits. On the other hand, developing countries suffer from a huge lack of data, deficient databases, and defective information. As a result, many decision problems in developing countries currently involve intangibles or difficult-to-monetize costs and benefits. Therefore, an analyst inevitably needs to make a trade-off between doing the analysis accurately and doing it quickly. That is to say, a decision making problem with a complete set of monetizable criteria may require several years of studies to monetize the decision criteria. It may be one of the reasons for the ever increasing application of the benefit–cost–AH/NP (BC-AH/NP) methods in engineering economy analyses in developing countries such as Iran.

As an example of the approach taken in developed countries, we can refer to Transit Cooperative Research Program (TCRP) report 78 (National Research Council 2002) used in the United States for analyzing the benefits and costs of public transportation services and presenting the results of these analyses to decision makers, the media, and the public. This report also covers the monetization of the transit system's secondary impacts; for example, impacts on air quality and emissions, noise, water pollution (due to motor vehicles), and accidents. Moreover, it provides the marginal cost of these items in urbanized areas (National Research Council 2002, ch. 4). In contrast, in Iran and during the feasibility study of the Tehran Monorail system (Khademi 2005), the BC-AHP was employed to quantify the aforementioned criteria, because there was a limitation in the number of domestic studies conducted on quantifying the transit system secondary impacts. Therefore, more intangible items were entered into that study, which would not usually be the case in a similar study performed in a developed country.

In addition to this problem, generally speaking, lack of specialists with considerable expertise in the field of decision problems is another issue of debate on applying AHP and ANP in developing countries. In particular, biased answers may be incurred by inexpert repliers attending the AHP session. For example, during the comprehensive study of the Gilan rural road network (see Khademi and Sheikholeslami 2010), a lack of specialists who were qualified to participate in the AHP was noticeable, persuading the researchers to leverage two other team decision-making techniques, conference and the Delphi survey (Kelly 1994), in addition to the AHP. The conference mostly addressed the administrative aspect of this project; in fact, it provided the endorsement and satisfaction of the authorities and specialists involved in the decision-making process, and the Delphi survey and, subsequently, the AHP, somehow insured the methodological credibility of the project and the production of valid and acceptable results.

In accordance with that mentioned above, analysts in developing countries may avail themselves of the opportunity to evaluate their strategies through a larger number of intangibles and difficult-to-monetize criteria than for the same projects performed in developed countries. However, the lack of qualified specialists in many scientific spheres, resulting in inexpert views, cannot be ignored.

This article provides a reference example in which the wrong results are obtained due to biased views of poorly qualified specialists. In the Theoretical Framework section, a mathematical expression is developed in order to identify the part of the theoretical basis of the BC-AHP that is affected by inexpert judgment. Here, a new benchmark is set in order to pave the way for examining the role of the AHP in fully judgmental BC decision analysis. This benchmark requires the following two properties:

1. Using the same analytical structure as AHP.
2. Giving results similar to those obtained in the traditional BC analysis.

This benchmark uses monetized values and performs the analysis exactly the same as the traditional benefit–cost ratio (BCR) analysis does. In this article, it is named the AHP with fictitious monetary values (AHP^f). It is not a new idea; in fact, it has been mentioned several times in some studies where the AHP has been used for BC analyses or benefit, opportunity, cost, and risk (BOCR) analyses (e.g., see Saaty 2004a, 2005; Saaty and Ozdemir 2003; Wijnmalen 2007). However, the AHP^f has one different feature; it is inherently a BCR analysis within an AHP framework, meaning that it cannot perform an analysis with non-monetizable criteria.

The Reference Example section provides an example for comparing the results of the AHP^f and AHP. This section shows how AHP is influenced by ambiguities in quantifying the problem from different levels of respondents' expertise. It also reveals when the ANP should be used instead of the AHP.

In conclusion, this article intends to shed light on the conditions under which the application of AHP in developing countries may distort the results. In the Discussion and Suggestions for Practitioners section some consequent guidance for practitioners who want to deploy AHP and ANP in a developing or underdeveloped country is provided.

AHP in Developing Countries

Based on the information registered at the Iranian Research Institute for Information Science and Technology since 1994, 90 master of science and Ph.D. theses on the subject of the AHP and ANP methods have been defended, of which nearly 27% were defended in 2010 (IRANDOC 2013) (see Figure 1a). However, the number of research projects as well as the number of real case projects in Iranian organizations are much higher than the number coming from universities.

In line with the growing demand for using AHP and ANP in Iran, three books have been published specifically in Persian (Ghodsipour 2009; Mohammadi-lord 2009; Nikmardan 2008) which focus only on the AHP and ANP methods and their theoretical framework and software.

As an illustration of the growing interest in AHP/ANP in developing countries, the number of scientific papers from Iran and Turkey published in scholarly journals shows a large increase in the past several years. Using Thomson Reuters's Academic Citation Indexing Service, ISI Web of Knowledge, one can observe that the number of scholarly journal articles on the subjects of AHP and ANP has grown considerably since 1998, as shown in Figure 1b (ISI Web of Knowledge 2010). This reveals an increasing tendency to use AHP and ANP. In addition, engineering sciences gain the highest share of the publications in scholarly journals, with 43% of the whole in Iran and 48% in Turkey.

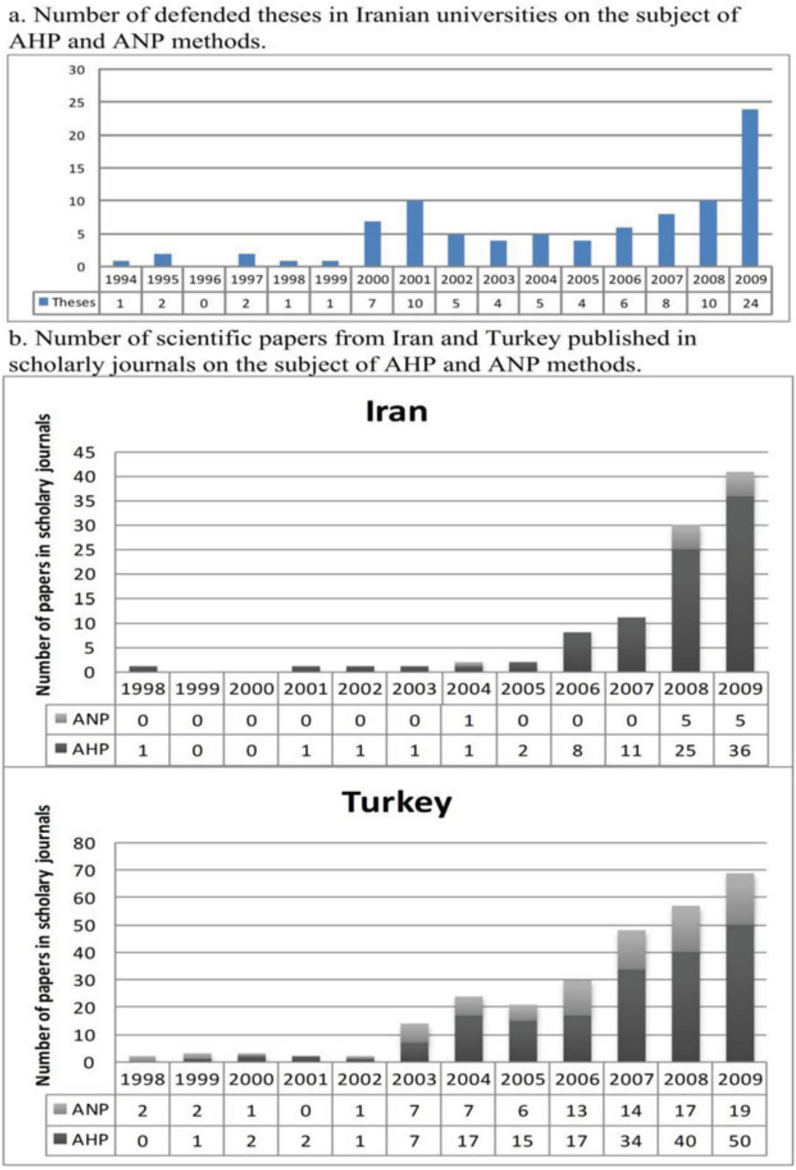

Figure 1. Scholarly publications on AHP and ANP in two developing countries.

Although one of the main reasons for using AHP and ANP in developing countries is the widespread attention given to these methods, to the best of the authors' knowledge, other reasons exist such as the following:

1. AHP and ANP could perform a study with fully intangible (i.e., nonmonetized) items, which conforms more to the situation existing in developing countries.
2. AHP and ANP embody a sound and mature theoretical basis taken from mathematics and psychology, but according to Khademi and Sheikholeslami (2010), this theoretical and mathematical foundation may wrongly induce decision-making

administrators to approve the results, notwithstanding the possibility that some unskilled analyst or participant (in the decision-making session) may provide some erroneous judgments.

3. The results and the overall weights of the AHP and ANP are difficult and expensive to validate in a post audit of the project; therefore, it may be difficult to check the validity of the final decision.

Theoretical Framework

In this section, the theoretical framework of a classic BC analysis is presented. The frameworks of AHP^f, classic AHP, as well as ANP are outlined, and the similarity of these methods to engineering economy techniques is investigated. The weak points of these methods in comparison with the BC analysis frameworks are discussed, paving the way for proving the required guidelines on the use of AHP and ANP in developing and underdeveloped countries.

Benefit–Cost Analysis

There are a number of variants of approaches taken from economics that are used for appraising or evaluating investment projects. Among these decision rules, the most well known are the net present value (NPV) and BCR analyses (Campbell and Brown 2003). The NPV or BCR analyses mainly deal with projects having positive criteria such as benefits (B_i) and negative criteria such as costs (C_i) in common currency.

Table 1 summarizes different items of a classic BC analysis. In this table, b_{ij} denotes the benefit amount (positive) of criterion j for alternative i, c_{ij} is the cost (negative) of criterion j with respect to alternative i, and n_b and n_c stand for the number of benefit and cost criteria, respectively. It should be mentioned that b_{ij}s and c_{ij}s are the present benefit and cost values after shifting the time-based values on the cash flow diagram (Mishra 2009) to the beginning period ($t = 0$) using inflation and interest rates. Also, the c_{ij}s in Table 1 have positive values yet in the negative cluster of costs.

Table 2 demonstrates the BCR of m alternatives prepared for the analysis by dividing the present value of benefits (PVBs) by the present value of costs (PVCs). For the PVB^n, PVC^n, and NPV^n, the superscript n denotes the normalized values; however, the normalized NPV does not sum to unity. If BCR $\succ$ 1, the net benefit will outweigh its net cost. If only

Table 1
Benefit and cost criteria

	Criteria							
Alternatives	B_1,	B_2,	...	B_{n_b}	C_1,	C_2,	...	C_{n_c}
1	b_{11}	b_{12}	...	b_{1n_b}	c_{11}	c_{12}	...	c_{1n_c}
2	b_{21}	b_{22}	...	b_{2n_b}	c_{21}	c_{22}	...	c_{2n_c}
...	...	...	...	...	...	...	...	...
m	b_{m1}	b_{m2}	...	b_{mn_b}	c_{m1}	c_{m2}	...	c_{mn_c}

Table 2
PVB, PVC, NPV, and BCR analyses

Alternatives	PVB	PVB^n	PVC	PVC^n	BCR	NPV	NPV^n
1	$\sum_{j=1}^{n_b} b_{1j}$	$\frac{\sum_{j=1}^{n_b} b_{1j}}{S_b}$	$\sum_{j=1}^{n_c} c_{1j}$	$\frac{\sum_{j=1}^{n_c} c_{1j}}{S_c}$	$\frac{\sum_{j=1}^{n_b} b_{1j}}{\sum_{j=1}^{n_c} c_{1j}}$	$\sum_{j=1}^{n_b} b_{1j} - \sum_{j=1}^{n_c} c_{1j}$	$\frac{\left(\sum_{j=1}^{n_b} b_{1j} - \sum_{j=1}^{n_c} c_{1j}\right)}{S}$
2	$\sum_{j=1}^{n_b} b_{2j}$	$\frac{\sum_{j=1}^{n_b} b_{2j}}{S_b}$	$\sum_{j=1}^{n_c} c_{2j}$	$\frac{\sum_{j=1}^{n_c} c_{2j}}{S_c}$	$\frac{\sum_{j=1}^{n_b} b_{2j}}{\sum_{j=1}^{n_c} c_{2j}}$	$\sum_{j=1}^{n_b} b_{2j} - \sum_{j=1}^{n_c} c_{2j}$	$\frac{\left(\sum_{j=1}^{n_b} b_{2j} - \sum_{j=1}^{n_c} c_{2j}\right)}{S}$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
M	$\sum_{j=1}^{n_b} b_{mj}$	$\frac{\sum_{j=1}^{n_b} b_{mj}}{S_b}$	$\sum_{j=1}^{n_c} c_{mj}$	$\frac{\sum_{j=1}^{n_c} c_{mj}}{S_c}$	$\frac{\sum_{j=1}^{n_b} b_{mj}}{\sum_{j=1}^{n_c} c_{mj}}$	$\sum_{j=1}^{n_b} b_{mj} - \sum_{j=1}^{n_c} c_{mj}$	$\frac{\left(\sum_{j=1}^{n_b} b_{mj} - \sum_{j=1}^{n_c} c_{mj}\right)}{S}$
$\sum ABS(\cdot)$	$S_b = \sum_{i=1}^{m} \sum_{j=1}^{n_b} b_{ij}$	1	$S_c = \sum_{i=1}^{m} \sum_{j=1}^{n_c} c_{ij}$	1	—	$S = \sum_{i=1}^{m} ABS\left(\sum_{j=1}^{n_b} b_{ij} - \sum_{j=1}^{n_c} c_{ij}\right)$	1

one project from among a number of projects is to be preferred, then the one with the highest ratio among the decision set would be the one to be selected.

In the next subsection, the AHP^f will be introduced with its characteristics that reveal an absolute conformity with the results derived by the BCR and NPV analyses.

Benefit–Cost Analysis within the AHP Structure Using Fictitious Monetary Values (i.e., AHP^f)

There are only a few studies dealing with the BCR for MCDM problems, and within this realm, the study performed by Saaty (1980) was the pioneer for using BCRs. Saaty (1990) pointed out that the AHP is similar to regular BC analysis using money as the common currency. He explained how a BC analysis from two hierarchies can be applied, and from it one can also calculate marginal BCRs. On the other hand, Bernhard and Canada (1990) argued that the use of BCRs by Saaty will not definitely give an optimal alternative and, therefore, incremental BC analysis is necessary. They showed that while Saaty's (1980) procedure does not change its optimal choice, any one of the available alternatives can be the optimal choice depending on the level of the cutoff ratio in the incremental BC analysis, which Saaty's procedure ignores. The cutoff ratio is defined as the total costs, in dollars, divided by the total benefits, in dollars, of all projects.

Yang et al. (2004) claimed that the incremental BC analysis is not suitable for the AHP situation. They believed that the cutoff ratio cannot be determined unless decision makers understand the subtle benefits and costs. Therefore, the benefits and costs are difficult to decide. They suggested that decision makers adopt Saaty's BOCR AHP method (Saaty and Cho 2001) and BC procedures (Saaty 1994, pp. 151–166) for selecting the best project. They also pointed out that Saaty's procedures are popular and flexible and can effectively deal with BC analysis.

Wedley et al. (2001) made magnitude adjustments for AHP BCRs. They suggested a magnitude adjustment procedure that converts the benefit and cost hierarchies to a common unit. Furthermore, Wijnmalen (2007) studied the conventional BOCR equations in the AHP/ANP and concluded that none of them offer reliable results of profitability. Trying to make the BOCR items commensurable, he suggested that modified equations will give correct indicators of profitability. Moreover, he supported Millet and Schoner's (2005) idea that considering reciprocals of negative priorities (i.e., cost and risk priorities) is an incorrect transformation. Subsequently, it has been deduced that reciprocals of negative priorities should be avoided in the BOCR analysis and negative values allowed (Millet and Schoner 2005; Saaty and Ozdemir 2003; Wedley 2010). It should be mentioned that in the current study the BC analysis based on the idea of Wedley and his colleagues (2001) is employed as the theoretical framework of the proposed example.

There are two types of weights in the AHP that are relative preferences within criteria (alternative relative weights with respect to the criteria) and those between criteria (criteria relative weights with respect to the goal). Even though the within-criteria preferences are in the commensurate unit, the between-criteria preferences are not necessarily scaled.

Supporting validation examples by fictitious monetary values is a common routine in the literature on BC analysis via the AHP/ANP. Stated more precisely, in order to investigate whether the proposed theories on the BC-AHP/ANP are true, actual dollar figures are ascribed to benefits and costs for each alternative but in such a way that the original priorities are reproduced (e.g., see Bernhard and Canada 1990; Millet and Schoner 2005; Millet and Wedley 2002; Wedley et al. 2001, 2003; Wijnmalen 2005, 2007). In line with this idea, the current study does not follow a different process in its validation phase than the methodology examined several times in the literature on BC-AHP/ANP. Looking at the well-known studies in the literature that extend the theoretical framework of the BC-AHP/ANP, we find that most of them follow these identical stages (Khademi et al. 2012):

Stage 1: A reference example is introduced usually having alternative normalized priorities with respect to decision criteria for each benefit and cost factor. In this stage, the criteria or some criteria are supposed to be difficult to quantify in monetary terms.
Stage 2: A set of monetary values that generate these priorities is provided.
Stage 3: The problem is solved by conventional BCR analysis or NPV analysis using the monetary values.
Stage 4: The problem is solved by the proposed BC-AHP/ANP method using the normalized priorities.
Stage 5: A comparison is made between the results of Stages 3 and 4 to verify the validity of the proposed method.

In this regard, the fictitious monetary values for our AHP^f problem are the ones provided in Table 1. Figure 2 graphically represents the synthesis process of the data in the AHP^f based on the fictitious monetary values shown in Table 1, which is similar to the combined benefit and cost hierarchies in studies performed by Wedley and his colleagues (2001, 2003). In Figure 2, X and Y denote the relative importance of the benefit and cost clusters used to derive the commensurate preferences.

Applying a standard normalization technique to the amounts in Table 1 gives

$$b_{ij}^{n} = b_{ij} \Big/ \sum_{i=1}^{m} b_{ij},\ c_{ij}^{n} = c_{ij} \Big/ \sum_{i=1}^{m} c_{ij}. \tag{1}$$

In order to introduce the AHP^f for the BC analysis, the question of how one can extract the criteria weights (x_k and y_k) and cluster weights (X and Y) in Figure 2 must be answered so

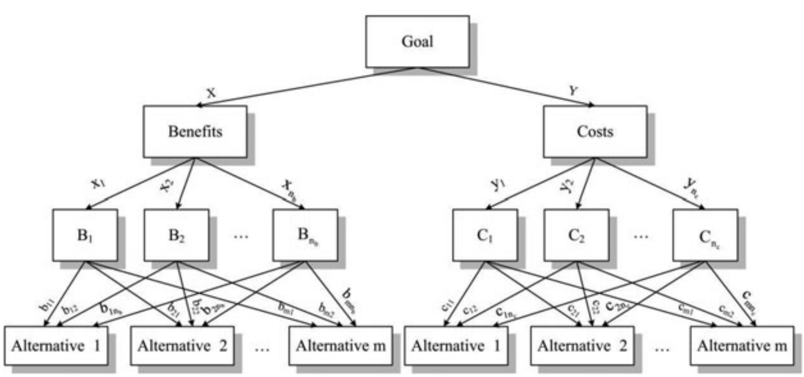

Figure 2. Synthesized process of AHP for benefit–cost analysis.

that the AHP results coincide with the BC analysis results in Table 2. In this regard, when the criteria are measured in the same unit, the priorities of the criteria should be derived from the priorities of the alternatives (Saaty 2005). If so, x_k and y_k are calculated as the total amounts of the alternatives with respect to criterion k divided by the total amounts of the alternatives with respect to all of the criteria in the same cluster (i.e., benefit or cost clusters) as follows:

$$x_k = \frac{\sum_{i=1}^{m} b_{ik}}{\sum_{i=1}^{m}\sum_{j=1}^{n_b} b_{ij}} = \frac{\sum_{i=1}^{m} b_{ik}}{S_b}, \quad y_k = \frac{\sum_{i=1}^{m} c_{ik}}{\sum_{i=1}^{m}\sum_{j=1}^{n_c} c_{ij}} = \frac{\sum_{i=1}^{m} c_{ik}}{S_c}. \tag{2}$$

This concept can be generalized to determine the relative importance of the benefit and cost clusters as follows:

$$\begin{aligned} X &= \frac{\sum_{i=1}^{m}\sum_{j=1}^{n_b} b_{ij}}{\sum_{i=1}^{m}\sum_{j=1}^{n_b} b_{ij} + \sum_{i=1}^{m}\sum_{j=1}^{n_c} c_{ij}} = \frac{S_b}{S_b + S_c}, \\ Y &= \frac{\sum_{i=1}^{m}\sum_{j=1}^{n_c} c_{ij}}{\sum_{i=1}^{m}\sum_{j=1}^{n_b} b_{ij} + \sum_{i=1}^{m}\sum_{j=1}^{n_c} c_{ij}} = \frac{S_c}{S_b + S_c}. \end{aligned} \tag{3}$$

Here we want to show that for a BC analysis, the overall benefit (cost) of alternatives computed based on the AHP^f coincides with the weights derived from the PVB (PVC) analyses. Suppose that there are m alternatives and n_b positive criteria leading to the decision matrix shown in Table 1. Using Eq. (1) derives $b_{ij}{}^n$, the normalized weight of alternative i with respect to criteria j. Equation (2) provides x_k for the positive criteria weights in the synthesis process. The overall benefit of alternative i (ba_i) is computed as follows:

$$\begin{aligned} ba_i &= \sum_{j=1}^{n_b}\left(b_{ij}^n \times x_j\right) = \sum_{j=1}^{n_b}\left(b_{ij}^n \times \frac{\sum_{i=1}^{m} b_{ij}}{\sum_{i=1}^{m}\sum_{j=1}^{n_b} b_{ij}}\right) \\ &= \sum_{j=1}^{n_b}\left(\frac{b_{ij}}{\sum_{i=1}^{m} b_{ij}} \times \frac{\sum_{i=1}^{m} b_{ij}}{\sum_{i=1}^{m}\sum_{j=1}^{n_b} b_{ij}}\right) = \frac{\sum_{j=1}^{n_b} b_{ij}}{\sum_{i=1}^{\mathrm{m}}\sum_{j=1}^{n_b} b_{ij}} = \frac{\sum_{j=1}^{n_b} b_{ij}}{S_b}. \end{aligned} \tag{4}$$

The BCR analysis in Table 2 delivers:

$$PVB_i^n = \sum_{j=1}^{n_b} b_{ij}/S_b. \tag{5}$$

This is the same result found in the overall positive weight of alternative i. In the same vein, it could also be calculated for the negative criteria.

This result implicitly indicates that when decision makers' subjective preferences for the criteria weights are used, the decision makers' expertise in quantifying the $x_k s$ and $y_k s$ are exploited. Indeed, the AHP tries to follow the BC analysis if the decision makers are experienced and skillful enough.

It is important to note that these results derive on the basis of the assumption that experts' preferences are linear in relation to monetary costs and benefits. That is, a monetary benefit that is twice as large is preferred by twice. This is in distinction to the case in which a monetary benefit that is twice as large would only be preferred by, for example, 1.8 because the decision maker has a decreasing preference function with monetary value.

Now let the relative importance of the benefit and cost clusters be given by X and Y using Eq. (3). Let $(\mathrm{BCR_i})^n_{\mathrm{AHP}^f}$ be the normalized BCR and $(\mathrm{NPV_i})^n_{\mathrm{AHP}^f}$ be the normalized NPV obtained by the AHP$^{\mathrm{f}}$. First, for $(\mathrm{BCR_i})_{\mathrm{EAF-AHP}}$ analysis and with X and Y from Eq. (3), it holds that

$$(\mathrm{BCR_i})^n_{\mathrm{AHP}^f} = \frac{X \times \mathrm{PVB^n_i}}{Y \times \mathrm{PVC^n_i}}. \tag{6}$$

For $X \times \mathrm{PVB^n_i}$, from above we have

$$X \times \mathrm{PVB^n_i} = \frac{\mathrm{S_b}}{\mathrm{S_b + S_c}} \times \frac{\sum_{\mathrm{j=1}}^{\mathrm{n_b}} \mathrm{b_{ij}}}{\mathrm{S_b}} = \frac{\sum_{\mathrm{j=1}}^{\mathrm{n_b}} \mathrm{b_{ij}}}{\mathrm{S_b + S_c}}.$$

Likewise, for $Y \times \mathrm{PVC}_i{}^n$:

$$Y \times \mathrm{PVC^n_i} = \frac{\sum_{\mathrm{j=1}}^{\mathrm{n_c}} \mathrm{c_{ij}}}{\mathrm{S_b + S_c}}. \tag{7}$$

Thus, for (6), it holds that

$$(\mathrm{BCR_i})_{\mathrm{AHP}^f} = \left(\frac{\sum_{j=1}^{n_b} b_{ij}}{S_b + S_c}\right) \Bigg/ \left(\frac{\sum_{j=1}^{n_c} c_{ij}}{S_b + S_c}\right) = \sum_{j=1}^{n_b} b_{ij} \Bigg/ \sum_{j=1}^{n_c} c_{ij}. \tag{8}$$

As the next step, for the $(\mathrm{NPV_i})_{\mathrm{AHP}^f}$

$$\begin{aligned}
(\mathrm{NPV_i})_{\mathrm{AHP}^f} &= X \times \sum_{j=1}^{n_b} \left(x_j \times b^n_{ij}\right) - Y \times \sum_{j=1}^{n_c} \left(y_j \times c^n_{ij}\right) \\
&= \frac{S_b}{S_b + S_c} \times \sum_{j=1}^{n_b} \left(\frac{\sum_{i=1}^{m} b_{ij}}{S_b} \times \frac{b_{ij}}{\sum_{i=1}^{m} b_{ij}}\right) - \frac{S_c}{S_b + S_c} \\
&\quad \times \sum_{j=1}^{n_c} \left(\frac{\sum_{i=1}^{m} c_{ij}}{S_c} \times \frac{c_{ij}}{\sum_{i=1}^{m} c_{ij}}\right). \\
&= \frac{\sum_{j=1}^{n_b} b_{ij}}{S_b + S_c} \times \frac{\sum_{j=1}^{n_c} c_{ij}}{S_b + S_c} = \frac{\sum_{j=1}^{n_b} b_{ij} - \sum_{j=1}^{n_c} c_{ij}}{S_b + S_c}
\end{aligned}$$

Considering $\frac{S_b + S_c}{S}$ with $S = \sum_{i=1}^{m} \mathrm{ABS}(\sum_{\mathrm{j=1}}^{\mathrm{n_b}} \mathrm{b_{ij}} - \sum_{\mathrm{j=1}}^{\mathrm{n_c}} \mathrm{c_{ij}})$, $S_b = \sum_{i=1}^{\mathrm{m}} \sum_{j=1}^{n_b} b_{ij}$, and $S_c = \sum_{i=1}^{\mathrm{m}} \sum_{j=1}^{n_c} c_{ij}$ as the normalization factor, we have

$$(\mathrm{NPV_i})^n_{\mathrm{AHP}^f} = \frac{\sum_{j=1}^{n_b} b_{ij} - \sum_{j=1}^{n_c} c_{ij}}{S}. \tag{9}$$

Equations (8) and (9) deliver the same results as those shown in Table 2. It shows that the alternative overall weights calculated by the AHP^f coincide with the weights resulting from the BCR and NPV analyses.

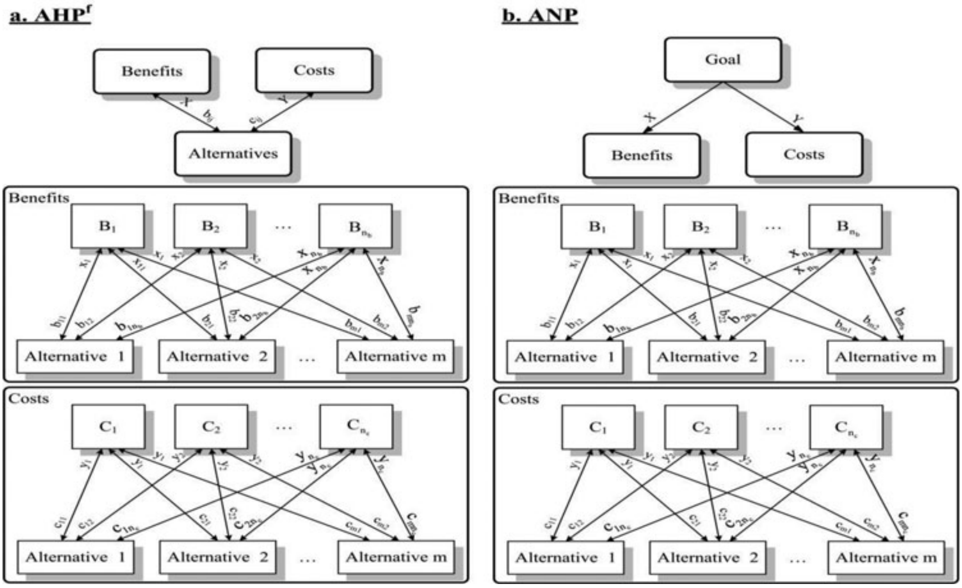

Figure 3. AHP with fictitious monetary values vs. ANP for BC analysis.

There is a benchmark that gives results similar to the BCR and NPV analyses but through an analytical structure similar to the AHP. If we have the monetized amounts of the alternative weights with respect to the decision criteria (i.e., b_{ij}s and c_{ij}s), there is no need to ask the experts about the relative importance of the criteria (i.e., x_k and y_k). This means that using the subjective assessment of experts for quantifying x_k and y_k is not necessary. In this case, the criteria and cluster weights are determined by Eqs. (2) and (3). Hence, the decision structure changes to the process presented in Figure 3a. This structure involves the interaction and dependence of higher-level elements on the lower-level elements similar to what exists for the ANP (Saaty 2001; Saaty and Vargas 2006); however, the ANP structure in this case is slightly different, as shown in Figure 3b, where the clusters' commensurate weights (X and Y) are determined only by the decision maker's subjective preferences. A section with the title "Benefit-Cost Analysis via the ANP" will be opened for ANP later.

Benefit–Cost Analysis via the Conventional AHP

AHP is used to measure the intangible and difficult-to-monetize items in decision problems and to derive the final alternative weights with respect to the goal. Inevitably, the decision makers should be asked about the relative importance of decision elements that are not originally quantifiable and scalable. Hence, instead of Figure 3a, a structure like Figure 2 exists for AHP.

In this study, in order to simplify the synthesis process, it is assumed that the quantified weights exist at the level of alternatives. In other words, the weights of the alternatives with respect to each criterion are available and quantifiable but not monetizable. So, we have alternative weights with respect to each criterion but we cannot compare and scale them from one criterion to another. Therefore, asking the experts for criteria relative weights is necessary. Then the weights of the criteria are calculated with respect to each control criteria (benefit and cost) from a pairwise comparison matrix (for more details about pairwise comparison matrices, weight elicitation techniques, and priorities derivation methods, see Barzilai [1997]; Ishizaka and Lusti [2006]; Saaty [2003]; Srdjevic [2005]). The cluster weights are also derived with respect to the goal using a similar method.

When the standard normalization is applied to local weights (see Eq. (1)), and if b_{ij} is the normalized weight of decision alternative i relating to benefit criterion j, and if wb_j^ns are the relative normalized criteria weights calculated from the pairwise comparisons, the overall weight of alternative i in the AHP structure (Figure 2) is calculated as

$$(ba_i)_{\mathrm{AHP}} = \sum_{j=1}^{n_b} \left(b_{ij}^n \times wb_j^n\right) = \sum_{j=1}^{n_b} \left(b_{ij} \Big/ \sum_{i=1}^{m} b_{ij} \times wb_j^n\right), \tag{10}$$

where n_b is the number of benefit criteria and m is the number of alternatives. In this regard, the difference between the AHP weights and the AHP^f weights (from Eq. (4)) is as follows:

$$(ba_i)_{\mathrm{AHP}^f} - (ba_i)_{\mathrm{AHP}} = \sum_{j=1}^{n_b} \left(b_{ij}^n \times x_j^n\right) - \sum_{j=1}^{n_b} \left(b_{ij}^n \times wb_j^n\right) = \sum_{j=1}^{n_b} b_{ij}^n \left(x_j^n - wb_j^n\right). \tag{11}$$

Considering $x_j^n = \frac{\sum_{i=1}^{m} b_{ij}}{\sum_{i=1}^{m}\sum_{j=1}^{n_b} b_{ij}}$ gives

$$(b_i)_{\mathrm{AHP}^f} - (b_i)_{\mathrm{AHP}} = \sum_{j=1}^{n_b} b_{ij}^n \left(\sum_{i=1}^{m} b_{ij} \Big/ \sum_{i=1}^{m}\sum_{j=1}^{n_b} b_{ij} - wb_j^n\right). \tag{12}$$

The same can be written for cost criteria with ca_i, c_{ij}^n, andwc_j^n instead of ba_i, b_{ij}^n, wb_j^n.

The AHP^f and BC analyses deliver the same results. Therefore, Eq. (11) reveals the fact that the differences between the AHP results and the BC analysis are due to the reasons discussed in the subsequent subsections.

Methodological Framework

The selected scale, as well as the experimental basis that the analyst employs to derive the AHP weights of criteria are important items for obtaining reasonable results in the AHP. Thomas Saaty has proposed a bipolar scale to determine how each item is compared with others. In its general form, the AHP pairwise comparison matrix is a positive reciprocal square matrix. In the case of m items (i.e., comparison of m alternatives with respect to a criterion or comparison of m criteria with respect to the goal), there are $m\,(m-1)\,/2$ pairwise comparisons to be performed. In the case of using a nine-unit scale (1–9 scale) together with their reciprocals (1/9, 1/8, $\cdots$, 1/2, 1), a total of 17 different values could be assigned to each cell of the pairwise comparison matrix. However, as shown in Beynon (2002), the alternative scales may offer better opportunities for following linguistics scales.

There is the additional problem of deriving the final weights from an inconsistent pairwise comparison matrix. Several methods for deriving priorities from an inconsistent pairwise comparison matrix have been introduced (Srdjevic 2005). Although it has been emphasized that analysts should only use the eigenvector method (Saaty and Hu 1998), the discussion regarding the prioritization methods is still open and relatively controversial, generally due to the fact that some methods present better results in some cases (Srdjevic 2005).

Level of Expertise

Equation (11) is used to calculate the differences between the actual relative values and the stated amounts as the main reason for the weight discrepancies in the AHP. Different levels of expertise of the individual respondents when evaluating the intangible items of the problem are the subject of the present researchers' concern for the studies performed in developing countries. An expert is a person having a high level of knowledge and enough skill in dealing with quite complex problems in a very simple manner. He is expected to overcome the difficulties in quantifying the benefits and costs of decision criteria for each alternative and to map the relative preferences correctly on the 1–9 scale. Therefore, having only rudimentary knowledge about the problem domain can cause distortions in the stated overall preferences.

Level of Ambiguity

Beyond the expertise of the individual respondents, the level of inherent ambiguities in the problem is counted as another source of error. In many AHP problems, not only does the importance of the criteria determine the importance of the alternatives but the importance of the alternatives also determines the importance of the criteria (Saaty 2005). Regardless of whether the respondent is an expert or not, his perceptual span limits him in giving the correct answer in ambiguous situations.

Benefit–Cost Analysis via the ANP

According to Saaty (1999, 2004a), the process of modeling a decision problem by the ANP can be outlined as follows: (1) problem identification and model construction, (2) pairwise comparisons and initial supermatrix formation, and (3) raising the weighted supermatrix to powers and deriving final weights from the synthesized supermatrix.

For a summarized description of the algebra of the ANP, first assume that a problem can be outlined into m clusters $(X_1, X_2, \ldots, X_m)$. Each cluster has n_i elements $(y_1^i, y_2^i, \ldots, y_{n_i}^i)$ where i is the index of clusters ($i = 1, 2, \ldots, m$). The initial supermatrix shows the magnitude of influence of an item on the top of the matrix on an item on the left of the matrix or, in other words, the weight of an item on the left with respect to an item on the top. The initial supermatrix is given schematically as follows:

$$
W = \begin{array}{cc} & \begin{array}{cccc} X_1 & X_2 & \cdots & X_m \\ y_1^1\ y_2^1\ y_3^1 \cdots y_{n_1}^1 & y_1^2\ y_2^2\ y_3^2 \cdots y_{n_2}^2 & \cdots & y_1^m\ y_2^m\ y_3^m \cdots y_{n_m}^m \end{array} \\ \begin{array}{cc} X_1 & \begin{array}{c} y_1^1 \\ y_2^1 \\ y_3^1 \\ \vdots \\ y_{n_1}^1 \end{array} \\ X_2 & \begin{array}{c} y_1^2 \\ y_2^2 \\ y_3^2 \\ \vdots \\ y_{n_2}^2 \end{array} \\ \vdots & \vdots \\ X_m & \begin{array}{c} y_1^m \\ y_2^m \\ y_3^m \\ \vdots \\ y_{n_m}^m \end{array} \end{array} & \begin{bmatrix} M_{11} & M_{12} & \cdots & M_{1m} \\ M_{21} & M_{22} & \cdots & M_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ M_{m1} & M_{m2} & \cdots & M_{mm} \end{bmatrix} \end{array},
$$

where M_{ij} is

$$
M_{ij} = \begin{bmatrix} w_{1,1}^{i,j} & w_{1,2}^{i,j} & \cdots & w_{1,n_j}^{i,j} \\ w_{2,1}^{i,j} & w_{2,2}^{i,j} & \cdots & w_{2,n_j}^{i,j} \\ \vdots & \vdots & \ddots & \vdots \\ w_{n_i,1}^{i,j} & w_{n_i,2}^{i,j} & \cdots & w_{n_i,n_j}^{i,j} \end{bmatrix}.
$$

Each column of the matrix M_{ij} is a priority vector derived from a pairwise comparison matrix.

The initial supermatrix (W) must change to the weighted supermatrix (W'). For this reason, this initial supermatrix is normalized by the cluster's weight to get the column sums to unity (Saaty and Vargas 1998). Subsequently, if the weighted supermatrix (W') is irreducible and primitive, the synthesis of all of the interactions among the items of the network structure is given by the synthesized supermatrix (W''), obtained by raising the weighted supermatrix to infinite power (Saaty 2001):

$$W'' = \lim_{k \to \infty} W'^{k}. \tag{13}$$

Like the AHP, there is a control hierarchy in the ANP that is a hierarchy with criteria, called "control criteria" (Saaty 2004b). It serves as the basis for making pairwise comparisons about the influences. In our example, there are benefit (B) and cost (C) control criteria. For each control criteria, there are two clusters: (1) an alternative cluster and ii) a criteria cluster. The overall alternative weights are derived from the synthesized supermatrix with respect to each control criteria (B and C), and the final ANP results are then calculated based on the simple hierarchical structure of the control hierarchy (Saaty 2004b). Afterwards, like the AHP^f, Eq. (6) is used for calculating the commensurate priorities of the ANP (Wijnmalen 2007). The relative weights of X and Y should be elicited from specialists.

Reference Example

While focusing on Eqs. (11) and (12), a reference example is given in this section in order to demonstrate the problems that arise from inexperienced decision makers when using the AHP and ANP. The proposed example concerns choosing a rail transit system for an urban corridor having a 32 km length between Tehran's Imam Khomeini International Airport and the Haram subway station in line 1 of the subway system.

For simplicity, suppose that there are only two benefit criteria: B_1, which is "tourism reputation," and B_2, which is "travel time saving (within just the national level of the travelers)." There are also two cost criteria: C_1, which is the construction cost, and C_2, which is the maintenance cost. The decision alternatives are as follows:

A_1: Extending the line of the current subway system having a maximum speed of 110 km/h.
A_2: High-speed rail (HSR), which is a type of passenger rail transit system. It operates considerably faster than a normal rail system and achieves a maximum speed of about 250 km/h.
A_3: Maglev system, which is an elegant system of suspended rail transportation using magnetic levitation from a very large number of magnets for lift and propulsion. It can reach the highest speed of 400 km/h.
A_4: Straddle-type monorail system that reaches a maximum speed of about 95 km/h.
A_5: Do-minimum strategy, which is the result of improving the current taxicab system.
A_6: Do-nothing strategy.

The cost and benefits of these systems were calculated in monetary terms (Khademi 2005), considering 30 years of operation and according to the exogenous rates for interest and inflation. The results are presented in Table 3. The BCR and NPV and their normalized amounts (BCR^n and NPV^n) are provided in this table according to the calculations shown in Table 2.

Among the decision alternatives, the subway system is the only one that has ever been constructed in Iran and its preliminary studies go back to 1974 (Khademi 2005). Hence, the subway system construction has experienced numerous technological changes during these

Table 3
Classic benefit–cost analysis of the reference example (unit: million $)

Alternatives	b_{i1}	b_{i2}	c_{i1}	c_{i2}	$\text{NPV}_i{}^*$	NPV_i^n	$\text{BCR}_i{}^{**}$	BCR_i^n
Subway	500	775	768	306	201	**0.265**	1.187	**0.223**
HSR	1,950	775	1,857	802	67	**0.088**	1.025	**0.193**
Maglev	3,200	775	2,660	1,577	−261	**−0.345**	0.938	**0.176**
Monorail	1,950	775	1,441	1,091	193	**0.255**	1.076	**0.202**
Do minimum (taxi cabs)	1,00	3,25	2,79	1,10	36	**0.047**	1.093	**0.205**
Do nothing	0	0	0	0	0	**0.000**	—	—
$\sum$ ABS (·)	7,700	3,425	7,004	3,885	758	1	5.319	1

Note: Bold values are the normalized amounts of the BCR and NPV analyses.
$^*\text{NPV}_i = b_{i1} + b_{i2} - c_{i1} - c_{i2}$.
$^{**}\text{BCR}_i = (b_{i1} + b_{i2})/(c_{i1} - c_{i2})$.

years. Nowadays, more than 90% of metro lines are constructed by domestic contractors and professionals, which implies a considerably lower construction and maintenance cost compared with other rail systems as shown in Table 3.

The results derived from AHP^f are presented in Table 4. Table 4 presents the relative criteria weights (x_k and y_k) and cluster weights (X and Y) calculated based on Eqs. (2) and (3). In this table, b_{i1}^n, b_{i2}^n, c_{i1}^n, and c_{i2}^n are calculated based on Eq. (1), and ba_i and ca_i are calculated according to Eq. (4). The BCR and NPV amounts in this table are calculated using Eqs. (8) and (9). The AHP^f results are apparently the same as those obtained from the BCR and NPV analyses (in Table 3).

Table 5 provides the relative weights of criteria for each alternative. As can be seen, the relative weights of the benefit criteria are considerably different from one alternative to another, implying that the importance of alternatives determines the importance of the criteria. So, there exists feedback in the AHP structure or, stated equivalently, there is no longer an AHP structure.

Regarding the second stage, as mentioned before in the reference example, it is assumed that there are quantified weights at the level of alternatives. This means that the weights of alternatives with respect to each criterion are available and quantifiable.

For the AHP, consider that the benefit criteria weights are the source of problems or, in other words, the cost criteria are quantifiable and monetizable, but the benefit criteria are quantifiable and not monetizable, so the benefit criteria cannot be scaled. In other words, suppose that there are quantified amounts for the benefit criteria, tourism reputation (B_1) and travel time saving (B_2), but they cannot be scaled from one criterion to another one. The tourism reputation criterion has been calculated by the stated preference survey in the airport where the relative preferences of the rail system have been questioned from travelers. The travel time saving criterion (B_2) has also been calculated based on the unit of time, which is not convertible to monetary amounts.

The AHP analysis will be simplified by the following approaches:

1. While taking into account a more optimistic view regarding the respondents' answers, we need only ask the specialist the relative importance of the benefit criteria (i.e., wb_1/wb_2). This means that, for the cost criteria and for the relative importance of the clusters (X/Y), the real relative amounts were computed from Table 4. It is

Table 4
AHP[f] analysis for the reference example

Alternatives ↓	Relative weights ↳	$x_1 =$ 0.692 b^n_{i1}	$x_2 =$ 0.308 b^n_{i2}	$y_1 =$ 0.643 c^n_{i1}	$y_2 =$ 0.357 c^n_{i2}	$X =$ 0.505 ba_i*	$Y =$ 0.495 ca_i*	BCR_i**	BCR^n_i***	NPV_i**	NPV^n_i***
Subway		0.06	0.23	0.11	0.08	0.115	0.099	1.187	**0.223**	0.009	**0.265**
HSR		0.25	0.23	0.27	0.21	0.245	0.244	1.025	**0.193**	0.003	**0.088**
Maglev		0.42	0.23	0.38	0.41	0.357	0.389	0.938	**0.176**	−0.012	**−0.345**
Monorail		0.25	0.23	0.21	0.28	0.245	0.232	1.076	**0.202**	0.009	**0.255**
Do minimum (taxi cabs)		0.01	0.09	0.04	0.03	0.038	0.036	1.093	**0.205**	0.002	**0.047**
Do nothing		0.00	0.00	0.00	0.00	0.000	0.000	—	—	0.000	**0.000**
$\sum$ ABS (·)		1.00	1.00	1.00	1.00	1.000	1.000	5.319	1.000	0.034	1

Note: Bold values are the normalized amounts of the BCR and NPV analyses.
*$ba_i = b^n_{i1} \times x_1 + b^n_{i2} \times x_2$ and $ca_i = c^n_{i1} \times y_1 + c^n_{i2} \times y_2$.
**$\mathrm{BCR}_i = (ba_i \times X)/(ca_i \times Y)$ and $\mathrm{NPV}_i = X \times ba_i - Y \times ca_i$.
***$\mathrm{BCR}^n_i = \mathrm{BCR}_i/(\sum_{i=1}^{m} \mathrm{BCR}_i)$; $\mathrm{NPV}^n_i = \mathrm{NPV}_i/S$ and $S = \sum_{i=1}^{m} \mathrm{ABS}(\mathrm{NPV}_i)$.

Table 5
Dependency of the criteria weights on the decision alternatives

Alternatives	$x_1 = \frac{\sum_{i=1}^{m} b_{i1}}{\sum_{i=1}^{m}\sum_{j=1}^{n_b} b_{ij}}$	$x_2 = \frac{\sum_{i=1}^{m} b_{i2}}{\sum_{i=1}^{m}\sum_{j=1}^{n_b} b_{ij}}$	$y_1 = \frac{\sum_{i=1}^{m} c_{i1}}{\sum_{i=1}^{m}\sum_{j=1}^{n_c} c_{ij}}$	$y_2 = \frac{\sum_{i=1}^{m} c_{i2}}{\sum_{i=1}^{m}\sum_{j=1}^{n_c} c_{ij}}$
Subway	0.392	0.608	0.715	0.285
HSR	0.716	0.284	0.698	0.302
Maglev	0.805	0.195	0.628	0.372
Monorail	0.716	0.284	0.569	0.431
Do minimum (taxi cabs)	0.235	0.765	0.717	0.283
Do nothing	—	—	—	—

assumed that the expert s' views have no deviations from the correct amounts for $b_{ij}{}^{n}$s, wc_1/wc_2 (instead of x_1/x_2), and X/Y (in Eqs. (1), (2), and (3)).

2. For the benefit criteria, only the relative importance of wb_1/wb_2 was asked of the specialist respondents.

These simplifying assumptions help in focusing attention only on the issues discussed in this article, which arise from Eqs. (11) and (12).

Three specialists were selected for the proposed decision making problem:

- Expert no. 1, who has been working extensively in studies for subway system construction or extension in the Tehran Urban and Suburban Railway Company. He assigned the amount for wb_1/wb_2 equal to 1/2 (i.e., between the inverse of equal importance and inverse of moderate importance). This means that the real relative weights of the benefit criteria of the Maglev, monorail, and HSR systems were distorted (see Table 5).
- Expert no. 2, who knew perfectly the specifications of the HSR and monorail systems. He submitted the relative amount of 3/1 to wb_1/wb_2 (3/1: moderate importance), which means that he had a perfect knowledge about HSR and monorail systems; however, he understood that other systems may have the same features.
- Expert no. 3, who was a specialist in the realm of Maglev systems. He drew $wb_1/wb_2 = 4/1$ (i.e., between moderate importance and strong importance).

These specialists were questioned regarding the relative weights of the cost criteria but, for simplicity, the relative weights of the cost criteria and those of the clusters were extracted from Table 4. With these weights, Eq. (10) gives the AHP weights as provided in Table 6. This example shows that the biased relative preferences can completely reverse the ranks in addition to changing the highest priorities.

In addition, for the ANP, only the relative weights of the benefit criteria were obtained from our specialists, but in a different manner; namely, the relative weights of the benefit criteria for each system were asked of the corresponding expert who had special knowledge of that system. For example, the wb_1/wb_2 amount, with respect to the subway, was asked of the expert who had enough expertise in evaluating this system. The same was performed for the wb_1/wb_2 with respect to other rail transit systems.

In the same vein as the AHP, for the ANP, the relative weights of the cost criteria and also the relative weights of the clusters (i.e., X/Y) were extracted from AHP^f in Table 4. As a result, the supermatrixes of the ANP problem can be formed as shown in Table 7.

Table 6
AHP results of the three specialists for the reference example

Experts	Alternatives	ba$_i$*	ca$_i$*	BCR$_i$**	BCR$_i^{n}$***	NPV$_i$**	NPV$_i^{n}$***
Expert no. 1	Subway	0.173	0.099	1.787	0.284	0.03841	0.359
($wb_1 = 0.333$,	HSR	0.235	0.244	0.985	0.157	−0.00185	−0.017
$wb_2 = 0.667$)	Maglev	0.289	0.389	0.760	0.121	−0.04623	−0.433
($wc_1 = 0.643$,	Monorail	0.235	0.233	1.034	0.164	0.00388	0.036
$wc_2 = 0.357$)	Do minimum	0.068	0.036	2.163	0.344	0.01650	0.154
($X = 0.505$,	(taxi cabs)						
$Y = 0.495$)	Do nothing	0	0	—	—	0	0
Expert no. 2	Subway	0.105	0.099	1.090	0.172	0.00441	0.177
($wb_1 = 0.75$,	HSR	0.247	0.244	1.032	0.163	0.00383	0.154
$wb_2 = 0.25$)	Maglev	0.368	0.389	0.967	0.153	−0.00634	−0.255
($wc_1 = 0.643$,	Monorail	0.247	0.233	1.083	0.171	0.00957	0.384
$wc_2 = 0.357$)	Do minimum	0.033	0.036	2.163	0.341	−0.00076	−0.030
($X = 0.505$,	(taxi cabs)						
$Y = 0.495$)	Do nothing	0	0	—	—	0	0
Expert no. 3	Subway	0.097	0.099	1.007	0.160	0.00033	0.017
($wb_1 = 0.8$,	HSR	0.248	0.244	1.037	0.165	0.00451	0.232
$wb_2 = 0.2$)	Maglev	0.378	0.389	0.992	0.158	−0.00155	−0.080
($wc_1 = 0.643$,	Monorail	0.248	0.233	1.089	0.173	0.01025	0.526
$wc_2 = 0.357$)	Do minimum	0.029	0.036	2.163	0.344	−0.00283	−0.145
($X = 0.505$,	(taxi cabs)						
$Y = 0.495$)	Do nothing	0	0	—	—	0	0

$^{*}ba_i = b_{i1}^n \times wb_1^n + b_{i2}^n \times wb_2^n$ and $ca_i = c_{i1}^n \times wc_1^n + c_{i2}^n \times wc_2^n$.
$^{**}\mathrm{BCR}_i = (ba_i \times X)/(ca_i \times Y)$ and $\mathrm{NPV}_i = X \times ba_i - Y \times ca_i$.
$^{***}\mathrm{BCR}_i^n = \mathrm{BCR}_i / \left(\sum_{i=1}^m \mathrm{BCR}_i\right)$; $\mathrm{NPV}_i^n = \mathrm{NPV}_i/S$ and $S = \sum_{i=1}^m \mathrm{ABS}\,(\mathrm{NPV}_i)$.

In order to evaluate the effect of differences in expert opinion, Spearman's rank correlation coefficient (R_s) statistic is calculated (Gibbons 1971) to examine the correlation between the ranks generated by the benchmark AHP^f and the AHP/ANP methods. This statistic reveals the degree of correlation between the two sets of rankings. If U_i denotes the ranks achieved by the AHP/ANP and V_i denotes the actual ranks for the same alternative i, then coefficient R_s is defined as

$$R_s = 1 - \frac{6\sum_{i=1}^m d_i^2}{m(m^2-1)}, \tag{14}$$

where m stands for the number of alternatives involved in the test, i is the index of the alternatives ($i = 1, 2, \ldots, m$), and d_i is the difference between U_i and V_i.

In order to compare the AHP and ANP results with the BC analysis or with AHP^f, three measures are defined: (1) Spearman's rank correlation coefficient among the ranks derived from the BCR analysis and AHP/ANP, (2) Spearman's rank correlation coefficient among the ranks derived from the NPV analysis and AHP/ANP, and (3) the index showing whether the applied method (i.e., AHP/ANP) has changed the highest priority of NPV and BCR analyses or not. Table 8 draws these comparisons between the BC analysis, NPV analysis, AHP^f, AHP, and ANP. The following results are important:

Table 7
ANP results of the reference example

i. Benefit cluster

Initial supermatrix	B_1	B_2	Subway	HSR	Maglev	Monorail	Do minimum	
B_1	0	0	0.392	0.716	0.805	0.716	0.235	
B_2	0	0	0.608	0.284	0.195	0.284	0.765	
Subway	0.065	0.226	0	0	0	0	0	
HSR	0.253	0.226	0	0	0	0	0	
Maglev	0.416	0.226	0	0	0	0	0	
Monorail	0.253	0.226	0	0	0	0	0	
Do minimum (taxi cabs)	0.013	0.095	0	0	0	0	0	
Synthesized supermatrix	B_1	B_2	Subway	HSR	Maglev	Monorail	Do minimum	
B_1	0	0	0.671	0.671	0.671	0.671	0.671	
B_2	0	0	0.298	0.298	0.298	0.298	0.298	
Subway	0.111	0.111	0	0	0	0	0	**0.115**
HSR	0.237	0.237	0	0	0	0	0	**0.245**
Maglev	0.347	0.346	0	0	0	0	0	**0.358**
Monorail	0.237	0.237	0	0	0	0	0	**0.245**
Do minimum (taxi cabs)	0.037	0.037	0	0	0	0	0	**0.038**

ii. Cost cluster								
Initial supermatrix	C_1	C_2	Subway	HSR	Maglev	Monorail	Do minimum	
C_1	0	0	0.715	0.698	0.628	0.569	0.717	
C_2	0	0	0.285	0.302	0.372	0.431	0.283	
Subway	0.110	0.079	0	0	0	0	0	
HSR	0.265	0.206	0	0	0	0	0	
Maglev	0.380	0.406	0	0	0	0	0	
Monorail	0.206	0.281	0	0	0	0	0	
Do minimum (taxi cabs)	0.040	0.028	0	0	0	0	0	
Synthesized supermatrix	C_1	C_2	Subway	HSR	Maglev	Monorail	Do minimum	
C_1	0	0	0.686	0.686	0.686	0.686	0.686	
C_2	0	0	0.381	0.381	0.381	0.381	0.381	
Subway	0.106	0.105	0	0	0	0	0	**0.099**
HSR	0.260	0.260	0	0	0	0	0	**0.244**
Maglev	0.415	0.415	0	0	0	0	0	**0.389**
Monorail	0.248	0.248	0	0	0	0	0	**0.233**
Do minimum (taxi cabs)	0.038	0.038	0	0	0	0	0	**0.036**

Note: Bold values are the normalized amounts of the BCR and NPV analyses.

Table 8
Conformity of the proposed methods with BCR and NPV analyses

Method	With respect to BCR analysis		With respect to NPV analysis	
	R_s	Change the highest priority	R_s	Change the highest priority
AHP[f]	1	✗	1	✗
AHP with expert no. 1	0.90	√	0.71	✗
AHP with expert no. 2	0.40	✗	0.89	√
AHP with expert no. 3	−0.10	√	0.66	√
ANP	1	✗	1	✗

1. The relative weights provided by experts 2 and 3 deliver poor results in the AHP. There is a low correlation between the alternative ranks from the AHP and the actual ranks in the BCR analysis.
2. The numerical example explained in this article is the case in which the relative weights of criteria are different within the alternatives. It is clearly shown that the ANP is the most suitable method in these situations.
3. The critical issue is the change in the highest priority that appears in the AHP analysis. It shows that the biased views may be extremely harmful for the selection problems as well.
4. Cross-classification of the respondents in the ANP is a considerable help in obtaining the correct results.
5. The ability to incorporate negative values in AHP/ANP (Millet and Schoner 2005) enables the analyst to employ these methods for NPV analysis.

This numerical example mainly tries to show that the idea of those experts having biased views, due to their limited expertise, may completely reverse the final ranks.

Discussion and Suggestions for Practitioners

Based on the ideas presented in the reference example, and also on the basis of the lessons learned in several real case studies performed by these authors in Iran, the following guidelines may be useful for researchers and practitioners who work with MCDM problems in an underdeveloped or developing countries.

Cross-Classification of Experts

As shown in the research by Yedla and Shrestha (2003), it is quite interesting to see that a group of actors from different fields may give contradicting ranks to the decision alternatives. Therefore, it may be better to cross-classify the experts expected to participate in the AHP and ANP by their field and ask them only questions relevant to their area of expertise.

As an example, we can refer to our study of the city of Mashhad (Atieh Saze Shargh Counsulting Engineers 2009) in Iran aimed at choosing the best congestion pricing plans from among several congestion pricing plans for the central business district of this city.

Because selecting the best congestion pricing plans was a very dynamic and complex problem (Liu et al. 2010), it seemed better to cross-classify the experts in their fields into the following categories: environmental experts, energy engineers, specialists, travelers, federal department/policy makers, automobile associations and manufacturers, local-level implementing agencies, shopping syndicate, transportation system operators, taxicab syndicate, transportation industry professionals, government transportation specialists, academia transportation specialists, roadway safety activists, police, toll concessionaires, and local authorities. Through this classification, it was possible to have specific questionnaires corresponding to the specialties assigned to each class; for example, the environmental impact questionnaire for environmental experts and public transit impact questionnaire for public transport/transit system operators. In addition, some experts like federal policy makers, government officials, transportation specialists, and academia transportation specialists were known to be eligible to answer all the questions and also to participate in the criteria relative preference derivation stage.

Using Team Decision-Making Techniques

Although the AHP can incorporate a team decision-making phase, due to the fact that this group decision-making phase is incorporated in the mid-stages of AHP (weight assignment to the elements of the problem), it might lead to the following three deficiencies (Khademi and Sheikholeslami 2010):

1. Failing to wholly consider every important and efficacious decision criterion in solving the problem.
2. Failing to select an appropriate specialist group for the AHP who will conform to the needs and, moreover, failing to receive the recommendations from relevant organizations in the domain of the project.
3. Failing to convince different stakeholders in terms of the organization, decision-making criteria, and the method of solving the problem.

Prior to applying the AHP, it may be helpful to take advantage of the team decision-making techniques. In Khademi and Sheikholeslami (2010), two group decision-making techniques, conference (Coenen 2008) and Delphi survey (Kelly 1994; Köksalan and Zionts 2001) were integrated to minimize the potential effects of the aforementioned three problems. Consequently, the methodology for that study was determined to be a combined conference–Delphi–AHP method.

As another example, in Khademi et al. (2010), brainstorming as a team decision-making techniques was performed in two stages: first to determine the ANP clusters and their elements and then to determine the ANP network of the influences.

Last but not least, the group–AHP is also strongly recommended in developing countries. It can be helpful due to encountering a range of knowledge and biased views and to help the specialist with implicit and explicit ambiguities of the questionnaire.

Sensitivity Analysis with Fuzzy AHP/ANP

Sensitivity analysis is needed to discover the impact of the priority structures of the decision alternatives. It is carried out to test the stability of the priority ranking. Sensitivity analysis can be useful in eliminating alternatives, enhancing a group decision process, and/or providing information as to the robustness of a decision (Erkut and Tarimcilar 1991). It offers insight into the robustness of the decision and shows when the final alternative priorities will change as a result of perturbations in criteria or alternative weights.

Although Saaty disagreed with the application of fuzzy theory in the AHP and ANP (Saaty 2006; Saaty and Tran 2007) and he believed that the judgments in the AHP are already fuzzy and that adding more fuzzy items does not produce more valid results, the fuzzy sensitivity analysis proposed by Promentilla et al. (2008) can lead to a more structured sensitivity analysis in the AHP. The AHP/ANP traditional sensitivity analysis is held by changing the crisp relative preferences of one or more criteria and/or alternatives to observe when the alternative ranks will finally change. However, Promentilla and his colleagues (2008) suspected that this approach was not able to capture the realistic deviations thoroughly in the weight elicitation phase, which may not correspond to the perturbation in the weights themselves made by sensitivity analysis. In other words, the AHP/ANP traditional sensitivity analysis is a single-parameter test where all of the parameters are kept fixed excluding a single one that is perturbed. However, the extent and the direction of the deviation from the actual amounts that arise from the respondent's views may not follow a single parameter test, meaning that the perturbations are a function of (1) the degree of the inherent ambiguity of the problem affecting a group or all of the preferences and (2) the level of the respondent's expertise, which usually leads to systematic preference deviations for all of the parameters.

Furthermore, the sensitivity analysis proposed by Promentilla and his colleagues (2008) provides a useful tool for the sensitivity analysis of an AHP problem based on (1) the degree of the optimism–pessimism of the respondent and, more important, (2) the degree of uncertainty in the answers. It can be very useful for the AHP/ANP problems in developing and underdeveloped countries and when the group of respondents is not expert enough or only partially expert to answer the questions. In such cases, a sensitivity analysis can be performed for different degrees of uncertainty and it can be checked to see whether the alternative ranks are currently robust enough or not.

ANP Instead of AHP

As shown in Table 8, not only can ANP be applied to capturing any dependency among the items entered into the problem structure, but it should also be used instead of the hierarchical structure that embodies considerable variation in the criteria's relative weights from one alternative to another.

Specialists from Countries Abroad

The number of specialists in every realm of scientific domains in a developed country is likely to be higher than in a developing country. As a result, using specialists from foreign countries is useful to consolidate the AHP/ANP results. Therefore, it may be necessary to consider the recruitment of a foreign expert or a group of foreign experts.

Meta-Analysis

When a study is done in a developing country, the meta-analysis of the results of similar studies performed in other countries, especially in developed countries, is useful to identify the boundary of the preferences and overall weights of the items. The statistical analysis of a large collection of analyses (AHP, ANP, or even BC analysis) for the purpose of integrating the findings could help analysts to discover the limitations and boundaries of the analysis.

Conclusion

This article addresses problems in the application of the AHP and ANP methods for benefit–cost analyses in developing countries where there is limited actual financial data for CB analysis and the level of local expertise for providing technical and economic judgments is low.

At the outset, this article presented evidence for growing interest in the AHP/ANP methods in developing countries. It also discussed the major differences in the specifications, situations, and limitations of these methods in both developed and developing countries. We then presented the theoretical outline of the benefit–cost analysis via the AHP, AHP^f (i.e., AHP with fictitious monetary values), and ANP. Through the comparison made between the AHP and the benchmark BC analyses (NPV and BCR analyses), the major issues in the application of AHP and ANP in developing countries were explained. Then, through a real case example, the proposed idea was demonstrated. Finally, in the Discussion and Suggestions section, key points for better utilizing the AHP and ANP in developing countries were presented.

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