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Management decision-making by the analytic hierarchy process: a proposed modification for large-scale problems

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Abstract: The use of the analytic hierarchy process (AHP) for decision making is sometimes marred by the laborious effort of conducting a large number of pairwise comparisons, especially in the presence of a large number of criteria. The present empirical study attempts to investigate the possibility of eliminating insignificant criteria in order to reduce AHP computational time. Using Expert Choice software, findings confirmed that criteria assigned with comparatively lesser weights can be excluded from the hierarchy and thereby the total time required for making pairwise comparisons is reduced. To solve large-scale enterprise multi-criteria decision-making problems (that involve large number of criteria) by AHP, it is proposed that, at the very outset, decision-makers can apply nominal group technique to identify the more significant criteria and drop lesser important criteria from the list. This proposed methodology is expected to enhance the applicability of AHP in solving various kinds of larger sized multi-criteria decision-making problems in any enterprise.

Keywords: analytic hierarchy process; decision support; international business; large-scale problems; multiple criteria decision-making; nominal group technique.

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1 Introduction

Making decisions is an important part of all managers' jobs. There are numerous types of decision-making problems with which a typical manager has to deal – where to locate a new facility or a new branch, which supplier to select, whether or not to opt for outsourcing, how much budget to allocate among competing departments, etc. Most of these decision-making problems involve multiple criteria. Many quantitative methods have been developed to facilitate making rational decisions involving multiple criteria. One such method is the Analytic Hierarchy Process (AHP) developed by Professor Thomas Saaty in 1977 (Saaty, 1977). Since its development, the AHP has been successfully applied to solve a wide range of multi-criteria decision-making problems. Some areas where AHP has been applied are: location analysis (Min, 1994), resource allocation (Cheng and Li, 2001; Ramanathan and Ganesh, 1995), outsourcing (Udo, 2000), evaluation (Cheng, 1997; Chin et al., 1999; Davis and Williams, 1994; Liang, 2003), manufacturing (Joh, 1997; Labib et al., 1998; Razmi et al., 1998), marketing (Bahmani et al., 1986; Davies, 2001; Dyer et al., 1992), supplier selection (Bhutta and Huq, 2002), finance (Bolster et al., 1995), energy (Kim and Min, 2004; Saaty and Gholamnezhad, 1981), education (Saaty, 1991; Tadisina et al., 1991) and risk analysis (Millet and Wedley, 2002; Saaty, 1987). All these applications amply show the suitability of AHP in solving various types of business decision-making problems.

Despite the impressive success of AHP in solving myriad types of decision-making problems, the method suffers from the fact that it requires a large number of pairwise comparisons (consequently, a significant amount of computational time), especially for the problems that involve larger numbers of criteria. The primary objective of this paper is to propose a new mode of application of AHP, which is expected to enhance its applicability in solving large-scale problems. To demonstrate, we will apply AHP to solve a multi-criteria decision-making problem in two stages. In the first stage, the problem will be solved using the traditional approach of AHP and in the second stage, AHP will be applied to solve the same problem but by considering only the relatively more important criteria. Results and findings will then be presented. The significance of this proposed methodology on managerial decision-making and how practical applicability can be enhanced by incorporating the Nominal Group Technique are also discussed. Before presenting our proposed mode of application of the AHP for large-scale problems, we provide a brief description of the AHP.

2 The analytic hierarchy process (AHP)

The analytic hierarchy process (AHP) is a method that solves multi-criteria decision-making problems involving objective as well as subjective criteria (Saaty, 1977). The method has the following four steps:

- Step 1: decompose the decision-making problem and find out the salient factors or elements (criteria, sub-criteria, alternatives, etc.) of the problem. Then construct the linear hierarchy of the problem consisting of a finite number of levels or components. Each level consists of a finite number of decision elements. The goal, or focus, of the problem lies at the first level. Usually, the criteria and sub-criteria occupy the second and third levels respectively. Lastly, the decision alternatives are placed at the lowest level of the hierarchy.
- Step 2: construct pairwise comparison matrices for all the criteria, sub-criteria, and alternatives. The typical form of a pairwise comparison matrix is as follows:

$$\mathbf{A} = \begin{array}{c|cccc} \text{‘O’} & F_1 & F_2 & \dots & F_n \\ \hline F_1 & a_{11} & a_{12} & \dots & a_{1n} \\ F_2 & a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ F_n & a_{n1} & a_{n2} & \dots & a_{nn} \end{array}$$

where $a_{ij} = \frac{w_i}{w_j}$ (for $i, j = 1,2, \dots, n$) represents the strength of importance/preference of the factor (criterion/alternative) F_i over F_j with respect to the objective ‘O’, $a_{ji} = \frac{1}{a_{ij}}$ w_i, $i = 1, 2, \dots, n$ are the priority weights (to be determined) of the factors. The entries a_{ij}s are normally taken from the (1/9–9) ratio-scale (Saaty, 1980). The semantic interpretation of the matrix elements is provided in Table 1.

Table 1 Scale of relative measurement of AHP

Intensity of importance/preference	*Definition*	*Explanation*
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favour one activity over another
5	Essential or strong importance	Experience and judgment strongly favour one activity over another
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; dominance is demonstrated in practice

Table 1 Scale of relative measurement of AHP (continued)

Intensity of importance/preference	*Definition*	*Explanation*
1	Equal importance	Two activities contribute equally to the objective
9	Absolute importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between adjacent scale values	When compromise is needed
Reciprocals of above nonzero ratios	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*.	A reasonable assumption

- Step 3: determine the weights of the criteria, sub-criteria, alternatives, etc. from the pairwise comparison matrices obtained in Step 2 by using the eigenvalue method. This is done by solving the following linear simultaneous equations:

$$w_i = \frac{1}{\lambda_{\max}} \sum_{j=1}^{n} a_{ij} w_j, \quad i = 1, 2, ..., n$$

where λ_{max} is the largest eigenvalue of the pairwise comparison matrix A. For uniqueness, we normalise the set of weights such that $\sum_{i=1}^{n} w_i = 1$.

- Step 4: using the principle of hierarchical composition, synthesise all the local set of weights and obtain the set of overall or global weights for the alternatives. The alternative that receives the overall highest weight with respect to the goal of the problem is selected as the best.

3 Literature review

Harker (1987a) suggested that the number of pairwise comparisons could be reduced by using his incomplete pairwise comparison technique. His suggestion was based on the premise that there might be times when the decision maker would not be able to decide his/her preferences for some alternatives, thereby allowing the decision maker to skip those comparisons and move on. Harker's proposed method was to complete less than the required $n\frac{(n-1)}{2}$ comparisons for an $n \times n$ pairwise comparison matrix but still there would remain sufficient comparisons for deriving a meaningful measure of the alternatives' relative weights. Harker (1987b) also proposed an extension of the eigenvector approach of AHP to approximate non-linear functions of the ratios of weights.

The method was based on the theory of non-negative, quasi-reciprocal matrices but it was found to be ineffective for problems with a large number of criteria and could be difficult to understand and apply by a non-mathematician.

On the other hand, Weiss and Rao (1987) presented a balanced incomplete block design (BIBD) technique to reduce the number of pairwise comparisons. Their work was different from Harker's (1987a, 1987b) in the sense that they developed a factorial design of the comparisons for large scale problems. The proposal was to allocate the appropriate portions of the hierarchy to different respondents rather than having each respondent working on the entire hierarchy. The proposal was also based on the assumption that people who make large numbers of comparisons become less consistent. They also suggested deleting attributes that were identical to one another. However, their guidelines for deletion of attributes seemed arbitrary.

In view of the above shortcomings of the various proposed methodologies, Saaty (1980) suggested making clusters of alternatives according to a common attribute. The practicality of this approach was tested and found to be effective by Islam et al. (1997). The authors made several clusters of the set of alternatives and solved six problems adopting from the existing AHP literature and compared the results with the actual ones published in the corresponding literature. The results of this experimental study were found to be exactly the same as the actual ones. Another technique was proposed by Lim and Swenseth (1993), called the iterative procedure for reducing problem size in large-scale AHP problems. The iterative procedure was very similar to Harker's (1987a) incomplete pairwise comparison technique. In the proposed technique, when one dominant solution is obtained the remaining comparisons need not be completed, therefore, it reduces the effort required to arrive at a decision. The major drawback of this iterative procedure is that it is only relevant for problems with a dominant solution, otherwise, the analysis will be carried out as it is normally in the traditional AHP method.

Our proposed mode of application of AHP for large-scale problems is presented through an experiment in the following section.

4 The experiment: choosing a venue to host an international conference

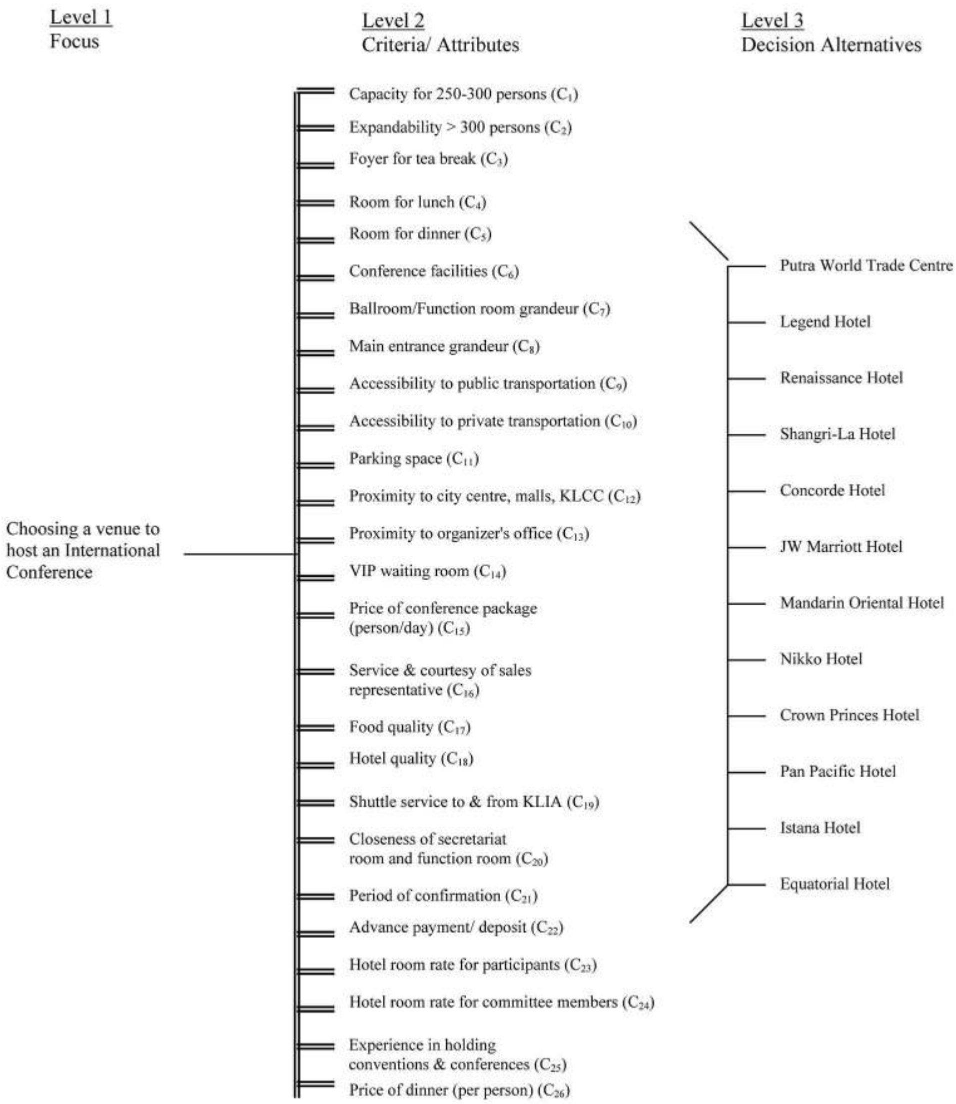
The authors' department organised an international conference on Islamic Gold Dinar during August 19–20, 2002. Initially, the organising committee members considered 12 hotels in Kuala Lumpur to host the conference. Of those 12 hotels, only one was finally selected based upon a large number of criteria. Twenty six independent criteria/attributes were initially thought to be important for the decision. Firstly, using AHP we have solved the problem considering all the 26 criteria. Secondly, the problem has been solved considering only the relatively more important criteria. The results from both the phases have been compared and correlation between the two sets of ranking for the alternatives has been computed and statistically tested.

4.1 Phase 1: considering all the criteria

4.1.1 Developing the decision hierarchy

The goal of the decision problem lies in level 1 of the hierarchy. The second level of the hierarchy contains the criteria (attributes) that contribute to the goal of the decision. The lowest level of the hierarchy contains decision alternatives, i.e. the hotels. The hierarchy is shown in Figure 1.

Figure 1 The decision hierarchy of the venue selection problem



- *Level 1:* the focus/goal is the decision of choosing a venue to host an international conference.
- *Level 2:* this level consists of criteria/attributes that are considered important in choosing the venue. In this study, a total of 26 criteria were identified based on a focus group involving five organising committee members: the chairman, deputy chairman, the secretary (the first author of this paper) and two other members. The group identified 26 criteria which were perceived to be important in the venue selection process. The criteria are shown at level 2 of the decision hierarchy. Some of the criteria are discussed in the following: though the exact number of participants was unknown at the time of booking the venue, the committee estimated the figure to be in the range of 250–300 persons (C_1). So the hotel, which could not accommodate 250 persons, was not considered as a possible venue. Some of the hotel's accommodation capacity exceeded 300 persons. The committee also felt that after booking for 300 persons, if needed, the hotel should be ready to accommodate the additional number of participants (C_2). 'Service and courtesy of sales representative (C_{16})' will be judged when the hotels are visited – careful attention is to be paid on how the committee members are treated by the hotel staff. Hotel room rate for participants and committee members (C_{23} and C_{24}) are not equal for all the hotels. Some hotels provide complimentary rooms for the committee members. Some hotels insist on an advance payment/deposit (C_{22}) whereas others do not require this. The conference organiser's office is located at Gombak, which is about 10 km north of Kuala Lumpur. In view of traffic jams in the early morning, the distance of the hotel from Gombak (C_{13}) is a matter of concern. Conference facilities (C_6) must include internet facilities for the participants, photocopying facilities, flip charts, projectors, etc. Hotel quality (C_{18}) is to be evaluated by the members on the basis of surroundings, overall cleanliness, etc. The price of dinner (C_{26}) varies from one hotel to another even for a pre-specified menu.
- *Level 3:* this level consists of the 12 decision alternatives (hotels) to host the international conference. The set of hotels includes Putra World Trade Centre (PWTC) (actually this is not a hotel but frequently considered for organising large conferences), Legend Hotel, Renaissance Hotel, Shangri-La Hotel, Concorde Hotel, JW Marriott Hotel, Mandarin Oriental Hotel, Nikko Hotel, Crown Princes Hotel, Pan Pacific Hotel, Istana Hotel, and Equatorial Hotel.

4.1.2 Assessing relative importance/preference of criteria/alternatives

After constructing the hierarchy, the next task is to assess the relative importance of the criteria in level 2 with respect to the goal of the decision problem and preference of level 3 decision alternatives with respect to each of the criteria in level 2.

The pairwise comparisons start with comparing criteria at level 2 with one another in relation to the importance in choosing the venue. A typical question in constructing the pairwise comparison matrix (PCM) for the criteria is: how important is 'capacity for 250 persons' relative to 'expandability to cater for more than 300 persons'? If the importance of 'capacity for 250 persons' relative to 'expandability to cater for more than 300 persons' is 2, then the importance of 'expandability to cater for more than 300 persons' relative to 'capacity for 250 persons' is 1/2. The ratios then form a matrix called a 'reciprocal matrix' where the lower triangular part is the reciprocal of the upper triangular part. The PCM is constructed using Saaty's (1/9–9) scale as shown in Table 1. Since the diagonal elements are all equal to one, only $n\frac{(n-1)}{2}$ comparisons are required where '*n*' is the number of factors in the level. Each of the group members (previously mentioned) constructed the PCM for the criteria separately. The members were briefed about AHP by the second author of this paper. The conference secretary's pairwise comparison matrix is shown in Table 2.

Matrices of the other four members were constructed similarly. Afterwards, the elements for each pairwise comparison (for all the five members) were synthesised using Team Expert Choice software which, in turn, uses geometric mean rule (Basak and Saaty, 1993). The synthesised PCM is shown in Table 3 where the weights are shown in the last column.

In the next stage, weights of the alternatives with respect to each of the criteria are computed in the same way as has been done for the criteria set. The prerequisite for determining the weights of the alternatives is to know the performances of the individual hotels on various criteria. For this matter, the committee members visited the hotels to collect first-hand information on their performances on the listed criteria. The weights of the alternatives are shown in Table 4. The weights of the alternatives with respect to the first criterion are to be noted. One may think that when two hotels have the capacity for 250 to 300 persons, they should receive the same weights or same preference but, in reality, this may not be the case on account of room size (how the chairs are arranged – cramped or sufficient space between chairs) and the arrangement (layout) of chairs. Since PWTC is not a hotel, for criteria C_{19}, C_{23}, and C_{24}, Legend Hotel is considered in lieu of PWTC. This is because Legend Hotel and PWTC are located in close proximity and Legend can be used for those criteria where PWTC is not applicable. The second last column provides the global weights (also computed using Team Expert Choice) of the alternatives. The last column provides the rank of the alternatives based upon the global weights.

Table 2 A pairwise comparison matrix for the 26 criteria

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	C_{20}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	*wts.*
C_1	1	6	2	1	1	1	1	1/2	5	5	5	5	7	1	1/2	8	1/2	1/2	9	2	9	9	3	3	1/2	1/2	0.053
C_2		1	1/5	1/6	1/6	1/6	1/7	1/7	1/2	1/2	1/2	1/2	1	1/7	1/8	1	1/8	1/8	2	1/5	2	2	1/3	1/3	1/9	1/9	0.008
C_3			1	1/2	1/2	1/2	1/3	1/3	4	3	4	4	6	1/2	1/3	7	1/2	1/2	8	1	8	8	2	3	1/2	1/2	0.038
C_4				1	1	1/2	1/2	1/3	5	4	4	5	7	1/2	1/3	6	1/2	1/2	9	2	9	9	3	3	1/3	1/3	0.046
C_5					1	1	1	1/2	5	5	5	6	7	1	1	7	1/2	1/2	9	2	9	8	3	4	1/2	1/2	0.055
C_6						1	1	1/2	6	5	5	5	7	1	1/2	8	1/2	1/2	9	2	8	8	2	3	1/2	1/2	0.054
C_7							1	1	5	5	6	5	8	1	1/2	9	1/2	1/2	9	2	8	8	3	3	1/2	1/2	0.058
C_8								1	6	5	6	5	8	1	1	9	1	1	9	2	9	9	3	3	1/2	1/2	0.071
C_9									1	1	1	1	2	1/5	1/6	2	1/6	1/6	2	1/4	2	2	1/2	1/2	1/7	1/7	0.012
C_{10}										1	1	1	2	1/5	1/6	2	1/6	1/6	2	1/4	2	3	1/2	1/2	1/8	1/8	0.012
C_{11}											1	1	2	1/5	1/5	2	1/5	1/6	2	1/4	2	3	1/2	1/2	1/8	1/8	0.012
C_{12}												1	2	1/5	1/6	2	1/6	1/6	2	1/4	2	3	1/2	1/2	1/8	1/8	0.012
C_{13}													1	1/8	1/9	1	1/9	1/9	1	1/5	1	1	1/3	1/3	1/9	1/9	0.007

Table 2 A pairwise comparison matrix for the 26 criteria (continued)

	C_{1}	C_{2}	C_{3}	C_{4}	C_{5}	C_{6}	C_{7}	C_{8}	C_{9}	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	C_{20}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	*wts.*
C_{14}														1	1/2	9	1/2	1/2	9	2	9	9	3	3	1/2	1/2	0.057
C_{15}															1	9	1	1	9	2	9	9	3	3	1	1	0.077
C_{16}																1	1/9	1/9	1	1/6	1	1	1/4	1/3	1/9	1/9	0.077
C_{17}																	1	1	9	2	9	9	3	3	1	1	0.076
C_{18}																		1	9	2	9	9	3	3	1	1	0.077
C_{19}																			1	1/7	1	1	1/4	1/4	1/9	1/9	0.006
C_{20}																				1	3	3	2	2	1/2	1/2	0.036
C_{21}																					1	1	1/4	1/3	1/9	1/9	0.007
C_{22}																						1	1/4	1/3	1/9	1/9	0.007
C_{23}																							1	1	1/3	1/3	0.023
C_{24}																								1	1/3	1/3	0.021
C_{25}																									1	1	0.085
C_{26}																										1	0.085

Table 3 The synthesised pairwise comparison matrix for the 26 criteria

	C₁	*C₂*	*C₃*	*C₄*	*C₅*	*C₆*	*C₇*	*C₈*	*C₉*	*C₁₀*	*C₁₁*	*C₁₂*	*C₁₃*	*C₁₄*	*C₁₅*	*C₁₆*	*C₁₇*	*C₁₈*	*C₁₉*	*C₂₀*	*C₂₁*	*C₂₂*	*C₂₃*	*C₂₄*	*C₂₅*	*C₂₆*	*wts.*
C_1	1	6.22	1.22	1.10	.95	.97	.89	.82	4.67	5.09	5.60	5.09	7	.93	.80	8	.78	.78	8.33	1.33	7.33	8.53	2.24	2.43	.76	.76	0.056
C_2		1	.19	.16	.15	.16	.14	.13	.75	.82	.90	.82	1.13	.15	.13	1.29	.13	.13	1.50	.21	1.50	1.50	.36	.39	.12	.12	0.009
C_3			1	.84	.78	.79	.73	.68	3.83	4.18	4.60	4.18	5.75	.77	.66	6.57	.64	.64	7.67	1.09	7.67	7.67	1.84	2	.62	.62	0.047
C_4				1	.93	.95	.87	.81	4.58	5	5.50	5	6.87	.92	.78	7.86	.76	.76	9.17	1.31	8.17	7.17	2.20	2.39	.74	.74	0.055
C_5					1	1.02	.94	.87	4.92	5.36	5.90	5.36	7.37	.98	.84	8.43	.82	.82	8.83	1.40	8.83	8.63	2.36	2.56	.79	.79	0.059
C_6						1	.92	.85	4.83	5.27	5.80	5.27	7.25	.96	.83	8.28	.80	.80	8.67	1.38	7.67	8.87	2.32	2.52	.78	.78	0.057
C_7							1	.93	5.25	5.73	6.30	5.73	7.87	1.05	.90	9	.87	.87	8.50	1.50	8.50	8.00	2.52	2.74	.85	.85	0.062
C_8								1	5.67	6.18	6.80	6.18	8.50	1.13	.97	8.71	.94	.94	8.33	1.62	8.33	8.66	2.72	2.96	.92	.92	0.066
C_9									1	1.09	1.20	1.09	1.50	.20	.17	1.71	.16	.16	2	.28	2	2	.48	.52	.16	.16	0.012
C_{10}										1	1.10	1	1.37	.18	.16	1.57	.15	.15	1.83	.26	1.83	1.83	.44	.47	.15	.15	0.011
C_{11}											1	.90	1.25	.16	.14	1.43	.14	.14	1.67	.24	1.67	1.67	.40	.43	.13	.13	0.010
C_{12}												1	1.37	.18	.16	1.57	.15	.15	1.83	.26	1.83	1.83	.44	.47	.15	.15	0.011
C_{13}													1	.13	.11	1.14	.11	.11	1.33	.19	1.33	1.33	.32	.35	.11	.11	0.008

Table 3 The synthesised pairwise comparison matrix for the 26 criteria (continued)

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	C_{20}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	*wts.*
C_{14}														1	.86	8.57	.83	.83	9	1.42	9	9	2.40	2.61	.81	.81	0.060
C_{15}															1	9	.97	.97	8.67	1.67	8.66	8.66	2.80	3.04	.94	.94	0.068
C_{16}																1	.09	.09	1.16	.17	1.16	1.16	.28	.30	.09	.09	0.007
C_{17}																	1	1	9	1.71	8	8.50	2.88	3.13	.97	.97	0.070
C_{18}																		1	8	1.71	9	8.50	2.88	3.13	.97	.97	0.070
C_{19}																			1	.14	1	1	.24	.26	.08	.08	0.007
C_{20}																				1	7	7	1.68	1.82	.57	.57	0.043
C_{21}																					1	1	.24	.26	.08	.08	0.007
C_{22}																						1	.24	.26	.08	.08	0.007
C_{23}																							1	1.09	.34	.34	0.025
C_{24}																								1	.31	.31	0.023
C_{25}																									1	1	0.075
C_{26}																										1	0.075

Table 4 Weights of the criteria and the alternatives for the problem of choosing a venue to host an international conference (before the exclusion exercise)

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
	(0.056)	*(0.009)*	*(0.047)*	*(0.055)*	*(0.059)*	*(0.057)*	*(0.062)*	*(0.066)*	*(0.012)*	*(0.011)*	*(0.010)*	*(0.011)*	*(0.008)*
Alternatives													
PWTC	0.186	0.224	0.322	0.291	0.168	0.195	0.041	0.126	0.176	0.185	0.251	0.117	0.208
Legend Hotel	0.062	0.039	0.093	0.036	0.039	0.040	0.041	0.041	0.176	0.185	0.193	0.158	0.199
Renaissance Hotel	0.136	0.192	0.056	0.176	0.173	0.159	0.206	0.178	0.021	0.020	0.023	0.026	0.026
Shangri-La Hotel	0.153	0.124	0.097	0.115	0.127	0.108	0.125	0.119	0.021	0.024	0.023	0.022	0.025
Concorde Hotel	0.036	0.022	0.031	0.031	0.028	0.041	0.039	0.018	0.021	0.026	0.023	0.023	0.025
JW Marriot Hotel	0.080	0.076	0.038	0.057	0.076	0.087	0.119	0.105	0.020	0.019	0.023	0.143	0.024
Mandarin Oriental Hotel	0.136	0.153	0.121	0.090	0.158	0.129	0.211	0.198	0.020	0.021	0.023	0.026	0.024
Nikko Hotel	0.114	0.087	0.054	0.115	0.089	0.073	0.090	0.090	0.195	0.197	0.023	0.092	0.111
Crown Princess Hotel	0.017	0.013	0.022	0.013	0.014	0.013	0.015	0.015	0.125	0.082	0.132	0.210	0.098
Pan Pacific Hotel	0.040	0.028	0.022	0.019	0.085	0.081	0.058	0.064	0.185	0.197	0.240	0.135	0.208
Istana Hotel	0.027	0.028	0.024	0.028	0.026	0.050	0.037	0.029	0.019	0.021	0.023	0.024	0.025
Equatorial Hotel	0.012	0.014	0.120	0.030	0.016	0.023	0.017	0.015	0.020	0.022	0.023	0.022	0.025

Table 4 Weights of the criteria and the alternatives for the problem of choosing a venue to host an international conference (before the exclusion exercise) (continued)

Criteria	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	C_{20}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	*GW**	*R***
	(0.060)	*(0.068)*	*(0.007)*	*(0.070)*	*(0.070)*	*(0.007)*	*(0.043)*	*(0.007)*	*(0.007)*	*(0.025)*	*(0.023)*	*(0.075)*	*(0.075)*		
Alternatives															
PWTC	0.359	0.149	0.149	0.028	0.153	0.164	0.169	0.094	0.082	0.163	0.214	0.433	0.085	0.188	1
Legend Hotel	0.129	0.165	0.207	0.090	0.054	0.164	0.168	0.064	0.087	0.163	0.214	0.042	0.085	0.088	4
Renaissance Hotel	0.042	0.042	0.016	0.108	0.166	0.088	0.024	0.099	0.121	0.041	0.055	0.040	0.128	0.109	2
Shangri-La Hotel	0.042	0.028	0.038	0.076	0.125	0.066	0.038	0.094	0.082	0.014	0.025	0.041	0.082	0.083	6
Concorde Hotel	0.042	0.098	0.043	0.041	0.021	0.062	0.032	0.084	0.067	0.171	0.025	0.039	0.087	0.045	10
JW Marriot Hotel	0.055	0.172	0.040	0.065	0.123	0.07	0.073	0.079	0.093	0.030	0.025	0.038	0.101	0.081	7
Mandarin Oriental Hotel	0.080	0.012	0.045	0.088	0.148	0.062	0.073	0.082	0.082	0.010	0.045	0.044	0.069	0.101	3
Nikko Hotel	0.080	0.036	0.044	0.079	0.095	0.081	0.079	0.067	0.093	0.022	0.025	0.145	0.077	0.086	5
Crown Princess Hotel	0.037	0.064	0.118	0.033	0.017	0.062	0.146	0.082	0.082	0.077	0.074	0.042	0.056	0.043	11
Pan Pacific Hotel	0.054	0.099	0.022	0.030	0.035	0.075	0.082	0.094	0.064	0.099	0.207	0.042	0.085	0.068	8
Istana Hotel	0.046	0.064	0.090	0.036	0.027	0.046	0.058	0.087	0.067	0.099	0.025	0.042	0.067	0.041	12
Equatorial Hotel	0.032	0.070	0.188	0.327	0.032	0.062	0.054	0.076	0.082	0.109	0.068	0.053	0.079	0.065	9

Notes: * GW = Global weights of the alternatives, **R = Rank

4.2 Phase 2: the exclusion exercise

Since there are 26 criteria, altogether 26(26 - 1)/2 = 365 comparisons are made to construct the criteria PCM. Further, for each of these 26 criteria, a PCM is constructed for the alternatives. The size of each matrix is 12. Hence for all the 26 criteria, the total number of pairwise comparisons made (for alternatives only) is 26 × 12(12 - 1)/2 = 1716. Therefore, at the first phase, the total number of pairwise comparisons made is 365 + 1716 = 2081.

In the next phase of the study, we exclude the criteria that carry relatively lesser weights. In order to observe the effect on the ranking of the alternatives, we kept the following 12 criteria:

1) capacity for 250–300 persons (C_1)
2) room for lunch (C_4)
3) room for dinner (C_5)
4) conference facilities (C_6)
5) ballroom/function room grandeur (C_7)
6) main entrance grandeur (C_8)
7) VIP waiting room (C_{14})
8) price of conference package (C_{15})
9) food quality (C_{17})
10) hotel quality (C_{18})
11) experience in holding conventions and conferences (C_{25})
12) price of dinner (C_{26}).

These 12 criteria are selected because they possess relatively higher weights compared with the rest. The weights of these criteria are adjusted so that the sum becomes unity. Since the weights of the alternatives with respect to these criteria are already computed, no further pairwise comparison matrix is required to be constructed. The ranking of the alternatives with respect to these 12 criteria has been shown in Table 5.

The correlation coefficient of the ranks obtained for the alternatives in the above two exercises is 0.923, which is highly significant ($p < 0.001$). This result suggests that there is a strong positive correlation between the ranks of the alternatives before and after the exclusion exercise. It is also to be noted that, in the second phase, the total number of pairwise comparison required is:

$$\frac{12(12-1)}{2}+12\times\frac{12(12-1)}{2}=858 \text{ (for 12 criteria and 12 alternatives)}$$

Therefore, if only the dominant criteria are used, then we can save about 2081 - 858 = 1223 pairwise comparisons (58.77% saving). Even after these savings we have been able to derive rankings of the alternatives in two exercises that are sufficiently close to each other.

Table 5 Weights of the criteria and alternatives for the problem of choosing a venue to host an international conference (after the exclusion exercise)

Criteria	C_1	C_4	C_5	C_6	C_7	C_8	C_{14}	C_{15}	C_{17}	C_{18}	C_{25}	C_{26}	*GW*	*R*
	(0.072)	*(0.071)*	*(0.076)*	*(0.074)*	*(0.080)*	*(0.085)*	*(0.078)*	*(0.088)*	*(0.090)*	*(0.090)*	*(0.097)*	*(0.097)*		
Alternatives														
PWTC	0.186	0.291	0.168	0.195	0.041	0.126	0.359	0.149	0.028	0.153	0.433	0.085	0.183	1
Legend Hotel	0.062	0.036	0.039	0.040	0.041	0.041	0.129	0.165	0.090	0.054	0.042	0.085	0.069	7
Renaissance Hotel	0.136	0.176	0.173	0.159	0.206	0.178	0.042	0.042	0.108	0.166	0.040	0.128	0.127	2
Shangri-La Hotel	0.153	0.115	0.127	0.108	0.125	0.119	0.042	0.028	0.076	0.125	0.041	0.082	0.093	4
Concorde Hotel	0.036	0.031	0.028	0.041	0.039	0.018	0.042	0.098	0.041	0.021	0.039	0.087	0.044	10
JW Marriot Hotel	0.080	0.057	0.076	0.087	0.119	0.105	0.055	0.172	0.065	0.123	0.038	0.101	0.090	5
Mandarin Oriental Hotel	0.136	0.090	0.158	0.129	0.211	0.198	0.080	0.012	0.088	0.148	0.044	0.069	0.111	3
Nikko Hotel	0.114	0.115	0.089	0.073	0.090	0.090	0.080	0.036	0.079	0.095	0.145	0.077	0.089	6
Crown Princess Hotel	0.017	0.013	0.014	0.013	0.015	0.015	0.037	0.064	0.033	0.017	0.042	0.056	0.029	12
Pan Pacific Hotel	0.040	0.019	0.085	0.081	0.058	0.064	0.054	0.099	0.030	0.035	0.042	0.085	0.057	9
Istana Hotel	0.027	0.028	0.026	0.050	0.037	0.029	0.046	0.064	0.036	0.027	0.042	0.067	0.040	11
Equatorial Hotel	0.012	0.030	0.016	0.023	0.017	0.015	0.032	0.070	0.327	0.032	0.053	0.079	0.062	8

5 Reducing the number of criteria

The above experimental study shows the minimal effect of exclusion of the less important criteria from the decision tree. However, it is to be noted that, in the foregoing experiment, we have identified the less important criteria only after determining the weights of all the criteria by AHP. The proposal of this paper is to exclude less important criteria at the beginning of the exercise. Now the question is: in the beginning how do we know which criteria are important and which are not? A simple solution to this problem is to apply Nominal Group Technique (NGT) at the beginning of the exercise.

NGT is a highly useful, structured brainstorming technique that is used to produce a large number of ideas pertaining to an issue/problem while ensuring balanced participation among the group members (Delbecq et al., 1975). NGT not only generates a large number of ideas, but also it prioritises those ideas using certain voting techniques. After the voting session, the ideas that receive a higher number of votes are generally considered superior or important ideas. In the following, we provide the working rule of NGT that can be applied to reduce the number of criteria by eliminating the lesser important criteria.

Nominal Group Technique requires a group of about eight people. This group is facilitated by someone who is expected to have prior experience in conducting some nominal group sessions. The group members meet in a meeting room equipped with a marker board and marker pen and each of them has a few sheets of paper. The steps to be followed are as follows:

- Step 1: silent generation of criteria in writing – participants are given about ten minutes to write down as many criteria as possible pertaining to the decision making problem.
- Step 2: round-robin recording of criteria – the facilitator asks every participant (starting from one end of the room) to provide the most important criterion (participants have to judge which one is the most important criterion) from his/her list. If there are eight participants then there should be eight important criteria recorded in the first round. After this, the facilitator goes for the second round, collecting the second most important criterion from the lists of all the participants. Subsequent rounds are carried out till all the criteria are exhausted from the participants' lists. By this time, all the relevant criteria are written down on the marker board. The list generated is usually called the master list.
- Step 3: voting to select the most important criteria – each participant is asked to identify the most important five criteria from the master list on the board and rank them using a 1 to 5 scale according to their importance. The most important criterion is assigned a rating of 5 and the least among these five criteria receives the rating of 1. When all the participants finish the ranking task, cards are collected from them and votes are written against the criteria on the board. When the votes are aggregated, it is easy to single out the important criteria. If there are, say, 25 criteria in the master list and we want to consider the most important ten, then the ten criteria that receive higher votes are to be chosen.

With the above proposed modification of the traditional AHP, the number of criteria is reduced significantly. The nominal group session eliminates those criteria that are insignificant. The removal of such criteria has minimal effect on the choice of the best alternative as shown in the foregoing experimental study. With the reduction of the number of criteria, the number of pairwise comparisons is also reduced, decision analysis is simplified and the time needed for the whole work is reduced significantly. This makes the use of AHP less taxing on the part of the decision maker.

In the following, we cite an example where NGT has been applied to reduce the number of criteria for a multi-criteria decision-making problem.

5.1 Example

Choosing a foreign country for expansion of a certain manufacturing business – there are numerous multinational companies in the business world. To extend business across nations, these companies choose countries systematically and after thorough analysis. In fact, choice of a country is a well-known MCDM problem. For a typical manufacturing (electronics, electrical, chemical, etc) company, 24 criteria are identified from relevant literature which are shown in Table 6. Initially, the manufacturing company which is planning to expand business overseas may choose, say, 15 countries. All these countries are to be evaluated based upon all the 24 criteria. Application of AHP to solve the problem requires altogether 2796 pairwise comparisons. However, it is to be noted that all these criteria are not equally important. In the initial phase, the criteria can be reduced by applying NGT. In fact, we conducted a nominal group session and seven academic staff from the authors' department and one academic staff member from the Economics department participated[1]. The results are shown in the third column of Table 6. The outcome of the nominal group session is the identification of the major criteria (out of a total 24) in choosing the foreign country for expansion of a manufacturing business.

Table 6 Major criteria in choosing a country for expansion of a manufacturing business

No.	*Criteria*	*Weights*	*Rank*
1	Economy of the country	4 + 4 + 4 + 3 = 17	3
2	Language		
3	Threat of expropriation		
4	Government interference	2 + 4 = 6	7
5	Government stability	5 + 5 + 5 + 5 + 5 + 2 = 27	1
6	Labour skill (training requirement)	2	
7	Work culture/worker productivity	1	
8	Local equity and financing		
9	Availability of technology	3 + 3 = 6	7
10	Transportation and distribution systems	3 + 4 + 2 + 3 + 1 + 5 = 18	2
11	Competitors' strength		
12	Distance from market concentration		
13	Climate		
14	Raw materials cost	5	

Table 6 Major criteria in choosing a country for expansion of a manufacturing business (continued)

No.	*Criteria*	*Weights*	*Rank*
15	Tax structure	1 + 3 + 3 = 7	6
16	Availability of raw materials	5	
17	Construction cost		
18	Business climate/opportunity	2 + 4 = 6	
19	Wage rate	2 + 2 + 1 + 4 = 9	4
22	Quality of life		
21	Real estate, utility costs		
22	Exchange rate	1 + 2 + 2 = 5	
23	Financial incentive by local government	1 + 4 + 3 = 8	5
24	Possibility of future expansion	1	

For the actual evaluation of the countries by AHP, the decision makers can consider those criteria that receive higher weights. They may consider five, seven or ten criteria. For the current exercise, the seven most important criteria (obtained from the nominal group session) are listed below:

- government satiability
- transportation and distribution systems
- economy of the country
- wage rate
- financial incentive by the local government
- tax structure
- availability of technology (or Government interference).

If the decision makers decide to consider only these seven criteria, then the total number of pairwise comparisons required for the 15 countries is 756. Therefore, elimination of insignificant criteria saves 2796 - 756 = 2040 pairwise comparisons.

Occurrences of multi-criteria decision-making (MCDM) problems are quite common in many areas. Saaty and Forman (2000) have compiled about 352 MCDM problems in the areas of conflict analysis, education, energy, finance, forestry, health, information system, marketing, military, polities, resource allocation, sports, technology, etc. Many of these problems involve large numbers of criteria. Table 7 provides 29 MCDM problems (adopted from Saaty and Forman (2000)) that involve 20 or more than 20 criteria.

Table 7 Selected MCDM problems that involve large numbers of criteria

No.	*Problem*	*No. of criteria*
1	Deciding whether to bid for a contract	20
2	Deciding which banks should be considered as candidates for acquisition?	19
3	Selecting the best company to acquire	23
4	Acquiring an MIS system for vehicle fleet management	31
5	Selecting a software package for local union's membership and dues processing	39
6	Selecting a desktop publishing software	32
7	Selecting a database system	25
8	Establishing priorities for recommended projects in order to distribute limited resources and time	29
9	Evaluating the quality of software products	28
10	Deciding which areas of land are suitable for commercial development	30
11	Prioritising new and backlog projects	33
12	Selecting a caterer	22
13	Selecting a site for a shopping centre	26
14	Choosing the best entry mode for a foreign market	38
15	Choosing a successor for a university president	32
16	Should the college of Arts and Sciences have a language requirement?	20
17	Establishing a policy for AIDS in a community college	20
18	Determine which MBA programmes best foster creative, competent managers	44
19	Should the US support an Arab Rapid Development Force?	30
20	Determining viable solutions to the problem of homelessness	20
21	Prioritising hazardous wastes to determine a schedule for clean up	44
22	Determining the best level of dam reservoir	30
23	Selecting a candidate to succeed to a vacated mid-level management position	21
24	Choosing an information network system for an economic community	28
25	Choosing the best health care plan	22
26	Should a public hospital continue operations, sell, or lease its facilities to a private organisation?	20
27	Selecting candidates for promotion to the coast guard officer crops	25
28	Selecting a graduate business school	25
29	Choosing stock(s) for portfolio selection	42
30	Choosing a city to live in	38

In view of the widespread occurrences of MCDM problems involving large numbers of criteria, application of the proposed methodology in this paper may be considered promising.

6 Conclusions

The Analytic Hierarchy Process is a useful multi-criteria decision making technique where a problem is represented in a hierarchical form. Frequently, the users of AHP encounter the problem of performing all the necessary pairwise comparisons. The task of forming all the pairwise comparison matrices is greater in the presence of larger number of criteria. Business managers who are frequently constrained by time are rather discouraged to apply AHP for large-scale problems. The proposal (integrating AHP with NGT) put forward in this paper is expected to provide a new insight in applying AHP for solving large-scale multi-criteria decision-making problems.

The proposed methodology is applicable when all the criteria are put in one level (usually level 2) of the hierarchy, as shown in Figure 1. However, when a large number of criteria exists, in AHP they are usually put under major categories, like ‘economical’, ‘technological’, ‘social’, etc. In this case, too, the proposed methodology can be applied by segregating the criteria from the categories and, after application of NGT, returning the reduced number of criteria to their respective original categories. Furthermore, NGT can also be applied for each of the categories should they consist of a large number of criteria.

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Notes

[1] The participants are: one professor (International Business), two associate professors (International Trade/Operations Management), two assistant professors (International Business/General Management), three lecturers (Finance/Management Science).