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A note on the use of the analytic hierarchy process for environmental impact assessment

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Environmental impact assessment (EIA) is an intrinsically complex multi-dimensional process, involving multiple criteria and multiple actors. Multi-criteria methods can serve as useful decision aids for carrying out the EIA. This paper proposes the use of a multi-criteria technique, namely the analytic hierarchy process (AHP), for the purpose. AHP has the flexibility to combine quantitative and qualitative factors, to handle different groups of actors, to combine the opinions expressed by many experts, and can help in stakeholder analysis. The main shortcomings of AHP and some modifications to it to overcome the shortcomings are briefly described. Finally, the use of AHP is illustrated for a case study involving socio-economic impact assessment. In this case study, AHP has been used for capturing the perceptions of stakeholders on the relative severity of different socio-economic impacts, which will help the authorities in prioritizing their environmental management plan, and can also help in allocating the budget available for mitigating adverse socio-economic impacts.

Keywords: environmental impact assessment, analytic hierarchy process, socio-economic impact assessment.

Introduction

Environmental impact assessment (EIA) is a procedure for assessing the environmental implication of a decision to enact legislation, to implement policies and plans, or to initiate development projects. It has become a widely accepted tool for environmental management. It has been defined as a process for identifying the likely consequences for the biogeophysical and socio-economic environments and for human health and welfare of implementing particular activities and for conveying this information, at a stage when it can materially affect their decision, to those responsible for sanctioning the proposals (Wathern, 1988). The United Nations Environment Programme has defined it as an examination, analysis, and assessment of planned activities with a view to ensure environmentally sound and sustainable development (UNEP, 1996). Detailed description of the general EIA methodology can be found in UNEP (1996), Sinha (1998) and websites such as http://www.ext.nodak.edu/iaia/eialist, www. worldbank.org and www.oneworld.org/iied/resource.

EIA is an intrinsically complex multi-dimensional process. Perhaps because of this complexity, implementation of EIA is not entirely satisfactory (e.g. Moon, 1998). New innovations and methodologies may be needed to improve the EIA process. In fact, the process of EIA has been evolving ever since it was adopted for analysing the environmental impacts of developmental projects. In this paper, we propose the analytic hierarchy process (AHP) to address the need for considering multiple criteria and multiple stakeholders in EIA.

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The analytic hierarchy process

AHP is an intuitive method for formulating and analyzing decisions. AHP has been applied to numerous practical problems in the last few decades (Shim, 1989). Because of its intuitive appeal and flexibility, many corporations and governments routinely use AHP for making major policy decisions (Elkarmi and Mustafa, 1993). A brief discussion of AHP is provided in this section. More detailed description of AHP and application issues can be found elsewhere (Saaty, 1980, 2000). Application of AHP to a decision problem involves four steps (see below).

Step 1: structuring of the decision problem into a hierarchical model

It includes decomposition of the decision problem into elements according to their common characteristics and the formation of a hierarchical model having different levels. Each level in the hierarchy corresponds to the common characteristic of the elements in that level. The topmost level is the 'focus' of the problem. The intermediate levels correspond to criteria and sub-criteria, while the lowest level contains the 'decision alternatives'. Figure 1 gives an illustration for a simple decision problem of choosing the best house to buy. The topmost level is the Focus of Goal ('Best house to buy'). The goal is characterised by several criteria, and the second level indicates these. The criteria considered in Figure 1 are Price (P), Location (L) and Age (A). One can think of subdividing the criteria further if necessary. For example, 'location' may be sub-divided into 'transport facilities', 'entertainment facilities', 'hospital facilities', etc. There can be more such intermediate levels, but Figure 1 illustrates the simplest hierarchy involving goal, criteria and alternatives. The last level represents the alternatives, which are the different houses from among which one or a few have to be chosen. If there are more decision-makers (DMs) (i.e. the persons from whom the judgements are elicited), then one can introduce a level of DMs just below the Goal. But, for the purpose of Figure 1, we assume only one DM.

Step 2: making pair-wise comparisons and obtaining the judgmental matrix

In this step, the elements of a particular level are compared pairwise, with respect to a specific element in the immediate upper level. A judgmental matrix is formed and used for computing the priorities of the corresponding elements.

First, criteria are compared pair-wise with respect to the goal. A judgmental matrix, denoted as A, will be formed using the comparisons. Each entry a_{ij} of the judgmental matrix is formed comparing the row element A_i with the column element A_j:

$$A=(a_{ij})(i,j=1,2,\ldots,\text{the number of criteria}).$$

The comparison of any two criteria C_i and C_j (say Price and Location) with respect to the goal is made using questions of the type: 'of the two criteria C_i

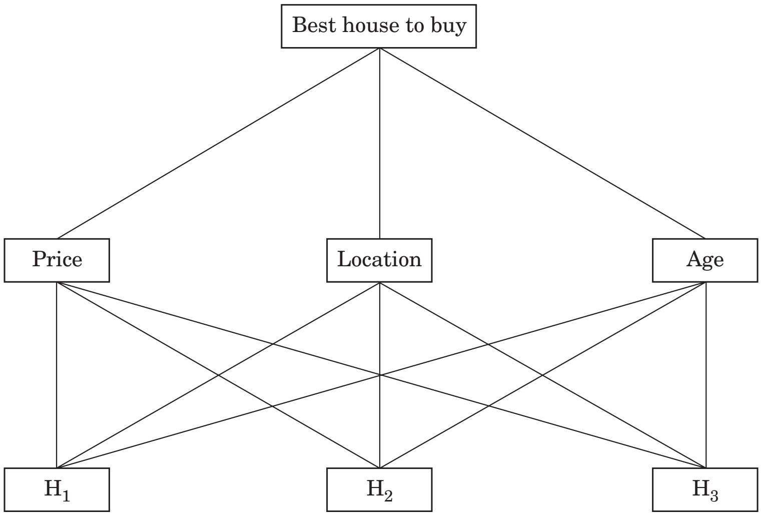

Figure 1. A simple AHP Model.

and C_j, which is more important[1] with respect to a best house and how much more?'.

Saaty (2000) suggests the use of a 9-point scale to transform the verbal judgements into numerical quantities representing the values of a_{ij}. The scale is explained in Table 1.

The entries a_{ij} are governed by the following rules:

$$a_{ij} > 0; \quad a_{ij} = 1/a_{ji}; a_{ii} = 1 \text{ for all } i$$

Because of the above rules, the judgmental matrix A is a positive reciprocal pairwise comparison matrix.

Step 3: local priorities and consistency of comparisons

Once the judgemental matrix of comparisons of criteria with respect to the goal is available, the local priorities of criteria is obtained and the consistency of the judgements is determined. It has been generally agreed (Saaty, 1980, 2000) that priorities of criteria can be estimated by finding the principal eigenvector w of the matrix A. That is:

$$A\mathrm{w} = \lambda_{\max} w$$

When the vector w is normalized, it becomes the vector of priorities of the criteria with respect to the goal. $\lambda_{\max}$ is the largest eigenvalue of the matrix A and the corresponding eigenvector w contains only positive entries.

The consistency of the judgmental matrix can be determined by a measure called the consistency ratio (CR), defined as:

$$CR = \frac{CI}{RI}$$

where CI is called the consistency index and RI, the Random Index.

CI is defined as:

$$CI = \frac{(\lambda_{\max} - n)}{(n-1)}$$

RI is the consistency index of a randomly generated reciprocal matrix from the 9-point scale, with reciprocals forced. Saaty (1980, 2000) has provided average consistencies (RI values) of randomly generated matrices (up to size 11×11) for a sample size of 500. The RI values for matrices of different sizes are shown in Table 2.

If CR of the matrix is higher, it means that the input judgements are not consistent, and hence are not reliable. In general, a consistency ratio of 0·10 or less is considered acceptable. If the value is higher, the judgements may not be reliable and have to be elicited again.

Table 1. The semantic scale used in AHP

Intensity of importance	Definition	Description
1	Equal importance	Elements A_i and A_j are equally important
3	Weak importance of A_i over A_j	Experience and Judgement slightly favour A_i over A_j
5	Essential or strong importance	Experience and Judgement strongly favour A_i over A_j
7	Demonstrated importance	A_i is very strongly favoured over A_j
9	Absolute importance	The evidence favouring A_i over A_j is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate	When compromise is needed, values between two adjacent judgements are used
Reciprocals of the above judgements	If A_i has one of the above judgements assigned to it when compared with A_j, then A_j has the reciprocal value when compared with A_i	A reasonable assumption

Table 2. The average consistencies of random matrices (The Random Index—RI-values)

Size	1	2	3	4	5	6	7	8	9	10
RI	0·00	0·00	0·58	0·90	1·12	1·24	1·32	1·41	1·45	1·49

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[1] 'Important' is not the only word representing the basis of comparison. Other words that may be used, depending on the context, include 'preferred', 'relevant', etc.

Using a very similar procedure, the local priorities of alternatives with respect to each criterion can be estimated. For example, when the houses are compared pairwise with respect to Price, the local priorities of the houses can be estimated.

Step 4: aggregation of local priorities

Once the local priorities of elements of different levels are available as outlined in the previous step, they are aggregated to obtain final priorities of the alternatives. For aggregation, the following principle of hierarchic composition (Saaty, 2000) is used:

$$\text{Final priority of House } H_1 = \sum_{\mathrm{i}} \begin{pmatrix} \text{Local priority of } H_1 \text{ with respect} \\ \text{to } C_{\mathrm{i}} \times \text{Local priority of} \\ C_{\mathrm{i}} \text{ with respect to the goal} \end{pmatrix} \qquad (1)$$

Note that the above is a simple weighted summation. The final priorities thus obtained represent the rating of the alternatives in achieving the focus of the problem. Sample AHP calculations are illustrated in the Appendix. As per these calculations, we find that House H_1 is the best house to buy for the hypothetical DM.

The usefulness of AHP for EIA

The AHP briefly described above can be potentially useful for EIA in many ways. AHP is a compensatory MCDM technique in the sense that it admits trade-offs among the various elements of the model. Hence it can provide an ideal framework for EIA which also involves trade-offs among various environmental problems and development. AHP helps to elicit the complex judgements of different experts in a common platform. It also ensures accuracy in the sense that it has an inbuilt method to check the inconsistency of judgements. This ensures that the judgements are provided only with sufficient care and the error due to negligence is thus minimised.

It should be noted that other multi-criteria methods such as the multi-attribute utility theory (e.g. Keeney and Raiffa, 1993) can also be applied and have also been applied in similar situations (Keeney, 1979). Both have their advantages and disadvantages as evident from a series of regular debates in prominent journals (e.g. Saaty, 1980; Dyer, 1990a,b; Harker and Vargas, 1990). The advantages of AHP over other multi-criteria methods, as often cited by its proponents, are its flexibility, intuitive appeal to the decision-makers (experts and stakeholders here), and its ability to check the inconsistencies in judgments (Saaty, 2000).

Combining qualitative and quantitative elements

In conventional EIA methods such as checklist or matrix methods, the choice of elements (or sub-elements) is constrained by the availability of a suitable measurable indicator. This restriction vanishes when AHP is used, as AHP has the ability to handle even qualitative attributes (by providing suitable quantification using a semantic scale) and has the versatility to mix quantitative and qualitative elements (Wedley, 1990). This is because the method can make use of human judgements. Sometimes, indicators may be segregated into measurable and non-measurable, and only the latter may be employed in the AHP model to get their corresponding scores, while for the former the appropriate measures form the respective scores (Ramanathan and Ganesh, 1995).

Aggregation of many expert opinions

As we have seen, EIA requires expert opinions from multiple actors in terms of multiple criteria. Typically, there will be more than one expert who will be consulted in each field of impact (such as air, water, land, noise, aesthetics, socio-economics, etc.), and there will be several such groups of experts from different fields. Consulting more experts will avoid bias that may be present when the judgements are considered from a single expert. When judgements from many experts are considered, it is necessary to aggregate them suitably. Several methods are available in AHP for performing the aggregation including the geometric mean method and arithmetic mean method (Ramanathan and Ganesh, 1994; Peniwati, 1996; Saaty, 2000).

Necessity to consider different groups of experts

We have seen that EIA requires consideration of expert opinion from many different fields. In such a case, it is important to study the opinions of experts from different fields on a common platform. Sometimes, weights have to be assigned to the opinions of groups of experts belonging to different fields. Conventional methods such as checklists cannot synthesise such diverse information. AHP possesses some models for the purpose (Ramanathan and Ganesh, 1994), which can be advantageously used.

For example, suppose that several groups of experts are involved in assessing a particular project, and that it is desired to assign weights to the groups. Assignment of such weights is quite difficult, as no group will accept those fixed by an external agency. However, as shown by Ramanathan and Ganesh (1994), a participatory approach can be adopted. This approach derives the weights of the different groups using intrinsically derived ratings of each group, which compares itself with the other groups. The method has been applied to compare different groups of experts when choosing the most appropriate energy mix for urban households (Ramanathan and Ganesh, 1995).

Participation of stakeholders

The recent disputes on environmentally sensitive projects have led to the necessity to consider all the stakeholders (i.e. key actors) of a project (such as the authorities, local and affected people, engineers, and others). Several studies on environmentally and socio-economically sensitive projects consider such a stakeholder analysis (Grimble and Chan, 1995; Grimble and Wellard, 1997; Adger *et al.*, 1998). The stakeholders and their interests in the project should first be identified. Proper corrective actions, if needed, should be carried out in time for ensuring smooth execution of the project. For example, the opinions of the people affected directly by the project on the impacts they are likely to face when the project goes on stream should be seriously considered. Any misconception by the local people in this regard should be rectified. Timely corrective actions should be taken so that local people feel positively about the project.

Several methods such as ranking are possible to elicit the subjective opinions of the stakeholders on the different impacts of the project. However, AHP can be a very valuable tool for the purpose as it can be devised to capture the feelings of the laymen and convert their feelings to a numerical scale that reflects their thinking. As the thoughts of laymen may not be very structured, it is necessary to verify the accuracy of their judgements. This verification is possible when AHP is used as the inconsistencies of judgments can be easily identified.

Some shortcomings and modifications of AHP

In spite of its immense popularity, several shortcomings of AHP have been reported in the literature. Several modifications have been suggested to the original AHP to overcome these shortcomings, and it is important that a user of AHP should know them. Hence, we review briefly some of the more obvious shortcomings and modifications in this section.

Scale

When introducing AHP, Saaty (1980) advocated the use of an additive scale ranging from 1–9 (see Table 1). He defended the scale by providing evidence from a variety of sources. However, several alternative scales have been proposed in the literature. One of the most widely cited alternative scales is the geometric scale (Lootsma, 1999), which uses the range ($e^{0\gamma}$ to $e^{8\gamma}$) for the same semantic descriptions available in Table 1 (γ is a constant). The argument for using this geometric scale is that AHP tries to capture ratio information (relative preference of one alternative over another), and hence one should use a ratio characterisation for the purpose.

Methods for the estimation of priorities

Saaty (1980) advocated the use of the eigenvector technique for deriving the weights from a given pairwise comparison matrix. It is possible to use other techniques for the same purpose. The most often discussed alternative technique is the Logarithmic Least Squares Technique (LLST) (Crawford and Williams, 1985). LLST tries to choose those weights that minimise the logarithmic squared deviations. Crawford and Williams (1985) have shown that the LLST solution can be easily obtained by geometric means.

Rank reversal

One of the most controversial issues in the use of AHP is the rank reversal phenomenon: the ranking of alternatives determined by the AHP may be altered by the addition of another alternative for consideration. Belton and Gear (1983) showed that the ranking of a set of three alternatives changes when a copy of one of the alternatives is added to the set. Dyer (1990a) claims that this problem is a symptom of arbitrary rankings provided by the AHP. Harker and Vargas (1987) claim that this problem can be overcome by constructing a network (a system in which the elements of a level are affected by the levels above as well as below it) rather than considering the system as a hierarchy (a system in which the elements of a level are affected only by the level above it). A more detailed discussion of the AHP networks is available in Saaty (2000).

The concept of absolute measurement (Saaty, 1987; Chattopadhyay and Ramanathan, 1998), as against the relative measurement conventionally used in AHP models, does not suffer from the rank reversal problem of Belton and Gear (1983). In this approach, the AHP is used to assign scores to ratings on the criteria, such as 'high', 'average', 'low', etc. and then alternatives are evaluated by assigning a rating to the performance of alternatives on each criterion.

MAHP, the multiplicative variant of AHP, does not suffer from rank reversals of the type shown by Belton and Gear (1983) (Lootsma, 1999). This is because it uses multiplicative operations throughout rather than mixing additive and multiplicative operations as done in conventional AHP. MAHP uses the LLST instead of eigenvector technique, and uses a multiplicative aggregation instead of the simple weighted aggregation of the principle of hierarchical composition. When multiplicative aggregation is used, (1) is modified as follows:

$$\text{Final priority of House } H_1 = \prod \begin{pmatrix} \text{Local priority of } H_1 \text{ with respect} \\ \text{to } C_i \times \text{ Local priority of} \\ C_i \text{ with respect to the goal} \end{pmatrix}$$

More details of the theory and applications of multiplicative AHP can be obtained from Lootsma (1993, 1999) and Ramanathan (1999).

Axiomatic framework

One of the earliest criticisms of AHP was of its lack of an axiomatic framework. Saaty (1986) has provided the necessary axioms, pertaining to reciprocal comparisons, homogenity, independence, and expectations.

Number of comparisons

AHP uses redundant judgements for checking consistency, and this can exponentially increase the number of judgements to be elicited from DMs. For example, to compare eight alternatives on the basis of one criterion, a total of 28 judgements is needed. If there are N criteria, then the total number of judgements for comparing alternatives on the basis of all these criteria will be 28N. This is often a tiring exercise for the decision-maker. Some methods have been developed to reduce the number of judgements needed (e.g. Millet and Harker, 1990).

Having highlighted the benefits of AHP and discussed its shortcomings and modifications, we now discuss a simple application of AHP below.

Application of AHP for socio-economic impact assessment: a case-study

Here, a practical application of AHP for socio-economic impact assessment (SEIA) is described briefly. SEIA is usually a part of EIA. For example, in India, the government requires a rehabilitation plan of a project affecting people as a part of an EIA report before granting environmental clearance (Ramanathan and Geetha, 1998). A more detailed discussion of the case-study reported here is available in Nag and Ramanathan (1996).

In this case-study, a SEIA for a proposed LPG recovery plant in an industrially backward area in the state of Maharashtra has been studied. First of all, the likely major socio-economic impacts due to the proposed project were identified by preliminary surveys. These include housing, transport, water supply, sanitation and health.

However, the authorities responsible for the project would like to know not only the potential significant impacts, but also about their relative importance. While the experts in the SEIA team can reasonably estimate relative importance, it would be more desirable if the importance *as perceived by the different stakeholders* is also provided. This can help the authorities to decide the suitability of an environment management plan. However, it is difficult to compare the different impacts using any particular measure, as these are incommensurable. For example, it is not possible to propose a measure that compares the relative severity of impacts on housing with impacts on sanitation. Hence, this problem requires a methodology that captures perceptions of different people, and for the purpose of taking a decision, the perceptions should be converted to objective numbers. AHP is readily applicable in such cases.

The AHP model is shown in Figure 2. The second level lists the stakeholders—the company, local administration and people. However, local administration and people in different affected regions may behave separately, and hence a third level is introduced to distinguish the geographical locations. Usar is the village in which the project will take place and which has the highest stake. Other villages in the vicinity will also be affected. Alibaug and Revdanda are the two nearest towns which will bear some of the socio-economic impacts of the project. These impacts, whose relative severities have to be compared, form the last level.

A separate set of surveys was conducted for the purpose of prioritising the impacts using the model. These surveys required the detailed involvement of stakeholders. The stakeholders at the different localities were asked to compare pair-wise the relative severity of impacts and to complete a questionnaire. The questionnaire had to be translated into the local language during the interview.

From the pair-wise comparisons of the impacts, a judgmental matrix was formed for each stakeholder. This matrix was used for computing the priorities (which will be proportional to the relative severity) of the impacts, and the usual consistency check was carried out. The priorities expressed by different people in the same stakeholder-group were combined using arithmetic means (Ramanathan and Ganesh, 1994).

No attempt was made to assign weights to stakeholders, and the priorities as expressed by each stakeholder were analysed separately. It was found that the priorities expressed by the company and the local administration were similar to those expressed by the town people. In a similar way, the perceptions of the local administration of villages were similar to those of the villagers. People both in towns and in villages have perceived the water-supply problem to be the most severe impact during the construction phase. Town people have considered sanitation to be the next most severe impact, followed by housing, transport and finally, health. In the villages, transport has been expected to suffer the second most severe impact, followed by housing, sanitation and health.

The priorities can also provide an approximate guide for the allocation of total money available for mitigating the adverse socio-economic impacts. For example, the AHP exercise indicates that, to get the full co-operation of the project, it may be more prudent to allocate nearly half the funds (earmarked for minimising the negative socio-economic impacts) to improve the water-supply situation of the project area.

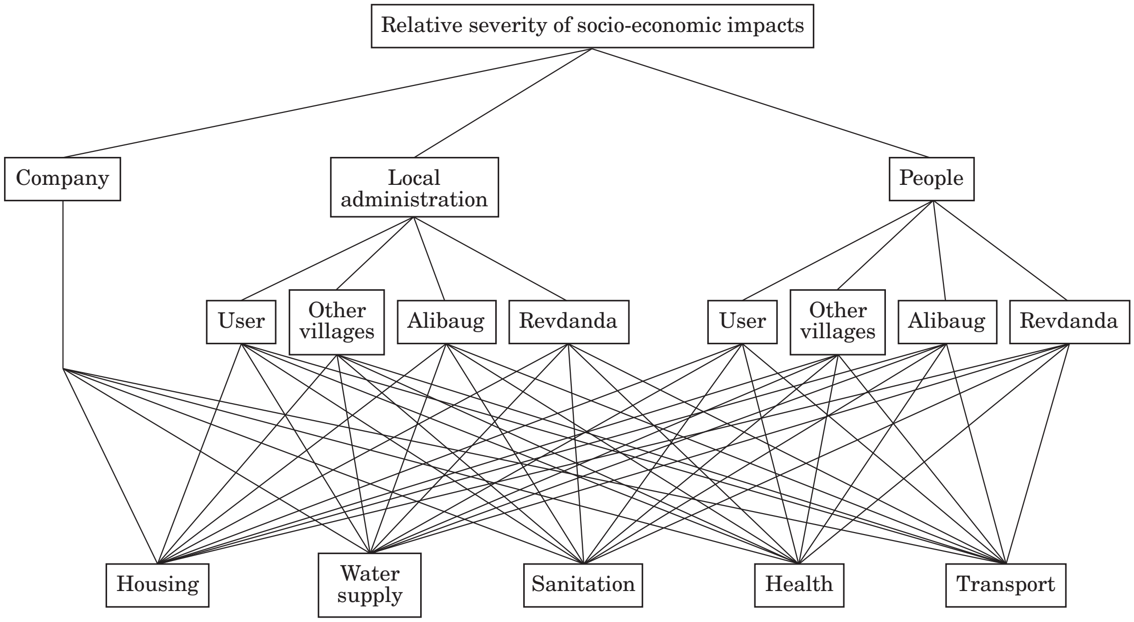

Figure 2. AHP model for socio-economic impact assessment.

Summary and conclusion

In this paper, several advantages of using the analytic hierarchy process (AHP) as a tool while carrying out an environmental impact assessment have been highlighted. Some shortcomings and modifications have been described briefly. A practical application of AHP for conducting socio-economic impact assessment has been discussed. In this application, AHP has been used for capturing the perceptions of stakeholders on the relative severity of different socio-economic impacts, which will help the authorities in prioritising their environmental management plan. Therefore, we conclude that AHP can be a useful tool for systematically analysing the opinions of several groups of experts belonging to diverse fields in an environmental impact assessment study, and hope that the technique will be advantageously employed in environmental impact assessment studies in future.

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Appendix

Illustration of calculations for the AHP model shown in Figure 1 using hypothetical data

Table A1. Comparison of criteria with respect to the overall objective

	Price	Location	Age	Local priorities
Price	1	3	5	0·637
Location	1/3	1	3	0·258
Age	1/5	1/3	1	0·105

$\lambda_{max}=3{\cdot}039$; CI=0·019; CR=0·033

Table A2. Comparison of the three houses with respect to Price

	H_1	H_2	H_3	Local priorities
H_1	1	4	6	0·691
H_2	1/4	1	3	0·218
H_3	1/6	1/3	1	0·091

$\lambda_{max}=3{\cdot}054$; CI=0·027; CR=0·046

Table A3. Comparison of the three houses with respect to Location

	H_1	H_2	H_3	Local priorities
H_1	1	3	5	0·637
H_2	1/3	1	3	0·258
H_3	1/5	1/3	1	0·105

$\lambda_{max}=3{\cdot}039$; CI=0·019; CR=0·033

Table A4. Comparison of the three houses with respect to Age

	H_1	H_2	H_3	Local priorities
H_1	1	5	4	0·674
H_2	1/5	1	1/3	0·101
H_3	1/4	3	1	0·226

$\lambda_{max}=3{\cdot}086$; CI=0·043; CR=0·074

Table A5. Final priorities of the three houses

	Final priorities
H_1	0·675
H_2	0·216
H_3	0·109