BALANCING STAKEHOLDER VIEWS FOR DECISION-MAKING IN STEEL STRUCTURAL FIRE DESIGN

Obinna Ukeni Akaa, Anthony Abu, MichaelSpearpoint and Sonia Giovinazzi
Department of Civil and Natural Resources Engineering,
University of Canterbury, Christchurch 8140, New Zealand.
obinna.akaa@pg.canterbury.ac.nz

ABSTRACT

Fire design stakeholders such as architects, regulators, fire service, etc., often have different opinions about which passive fire protection approach is the most appropriate one in meeting structural fire performance objectives. There are many options for protecting steel buildings in a fully developed fire, but there is the need to identify a strategy that could satisfy at best the different and sometimes conflictual stakeholder desires, thereby reducing design uncertainties. This paper proposes a three-stage approach to address this issue: (i) stakeholder engagement, to identify and extract stakeholder desires; (ii) decision analysis, and; (iii) risk-based parametric study. The paper focuses, in particular on the first two stages. The first stage describes the process of identification and extraction of stakeholder desires in steel structural fire design from literature and structured interviews through a stakeholder engagement plan. The second stage of the decision-making process is demonstrated using a simple stakeholder goal-rating and multi-criteria decision analysis (MCDA). In particular, the use of analytic hierarchy process (AHP) is proposed to manage the multiplicity of stakeholder desires towards common decision-criteria, manage possible inconsistent goal-rating, and to rank the different proposed passive fire protection options.

KEYWORDS

Stakeholder goal, structural fire design, fire protection, multi-criteria decision analysis (MCDA), analytic hierarchy process (AHP).

INTRODUCTION

Generally, building designs can be achieved by using prescriptive or performance-based codes (Alvarez *et al*. 2013). Prescriptive codes are established design requirements that stipulate the means of compliance but often without clear statements of their objectives, while in performance-based codes the desired design objectives are stated and designers are given the freedom to choose a solution that will meet the objectives. Performance-based design codes are being adopted in many countries due to their flexibility in satisfying design objectives and required performance of buildings. Studies have shown that building owners, architects, fire engineers, building insurers, fire service and authorities having jurisdiction are involved as stakeholders in most fire safety designs (Meacham 2000; Alvarez *et al*. 2013; and Park *et al*. 2014). These stakeholders have particular interests in specific design options and as a result of the flexibility of performance-based codes, the stakeholders in some scenarios misinterpret the codes, thereby compromising safety, causing delays and increasing costs. These factors present uncertainties in the design of buildings.

The fire design of buildings will typically need to consider the ability of the structure to resist fire. There are a number of options available to steel structural fire designers to achieve this goal such as compartmentation, concrete encasement of steel, board systems, intumescent coatings, and the use of unprotected steel. Using these options with a performance-based code may lead to uncertainty as to which is the most cost-effective. A robust decision-making process mitigates these uncertainties to achieve structural fire design adequacy of steel buildings. The divergent views of fire engineers and other practitioners in the fire industry during the 2014 New Zealand Ministry of Business, Innovation and Employment (MBIE) open stakeholders' forum gives further credence that steps need to be taken towards an agreed decision-making process within the fire design context. For instance, architects are keen on building aesthetics and prefer the use of intumescent coatings for passive fire protection of steel-framed buildings due to their aesthetic appeal (Meacham 2000). In contrast, the structural engineer could recommend partial or full concrete encasement of steel which eliminates the disadvantages of intumescent coatings such as adhesiveness and non-uniform thickness, but may increase the weight of the structure (Buchanan 2001). Each of these options will likely have different costs in terms of design, installation and maintenance. These situations illustrateun balanced stakeholder desires which give way to fire design uncertainties and highlight the need for optimised decision-making in order to fully take advantage of performance-based design.

To solve this problem, there is need to extract the views of stakeholders and understand their desires. Tools are also needed to process the stakeholder views in order to rank their design options for suitable decision-making. This paper presents an overview of the MCDA and AHP techniques. Building on findings from literature, the paper proposes a framework for the use of MCDA and AHP to manage divergent desires of steel structural fire design stakeholders. Finally, the paper explains the framework and approach with an example, which demonstrates how the AHP is used to manage the multiplicity of stakeholder desires towards common decision-criteria, manage possible inconsistent goal-rating, and to rank the different passive fire protection options.

BRIEF OVERVIEW OF MCDA AND AHP

Multi-Criteria Decision Analysis

Multi-criteria decision analysis (MCDA) is a widely used technique in operation research to solve complex problems that are characterised by divergent objectives, uncertainties, dissimilar data, varying interests and perspectives (Mateo 2012). MCDA is structured to provide more information on the contextual problem and stakeholder desires, and can aid a participatory process for the purpose of fairness and transparency, which are features that make the technique acceptable to stakeholders (Nordstrom *et al.* 2012). MCDA solutions assess available options with respect to the common decision criteria and rank the options for a decision to be made.

There are many MCDA solutions which can be applied depending on the peculiarity of the multi-criteria decision scenario. For example, the analytic hierarchy process (AHP) has been used for a hospital management decision problem (Saaty 1994a), the technique of order of preference by similarity to ideal solution (TOPSIS) was applied in decision-making for seismic structural retrofitting (Caterino *et al.* 2009), and the Extended Goal Programming (EGP) was considered for participatory forest planning (Nordstrom *et al.* 2012). In some cases, hybrid-MCDA solutions have been adopted e.g. AHP+TOPSIS, analytic network process (ANP) + VIKOR etc (Jato-Espino *et al.* 2014). Regardless of the type or form of application, MCDA solutions are mainly designed to help the decision-makers to approach a suitable decision, but not to make the actual decision.

Analytic Hierarchy Process (AHP)

Saaty in the early 1980s developed a decision-making process known as analytic hierarchy process (AHP), in which a problem is broken down and the solutions of the sub-problems are combined to aid the decision-makers to approach a decision. This tool entails the decomposition of a problem into a hierarchy of decision criteria and options, weighting them based on pairwise judgements to determine the performance/dominance of the criteria to the decision makers and aggregating these performance scores to rank the options (Saaty, 1980, 1994b). AHP allow for a consistency check of all pairwise comparisons, given that human beings are inconsistent in such judgements (Coyle 2004). Hence, this MCDA solution has been widely applied in over 20 countries in solving decision-making problems ranging from policy making, product marketing strategy, military analysis to cost-benefit assessment in construction (Jato-Espino *et al.* 2014). Recently, Yan *et al.*(2015) applied AHP to formulate an index criterion score system of fire risk assessment in a large business district.

There are many ways to carry out MCDA using AHP but in this paper, a summary of the procedure by Saaty(1980, 1994a)and Coyle (2004) is presented. Firstly, a goal must be stated, the key decision criteria are defined, and the sub-decision criteria are classified under their parent-key decision criterion as deemed appropriate taking into consideration the multiplicity of the stakeholder desires. In some scenarios, decision-makers may work as a group and agree on common decision criteria and sub-criteria. The competing options are identified at this stage as well. The second phase involves pairwise comparisons based on the level of importance in different categories using the Saaty's reciprocal pairwise comparison scale shown in Table 1.Here, values from Table 1 are assigned to each compared pair of criteria or options according to the intensity of the opinion of the decision-maker. The criterion or option with greater importance for every compared pair is assigned a whole number, while the other criterion or option in that same paired comparison is assigned the reciprocal of the whole number. The categories of pairwise comparisons in the AHP are thus classified: Category A is the pairwise comparison of the key decision criteria against each other with respect to the stated goal; and the pairwise comparison of the competing options against each other with respect to the stated goal. Category B is the pairwise comparison of the sub-criteria against each other with respect to their parent-key decision criteria as classified and Category C is the pairwise comparison of the options against each other with respect to every sub-decision criterion in the decision problem.

Table 1 Saaty's rating scale (Coyle, 2004)

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective.
3	Somewhat more important	Experience and judgement slightly favour one over the other.
5	Much more important	Experience and judgement strongly favour one over the other.
7	Very much more Important	Experience and judgement strongly favour one over the other. Its importance is demonstrated in practice.
9	Absolutely more important	The evidence favouring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed.

In the third phase, these pairwise comparison ratings are presented in the form of matrices. For every matrix, each element compares the intensity of importance of a criterion or option against each other, where 1is retained for a criterion or option compared against itself. This completes the pairwise comparison matrices, which are thenready for further assessment. In scenarios where decision-makers carried out the pairwise comparisons individually, there will be need to aggregate the individual ratings for each category to form a single or common group judgement of the criteria or options. In the aggregation of the various ratings of the decision-makers, either the arithmetic mean method (AMM) or the geometric mean method (GMM) is used. AMM represents an average interval of all ratings in a category, while GMM represents an average ratio of the same ratings. Using any of the methods, all decision-makers become a new individual whereby the aggregation of all of the individual matrices form a single group matrix at different categories. The GMM method used in aggregating individual judgements and priorities for ease of decision analysis has been explained elsewhere by Forman and Peniwati(1998). The GMM equation is thus:

$$Z^{[G]} = (z_{ij}^{[G]}), \text{ where } z_{ij}^{[G]} = \prod_{p=1}^{a} (z_{ij}^{[G]})^{\alpha_p}, \; i, j \in \{1, n\} \tag{1}$$

$Z^{[G]}$ is the geometric mean of the group; $z_{ij}^{[G]}$ is the aggregated judgements for the compared criteria or options i and j; a represents the number of decision makers, p is the p-th decision-maker with weight represented as α_p. The value for α_p is dependent on the weights assigned to decision makers, and $\alpha_p = 1/p$ if the decision-makers are assumed to have the same weight.

The fourth phase is to weight the key decision criteria, sub-criteria and options to determine their performance scores at each aggregated category. The dominance of a particular criterion or option is also deduced from this evaluation. In AHP, the performance scores of the key decision criteria and options are evaluated using Eigenvalue theory. Here Eigenvectors (performance scores) are assigned to the criteria or options from aggregated matrices of pairwise comparisons. These performance scores are determined by multiplying the entries in each row of the matrix, then calculating the n^{th}root of the rows' products give good approximations, which are summed up. This sum is used to normalise the elements of the performance scores to add up to 1.00. The consistency ratio (CR) of the aggregated pairwise ratings are checked by further normalisation of the performance scores with the matrix row entries to achieve a consistency index (CI), given as;

$$CI = \lambda_{max} - n / (n - 1) \tag{2}$$

where λ_{max} is the mean of the normalised new performance scores and n is the total number of weighted criteria or options.

CI is then divided by the corresponding value for n from Saaty's random judgement table of large matrix samples shown in Table 2.

Table 2 Saaty's random consistency index values for different values of n (Saaty, 1980)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Saaty (1980) and Coyle (2004) mention that a CR > 0.10 means that the pairwise judgements of the decision makers are at the consistency limit and in practice, it is unacceptable if it increases toward unity. In the case of determining the true performance scores of the sub-criteria under their parent-key decision criteria, the Eigenvalue process is applied but each resultant Eigenvector is multiplied by the performance score of their parent- key decision criterion. Hence, the summation of the performance scores of the sub-criteria must equal the exact value of their respective parent-key decision criterion performance score, and the summation of performance scores of all key decision criteria must equal 1.00.

The fifth phase of the AHP involves synthesis of performance scores of the options with respect to the sub-criteria under each key decision criterion. This is aimed at determining the preference scores of the competing options, which can be carried out either in the distributive or ideal synthesis mode. In the distributive (dominance) mode, the performance scores of each option are multiplied by the sub-criteria performance scores and summed to obtain the synthesis of overall preference scores of the options. Notably, the preference scores sum up to 1.00 and the dominance of an option can be deduced. In the ideal (performance) mode, the best option under each sub-criterion is normalised to 1.00 as a benchmark; then the other performance scores are divided by the score of the best option, multiplied by the respective sub-criteria performance scores and summed as well. This implies that the preference scores of any option do not depend on the performance scores of others except for the chosen benchmark option (Saaty 1994a). The total value from the addition of the summed-up column is used to normalise them to add up to unity. As part of the AHP guideline, Millet and Saaty (1999) suggests that the distributive synthesis mode should be used when the decision-makers wish to assess the amount of dominance of one of the options and the dependence among these options, given a unit weight distributed among them under a criterion; while, the ideal mode should be used to evaluate the performance of each option relative to a chosen benchmark.

The final phase of the AHP decision analysis is to rank the assessed options in order to aid decision-making. However, where benefits and costs are considered, the key decision can go in three directions: whether the benefits justify their costs, whether the costs outweigh the benefits or both variables are too close to call. Saaty (1994a) suggests that in complex decision-making problems, cost criteria with respect to the options should be separated and synthesised when all the benefits of the competing options have been assessed. Therefore, when these two variables are separated, they produce a scenario to determine benefit-cost ratios given as:

$$B_i/C_i \tag{3}$$

where B_i is the benefit preference score of the options and C_i is the cost preference score of the options.
Result from this calculation ranks the competing options and presents the option with the highest benefits and least costs as the top ranked option.

PROPOSED FRAMEWORK

The first part of the approach in balancing stakeholder desires is to engage the fire design stakeholders in a structured discussion to elicit their views toward an optimised decision-making outcome. In such participatory discussion, the stakeholders are given the opportunity to rate their fire protection preferences and decision criteria in designing steel buildings for fully developed fires. This paper proposes a three-phase stakeholder engagement plan consisting of planning, preparation and engagement, response and rating. The planning phase includes identification of the stakeholders involved in the decision making for an appropriate design option and getting their consent for stakeholder meetings. Meetings are scheduled at the preparation and engagement phase and structured for participatory discussions during the response and rating phase.

A questionnaire that consists of a pairwise comparison scale is employed in the stakeholder meetings to aid the stakeholders in rating the fire protection options, decision criteria and sub-criteria as the case may be.
Research has identified key decision criteria and sub-criteria (NZFS 1975; Spearpoint 2008; Alvarez *et al.* 2014 and Park *et al.* 2014)as shown in Table 3. In future, the stakeholders may be allowed to include and rate other desires they deem necessary.

Table 3 Key and sub-decision criteria desired by fire design stakeholders

Key decision criteria	Sub-decision criteria
Economy (costs)	Building cost, constructability, maintainability
Socio-environmental	Environmental sustainability, human comfort
Effectiveness	Fire spread beyond compartment, business continuity
Safety	Clarity in design details and specifications, building regulation approval, accessibility for fire-fighting operations

It is also ideal to construct hierarchical trees for costs and benefits to represent a breakdown of the decision problem into levels. The goal of choosing the best fire protection option should be placed at the top i.e. Level 1, the key decision criteria is placed at Level 2 and linked to the goal at Level 1, followed by the sub-decision criteria placed at Level 3 and linked to their respective parent-key decision criteria at Level 2. The fire protection options are placed at the base (Level 4) to complete the hierarchical tree.

In order to decide on the suitable fire protection option for the structural fire designs of steel buildings given the multiplicity of fire design stakeholder desires, a MCDA using the AHP procedure described in the previous section is proposed. The resultant performance scores are synthesised in the distributive and ideal modes and compared to identify dominance and performance of the fire protection options based on the pairwise ratings allotted by the stakeholders. A flowchart of the proposed framework in managing the decision problem described in this paper is shown in Figure 1. The AHP is applied bearing in mind that the fire design stakeholders are to make a decision that suits them out of the ranked fire protection options in consideration that the technique is not designed to make decisions for the users.

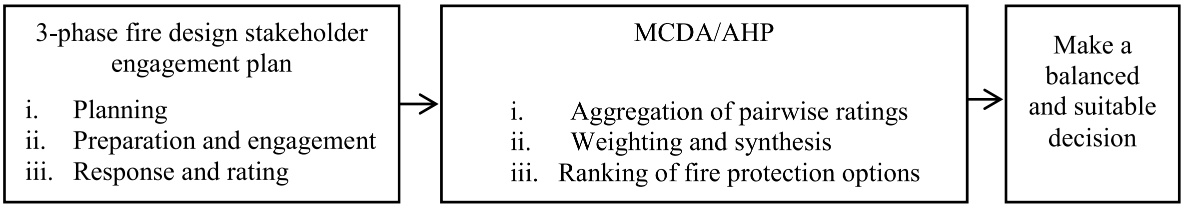

Figure 1 Proposed framework

At the weighting and synthesis phase of the AHP, the resultant performance and preference scores can be entered appropriately under the respective levels on the constructed AHP-hierarchical trees.

PILOT STUDY EXAMPLE

For the purpose of conducting this pilot study as well as demonstrating the approach described in this paper, ten full-time and part-time postgraduate students from the fire engineering programme at the University of Canterbury, were chosen. Several of the students have had a few years of professional engineering experience or are currently employed by fire engineering companies. The goal for this pilot study was stated as *'choose a cost-effective fire protection option for a steel-framed building'*. The stakeholder engagement plan was employed in which a questionnaire was constructed consisting of pairwise comparison matrices of the key and sub-decision criteria listed in Table 3 and the following passive fire protection options: *compartmentation, intumescent coatings, concrete encasement of steel (full or partial), board systems (e.g. gypsum, plaster etc.) and unprotected steel*. The Saaty-reciprocal pairwise rating scale shown in Table 1 was included in the questionnaire to aid the students in rating the fire protection options and decision criteria for steel structural fire design according to the intensity of their feelings during the scheduled meetings. The participants carried out the pairwise comparison ratings of the decision criteria and options individually.

The pairwise comparisons were carried out as described in the AHP procedure in categories. One of the participants' results of a pairwise comparison of the fire protection options with respect to the goal (Category A) of the pilot study is shown in Table 4. In this matrix, it is seen that the participant having used the Saaty rating scale, rated board systems as 'much more important' than compartmentation and allotted the value, 5 to board systems in the column on the left of the matrix. The participant also allotted the reciprocal of 5 i.e.1/5 to compartmentation in the top row of the matrix, as being 'much less important than' board systems. After the goal-rating exercise, participants selected the stakeholder that best represents their rating; and from a simple look at their ratings, the authors categorised their desires and preferences as shown in Table 5.

Table 4 Pairwise comparison matrix for fire protection options by a participant in the pilot study (Category A)

	Compartmentation	Intumescent coatings	Board systems	Concrete encasement	Unprotected steel
Compartmentation	1	1	1/5	1/3	1
Intumescent coatings	1	1	1/3	1	1
Board systems	5	3	1	3	1
Concrete encasement	3	1	1/3	1	1
Unprotected steel	1	1	1	1	1

Table 5 Divergent views of participants in the pilot study

Stakeholder role	No. of participants	Key decision criteria in order of importance to participants	Preferred passive fire protection option of participants
Building owners	1	Effectiveness, economy (costs), safety, socio-environmental	Compartmentation
Architects	2	Socio-environmental, effectiveness, safety, economy (costs)	Intumescent coatings
Building contractors	1	Economy (costs), safety, effectiveness, socio-environment	Concrete encasement of steel (full or partial)
Fire protection engineers	2	Safety, effectiveness, socio-environmental, economy (costs)	Compartmentation
Structural fire engineers	2	Safety, effectiveness, economy (costs), socio-environmental	Concrete encasement of steel (full or partial)
End-users (community)	2	Safety, effectiveness, socio-environmental, economy (costs)	Compartmentation

The divergent views of the participants are clear in Table 5and it identifies the likely dominance of a specific decision criterion, fire protection option and data skewness. Therefore, decision analysis is considered necessary to assess the competing fire protection options with respect to the key and sub-decision criteria in order to rank the fire protection options appropriately. Two hierarchical trees of benefits and costs were constructed as described in the proposed framework. The 'economy', key decision criterion, is separated from 'safety', 'socio-environmental', 'effectiveness'(deemed as benefits) and all economy-sub-criteria are identified as costs in this context. This is to allow for a broader view of the decision problem and thorough analysis of the competing variables (benefits and costs) to enable balanced decision-making.

Given that each individual carried out their ratings independently, there is the need to aggregate the results of the rated stakeholder desires to form a common or single group judgement for each category of pairwise comparisons. GMM is used for all the aggregation calculation as given in Eq. 1. One of the aggregated results is shown in Table 6. In this case, Table 6(a) is $Z^{[G]}$; $z_{ij}^{[G]}$ is the result from the 10×10 matrix-multiplication of the individual pairwise comparisons of the benefits key decision criteria (Category A) from the 10 participants and to the power of α_p. Notably, this pilot study assumed that all the participants are decision makers having same weight ($\alpha_p = 1/a$), where $a = 10$ (number of participants).

The AHP-Eigenvalue calculation is employed in weighting the aggregated ratings. Table 6 shows the performance scores (Eigenvectors) of the aggregated benefits key decision criteria. Here, 'safety' has the highest performance score, 0.48 from the Eigenvalue calculation and the summation of the performance scores equal 1.00.

Table 6 Group aggregated matrix and weighting of key decision criteria category

(a) Group aggregated matrix (b) Weightings from Eigenvalues

	Safety	Socio-environmental	Effectiveness	Performance scores (Eigenvectors)
Safety	1.00	1.62	2.19	0.48
Socio-environmental	0.61	1.00	0.81	0.24
Effectiveness	0.45	1.53	1.00	0.28

Total = 1.00

Consistency checks for all the aggregated pairwise ratings are carried out using the AHP guideline and Eq. 2. The pairwise comparisons of the benefits key decision criteria gives CR = 0.10, which is on the margin of acceptability. The performance scores achieved from the AHP-Eigenvalues calculation of each category are indicated on the hierarchical trees in their respective levels as shown in Figures 2 and 3.

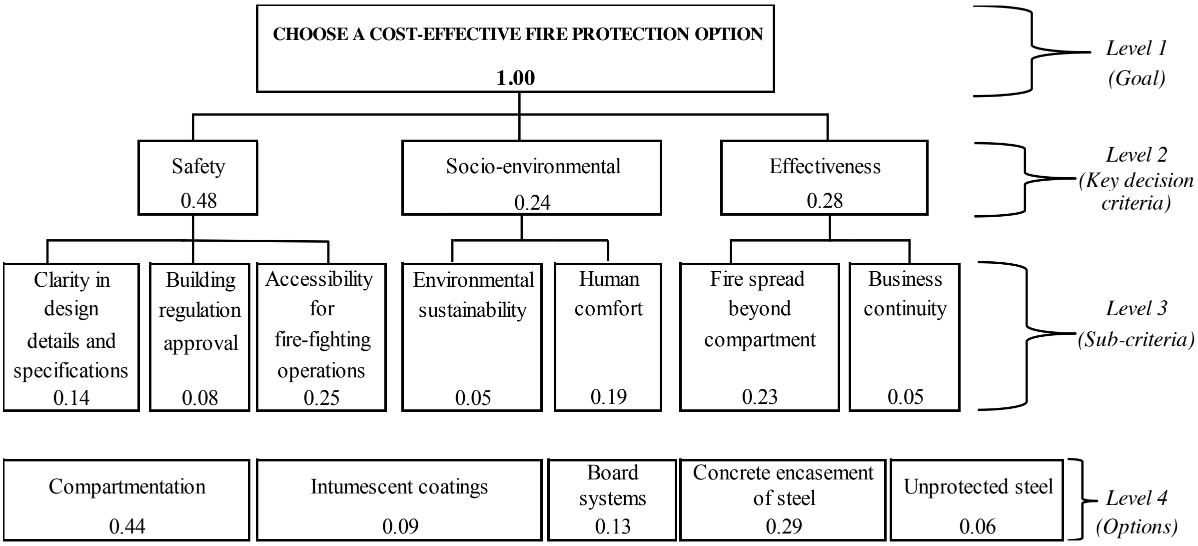

Figure 2 Ideal mode -AHP-benefits hierarchical tree of the decision criteria and passive fire protection options

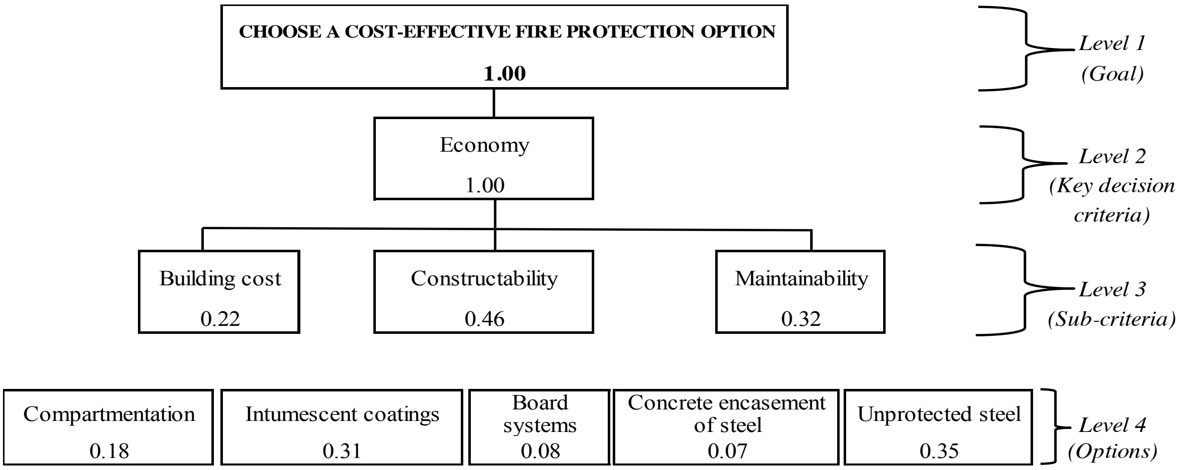

Figure 3 Ideal mode- AHP – costs hierarchical tree of the decision criteria and passive fire protection options

The benefits sub-criteria aggregated matrices achieved from their pairwise comparisons with respect to their parent-key decision criteria, are also weighted using the Eigenvalue procedure. In this scenario, the sub-criteria Eigenvectors are multiplied by the performance score of their respective parent-key decision criterion to achieve their performance scores. The calculated sub-criteria performance scores are indicated at Level 3 on Figure 2. In the benefits hierarchical tree, the summation of the sub-criteria performance scores (Level 3)under each key decision criterion of Level 2 equals the performance score of their respective parent-key decision criterion (Level 2). The performance scores of the sub-criteria under 'economy' were calculated using the same Eigenvalue procedure. Here 'economy' is treated as a single variable; hence all sub-criteria performance scores sum-up to 1.00 as indicated in Figure 3.

In completing the decision analysis for this pilot study, the performance scores of the competing fire protection options, achieved from their pairwise comparisons with respect to all sub-criteria in the pilot study (Category C) are synthesised in the distributive and ideal mode. The synthesis results are presented in Table 7. In the distributive synthesis mode, compartmentation is the dominating fire protection option as shown in Table 7, hence the normalised benchmark value of 1.00 seen in the compartmentation column (CPT) in the ideal mode. The preference scores of the fire protection options produced by the two synthesis modes are similar irrespective of the benefits and costs performance scores of the sub-decision criteria and fire protection options. For instance, Table 7 shows that the preference scores of compartmentation are 0.45 and 0.44 in the benefits distributive and ideal mode synthesis rows respectively and 0.17 and 0.18 in the costs distributive and ideal mode synthesis rows. The preference scores of the fire protection options in the benefits and costs ideal mode are also indicated on their respective hierarchical trees as an example.

Table 7 AHP-distributive and ideal mode synthesis to determine preference scores and ranking of options

	Distributive mode						Ideal mode				
	Performance scores	CPT	ITC	BSY	CEC	UPS	CPT	ITC	BSY	CEC	UPS
Benefits sub-criteria											
Clarity in design details & specifications	0.14	0.44	0.07	0.12	0.31	0.06	1.00	0.16	0.27	0.70	0.14
Building regulation approval	0.08	0.44	0.07	0.12	0.31	0.06	1.00	0.16	0.27	0.70	0.14
Accessibility for fire-fighting operations	0.25	0.44	0.07	0.12	0.31	0.06	1.00	0.16	0.27	0.70	0.14
Environmental sustainability	0.05	0.52	0.07	0.18	0.18	0.05	1.00	0.13	0.35	0.35	0.10
Human comfort	0.19	0.36	0.15	0.11	0.33	0.05	1.00	0.42	0.31	0.92	0.14
Fire spread beyond compartment	0.23	0.57	0.05	0.13	0.21	0.05	1.00	0.09	0.23	0.37	0.09
Business continuity	0.05	0.27	0.14	0.22	0.27	0.09	1.00	0.52	0.81	1.00	0.33
Benefits preference scores (B_i)		0.45	0.08	0.13	0.28	0.06	0.44	0.09	0.13	0.29	0.06
Costs sub-criteria											
Building cost	0.22	0.06	0.32	0.10	0.07	0.46	0.13	0.70	0.22	0.15	1.00
Constructability	0.46	0.07	0.41	0.08	0.07	0.36	0.17	1.00	0.20	0.17	0.88
Maintainability	0.32	0.40	0.17	0.08	0.07	0.28	1.00	0.43	0.20	0.18	0.70
Costs preference scores (C_i)		0.17	0.31	0.08	0.07	0.36	0.18	0.31	0.08	0.07	0.35
B_i/ C_i		2.61	0.27	1.53	4.01	0.16	2.45	0.29	1.54	4.09	0.16

Key: CPT – Compartmentation, ITC – Intumescent coatings, BSY- Board systems, CEC – Concrete encasement UPS – Unprotected steel.

Finally, the benefits and costs ratios of the preference scores of the competing fire protection options are calculated using Eq. 3. Table 7 shows that concrete encasement of steel in the distributive and ideal modes has the highest scores, 4.01 and 4.09 respectively and it is the top-ranked option. These benefits and costs ratios are also presented in a scatter plot for the ideal synthesis mode. The resultant top-ranked fire protection option, 'concrete encasement of steel 'has the highest benefit and least cost from the AHP-decision analysis of the divergent desires of the participants as shown in Figure 4.

DISCUSSION

The decision criteria and fire protection options assessed in the pilot study are valid based on the general view of steel structural fire design objectives and stakeholder opinions in the literature. However, all of the existing decision criteria and passive fire protection options in the design of buildings for fully developed fires were not exhaustively used in this paper, given that it is a pilot study aimed at showing the potential of the adopted technique/process in optimizing stakeholder decision-making. Other decision criteria e.g.: building aesthetics (Park *et al*. 2014), profit-making, code compliance etc.; and passive fire protection options e.g.: sprayed on cement-base material, water filling of hollow steel sections (Spearpoint 2008) could be included in the future. Fire industry stakeholders should be allowed to include all decision criteria and options they deem necessary in structural fire design of steel buildings during the engagement stage. In using AHP, the fire design stakeholders can participate in pairwise ratings as a collaborative group or as individuals at different times and places as in the pilot study, where GMM was used in aggregating individual ratings to achieve single group judgements.

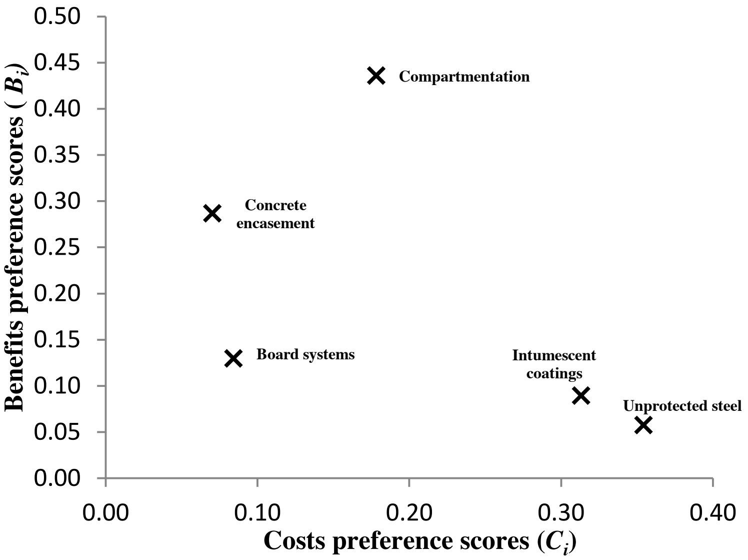

Figure 4 Ideal mode benefits versus costs preference scores for the passive fire protection options

The capability of AHP and other MCDA solutions to manage stakeholder desires and ranking of available options, were designed to help stakeholders to rank their options, but not for the tool to make decisions for the users. For instance, in a scenario where the participants in the example are more interested in the option with the highest benefits regardless of cost, then the second-ranked fire protection option, 'compartmentation' would be the obvious choice. This implies that a top-ranked option is not always the final choice. However, the analysis and ranking enables easy decision-making as it suits the stakeholders. The dominant option from the benefits synthesis may not be top-ranked one, given the costs synthesis as seen between compartmentation and concrete encasement shown in Table 6. In addition, the dominant or popular option among the stakeholders before the MCDA may not also be the top-ranked one at the end of analysis. This is clear where the initial dominance of compartmentation before the decision analysis as shown in Table 5 is compared with its rank after the analysis shown in Table 6 and Figure 4.

Another fundamental capability of the AHP shown in this decision-making process is the transition from the performance scores to the preference scores of the competing options using two distinct synthesis modes. In the pilot study, it can be seen that the different calculation procedure for the distributive and ideal synthesis mode did not produce a difference in the ranking of the fire protection options rather there is only a minor change in the preference scores as shown in Table 7. This may not always be the case in reality or in scenarios of complex decision hierarchies and data skewness. Saaty and Vargas (1993) also showed that there are minor differences in results produced by the distributive and ideal modes in a simulation. A further study of balancing the views offire industry stakeholders would be an opportunity to investigate these differences in a realistic scenario.

In relation to Millet and Saaty(1999),the ideal mode can be deemed appropriate for the synthesis of the competing passive fire protection options with respect to the benefits and costs sub-criteria in the pilot study. This is due to the independence of the competing options and the need to evaluate the performance of each option relative to the dominant option.

CONCLUSION

The purpose of this paper is to explain and demonstrate a decision-making process geared toward balancing stakeholder divergent views in steel structural fire design. The pilot study demonstrates the potential of the MCDA-AHP approach in solving decision problems. The sample population of ten student-participants is insufficient to test the process in real decision-making for fire protection of steel framed buildings. However, the process explained here is not about the outcome rather it is to test the viability of AHP in analysing decision-making problems inherent in steel structural fire design, given the flexibility of performance-based conditions. Hence, the results should not be used as a decision for fire protection.

This study also noted the effects of the weaknesses of AHP in analyzing unbalanced stakeholder desires in complex decision problems, these weaknesses include but are not limited to: outright dominance of a particular criterion or option at different categories of comparisons and inconsistencies of pairwise judgements. For instance, the example revealed some inconsistencies in the participants pairwise comparisons where CR is exactly 0.10, which is the limiting CR value (Saaty 1980). Coyle (2004) also mentions that items for pairwise comparisons are usually not more than seven. There are fivefire protection options compared in Table 4 hence, there is likelihood of a problem of consistent comparisons if we extend the study to include other fire protection options. A critical assessment of the AHP-ranked fire protection options through a risk-based parametric study has been identified as an additional process to manage the weaknesses from the decision analysis. Presently, there is ongoing research to this effect and will also entail the use of the proposed stakeholder engagement plan to extract the views of fire design stakeholders.

AHP is a viable decision analysis tool and it is proposed for use due to its potential in managing views of fire design stakeholders and helping them make suitable decisions toward designing better steel buildings for fully developed fires, and by extension enhancing the life cycle of engineered structures.

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