

Project Risk Assessment Using the Analytic Hierarchy Process

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Abstract—Often, construction projects fail to achieve their time, budget, and quality goals. This is frequently due to the failure of the contractor to analyze and assess unanticipated risks. The analytic hierarchy process (AHP) is a new approach that can be used to analyze and assess project risks during the bidding stage of a construction project and to overcome the limitations of the traditional approaches currently used by contractors. The AHP presents a flexible, easily understood way to assist the decision-maker in formulating his problem in a logical and rational manner. The paper also includes a review of the AHP and its application in the assessment of the riskiness of constructing the Jamuna Multipurpose Bridge in Bangladesh.

Keywords—Risk management; project management; construction management; risk assessment; the analytic hierarchy process; risk models; risk analysis; decision modeling.

I. INTRODUCTION

CONSTRUCTION, like many other industries in a free-enterprise system, has sizeable risk built into its profit structure [3]. From beginning to end, the construction process is complex and characterized by a number of uncertainties. For example, uncertainty about weather conditions, subcontractor failure, and different site conditions are typical risk variables that exist in every construction project. As a result, many construction projects fail to achieve their time, cost and quality goals.

Most contractors, however, have developed a series of rules of thumb to analyze and assess risk. These rules generally rely on the contractor's experience and intuition. Rarely do contractors quantify uncertainty and systematically assess the risks involved in a project [1]. One reason might be the lack of a rational, straightforward approach to combine all the facets of risk systematically into a prioritized and manageable scheme. However, as construction projects become more uncertain and complex, intuition and tested rules of thumb often fail to anticipate and respond effectively to the extent of uncertainty and risk in construction projects. Therefore, the need for a logical and rational risk assessment procedure rather than tested rules of thumb has increased [1].

Recently, a number of systematic models have been proposed for use in the risk evaluation phase of the risk management process. Kangari and Riggs [8] classify these methods into two overall categories: 1) classical models (i.e., probabilistic analysis); and 2) conceptual models (i.e., fuzzy set analysis). Examples of classical models include Monte Carlo simulation [1] and influence diagrams [4], [1]. An example of conceptual models is fuzzy sets [8]. Kangari and Riggs [8] note that probabilistic models suffer from two major limitations:

- 1) Some of these models require detailed quantitative infor-

mation which is not normally available in the real construction world.

- 2) The applicability of such models to real construction risk analysis is limited. This is mainly due to the fact that many of the contractor's decision problems are imprecise, ill-defined, and vague in nature. Such characteristics are mostly subjective in nature while classical models cannot handle subjectivity.

The object of this paper is to introduce a new approach for project risk assessment through the analytic hierarchy process (AHP). The AHP provides a flexible and easily understood way to analyze project risks. It is a multi-criteria decision analysis methodology that allows subjective as well as objective factors to be considered in the process which is precisely what is needed. In this respect, the new approach is aimed at augmenting and enhancing intuition rather than replacing it. The AHP gives managers a more rational basis on which to make decisions.

The AHP is used here to assist a contractor in the evaluation of the riskiness of a project on which there is bidding. Thus, the AHP will be used to provide a methodology for risk analysis and assessment. As described before, the use of AHP allows the management team to document and communicate an explicit, common, and shared understanding of the degree of a project's riskiness. In this way, the AHP becomes a living picture of the management's understanding of the project's risks.

AHP has been applied in different fields [2], [5], [9], [10], [12]–[20]. In the field of project/construction management, AHP has been applied in the evaluation of bidders (or biddings) [13], and in the selection of the best crashing scheme when factors other than time and cost are considered [14]. No prior work has been conducted on the utilization of the AHP in construction project's risk management. This paper attempts to provide a basic application of the AHP in risk assessment. In the next section we introduce the AHP. In Section III, we give a classification scheme of the risks encountered in a project. In Section IV, we apply the AHP to assess the riskiness of constructing a bridge project in Bangladesh. In the last section, we give a summary of the paper together with a discussion of the efficient use of the AHP.

II. THE ANALYTIC HIERARCHY PROCESS

The AHP developed by Saaty [16] is a robust and flexible multi-criteria decision analysis methodology. Formulating the decision problem in a hierarchical structure is the first and probably the most important step. The hierarchy should be constructed so that elements at the same level are of the same order of magnitude and must be capable of being related to some or all elements in the next higher level. In a typical hierarchy, the top level reflects the overall objective (focus) of the decision problem. The elements affecting the decision are represented in

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intermediate levels. The lowest level comprises the decision options. This type of hierarchy provides a clear and simple illustration of all the factors affecting the decision and their relationships. Once the hierarchy has been constructed, the decision maker begins the prioritization procedure to determine the relative importance of the element in each level of the hierarchy. Elements in each level are pairwise compared with respect to their importance in making the decision under consideration. The comparison takes this form: How important is element 1 when compared to 2 with respect to a specific element in the immediately higher level? For each level, starting at the top of the hierarchy and working down, a number of square matrices are formed from the results of comparing the elements of that level with respect to an element in the level immediately above. The elements are arranged into homogeneous groupings on clusters.

The decision maker can express his preferences between every two elements verbally as: equally preferred (or important, or likely), moderately preferred, strongly preferred, very strongly preferred or extremely preferred. These descriptive preferences would then be translated into absolute numbers [1], [3], [5], [7] and [9], respectively, with [2], [4], [6], and [8] as intermediate values for compromise between two successive qualitative judgments. The verbal scale used in AHP enables the decision maker to incorporate subjectivity, experience and knowledge in an intuitive and natural way.

After forming the comparison matrices, the process moves to the phase of deriving relative weights for the various elements. The relative weights of the elements of each level with respect to an element in the adjacent upper level are computed as the components of the normalized eigenvector associated with the largest eigenvalue of their comparison matrix. The composite weights of the decision alternatives are then determined by aggregating the weights through the hierarchy. This is done by following a path from the top of the hierarchy to each alternative at the lowest level and multiplying the weights along each segment of the path. The outcome of this aggregation is a normalized vector of the overall weights of the options. The mathematical basis for determining the weights has been established [16]. Questions raised about efficient use of AHP are addressed in the last section.

The use of the AHP to model and analyze real world problems can be made much easier using a microcomputer implementation of the method such as Expert Choice [6], [15]. It makes structuring and modifying the hierarchy simple and quick. It eliminates tedious calculations.

III. IDENTIFICATION AND CLASSIFICATION OF PROJECT RISKS

We now classify the various potential sources of risk in construction projects. Fig. 1 summarizes the general categories of risk. By considering these categories separately one can develop a detailed classification scheme of a project's risks.

Fig. 2 is a proposed classification scheme that shows the different sources of risk in construction projects. The proposed classification scheme is composed of six risk categories:

- acts of God risks;
- physical risks;
- financial and economical risks;
- political and environmental risks;
- design risks;
- job site-related risks.

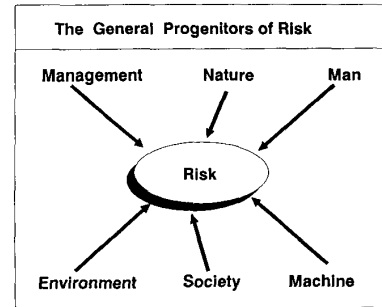


Fig. 1. The general progenitors of risk.

While the list of potential risks in every category is neither complete nor exhaustive, it represents most of the typical risks associated with a project. It would be impractical to describe every possible risk. Instead, we focus our attention on the details of general categories of risk.

Acts of God Risks

The risk of acts of God, or sometimes referred to as force majeure is a term appropriated, largely by the insurance industry, to describe events that are unpredictable and simply beyond anyone's direct control. These events occur as a result of nature and are often referred to as natural phenomena. The common risks under this category are those related to physical damages and personal injuries due to earthquakes, floods, fires, landslides, etc. force majeure is a term commonly used in contracts and normally covers war and civil commotion rather than embargoes and sabotage, etc.

Physical Risks

The typical risks that fall under this category are associated with damage of a property or asset that the contractor owns or has under his possession. Such risks include: damage to structure or property; damage to equipment and material; labor injuries and death; and forcible prevention of work or access to work.

Financial and Economic Risks

Most risks that evolve in construction projects are financially related. Project funding is obviously a potential economic risk for contractors. Inadequate sources of project funds by an owner or funding agent may create time delays and financing problems which to many contractors are unbearable. The owner must have enough funds to complete the work, and must make these funds available to the contractor in a suitable manner and time that enables the contractor to proceed with the work. Another potential risk, which is not frequently mentioned, is the risk of financial failure by one of the sub-contractors. While infrequent, the order of magnitude of the consequences of such failure needs to be considered.

Political and Environmental Risks

These risks may arise from the interactions between the contractor, the host government and the surrounding environment or society. Typically, political risks are salient in foreign operations or international projects. The main risks in this area include: expropriation of the contractor's equipment by the host government; customs and export/import restrictions on imported materials; and local laws and environmental control regulations.

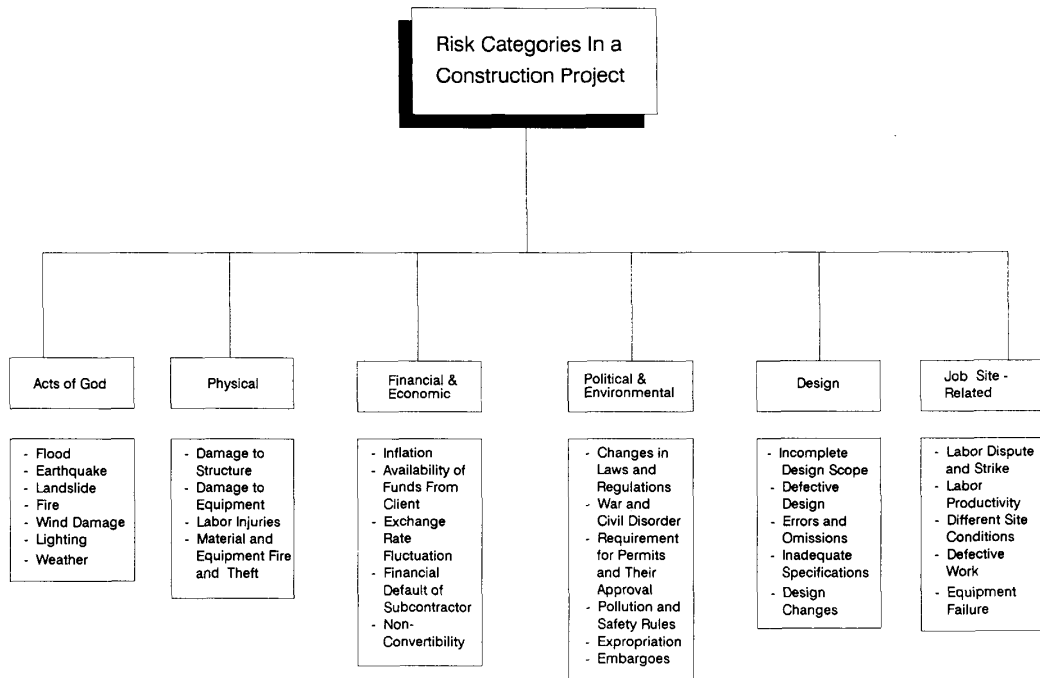


Fig. 2. The proposed risk classification scheme.

Design Risks

Risks normally incurred by the design professional include defective design, ambiguous specifications and plans, errors and omissions in design, inaccurate geological and geotechnical exploration, and interaction of design with methods of construction.

Job Site-Related Risks

Each sector of the construction industry has its own job site-related risks. Different site conditions, for example, are a major determinant of work progress in tunneling and earth moving contracts. On the other hand, building contractors may find labor productivity and equipment breakdown as a major determinant in schedule delays [2]. Hence, job site-related risks are numerous owing to the different operations in construction projects. The following are potential risks that are considered typical in every construction project:

- availability and productivity of labor;
- soil, site and other changed conditions;
- material shortages and quality.

Not every project involves all these kinds of risk. This classification can be used as a guide to identify the potential risks in a project.

IV. APPLICATION

We now give an application of the AHP to assess the riskiness of an international construction project: The Jamuna Multipurpose Bridge in Bangladesh [1].

Project Background

The project involves constructing a 4 760-m long span across the Jamuna river. The bridge will have multiple purposes: 1)

carrying road and rail traffic, 2) carrying high voltage electrical cables and communication lines across the river. Designs are being developed in steel and concrete for both the substructure and superstructures of the main bridge. River training works consist of guide bunds (dykes) at both river banks erected perpendicular to the bridge axis, and having a length of approximately 2 800 m each. Major dredging works (approximately 30 million m³) are required to construct the slope protection of the guide bunds to 30 m below the present flood plain. Floating equipment and other modern off-shore construction techniques with their associated hazards and risk will be used to build the bridge.

The AHP Risk Assessment Model

In this section, the steps followed in applying the AHP to assess the riskiness of the Jamuna Multipurpose Bridge project are discussed.

Step 1: Structuring the elements of the problem into a hierarchy.

For this purpose, various factors that affect the expected level of risk of the Jamuna Bridge Project are first identified. Because of space limitation, the significant risk factors of only the three most relevant risk categories have been selected for consideration in this demonstration. The following is a summary of these factors.

Financial and Economic Risks

Because of the project's complexity, the large number of contracts and the complications associated with involving international know how and equipment, it is critical to identify the financial risks that could be faced in this project. Those considered here are:

Subcontractors Financial Default: Subcontractors financial default may result in serious financial problems and time delays

for the prime contractor. The prime contractor should review carefully the qualifications of the potential subcontractors. Negligence by subcontractors such as failing to complete their job or to pay their bills may result in substantial delays, and consequently higher costs.

Unavailability of Funds: Unavailability of funds from the government and untimely payments for the contractors are risk factors that should be considered by a contractor. The project will be financed by the World Bank with co-financing from other international development financing agencies. However, there are a number of conditions and restrictions on the Government of Bangladesh regarding the use of funds allocated to this project.

Inflation and Price Escalation: These risks are generally speculative in nature. It is not possible to insure against cost increases which arise purely as a result of inflation. For example, the quotes price for tubular steel piles and fabricated steel box girders and other major items may fluctuate. The contractor may, or may not, incur additional costs due to price changes in such major construction items. In addition, charter rates for floating derricks, dredging equipment, piling barges and associated operations also vary. Any increase in charter rates for those heavy offshore equipment may result in substantial costs for the contractor. In addition, the contractor should assess the loss of use cost of such expensive equipment. Published price indices of various construction materials and the general trend of worldwide inflation are valuable sources for predicting inflation and assessing the potential for price escalation.

Political Risks

The country of Bangladesh is not at war with any neighboring country, and the chances of a war breaking out in the region are very small. Therefore, we only consider risk changes in local laws: civil disturbance, sabotage, changes in government policies regarding customs and export/import restrictions, embargoes and expropriation of contractor's equipment and plant.

Acts of God Risks

Equipment, materials used and the resulting structure are subject to loss or damage during their transportation to the work site and during construction because of the following types of risks:

Earthquakes: The selected bridge location at the town of Sirajganj is situated in a moderately active seismic region. The consultants are aware of the possible impact of an earthquake on the bridge, its foundations, the surrounding river training works and embankments. During the construction phase, however, there are other exposures to earthquake risks that include:

- the partially completed permanent works and how they can withstand all stresses within the design magnitude;
- the contractor's temporary works;
- the sensitivity of soil to liquefaction effects.

Water Damage and Floods: The site of the project is subject to annual flooding when the rivers and their tributaries are swollen by melting snow from the mountains and from monsoon rains. Therefore, protection of camp sites located in the flood plains and of river works are of paramount importance. Another source of concern is the possibility of the river overflowing to outflank the construction and subsequently causing damage to structures vulnerable to the force of water. An early or late flood would break through into the excavated basin and fill it up with

sand, or erode the river embankments before they are completed.

Soil Subsidence and Collapse: Areas considered vulnerable to subsidence and collapse are the approach roads, access routes, and flood embankments. It is known that the soils at the bridge location consist of loosely consolidated silty micaceous sand deposits, which extend to great depths. During the lengthy wet season, these soils will be relatively unstable, especially because of the proximity of the river, which is a cause for concern particularly for deep excavations. While the extent of the physical damage may be relatively small, the consequential delay costs could be extensive.

These factors are incorporated in levels 2 and 3 of the hierarchy as shown in Fig. 3. Level 1 represents the construction firm's overall goal, namely: The most likely risk in the bridge project. Level 4 contains the three possible levels or intensities of the total risk of the project. Although not in Figure 3 an additional level of outcomes (severe; moderate; strong; fair; weak; favorable; unfavorable) could be inserted and considered between the subfactors level and the risks level.

Step 2: Develop the relative weights of the various elements.

The importance of the factors and subfactors and the likelihood of the levels of risk are determined next. For this purpose, judgments are elicited from the management of the construction firm and matrices of judgments are formulated. For example, in order to determine the relative importance of the three factors of the second level (financial, political and acts of God), a 3×3 matrix is formed as shown in Table I.

This matrix shows that Financial risks are judged to be weakly more important than political risks on the AHP verbal ratio scale presented earlier (equivalent to three times on the numerical scale). The main reason for this is the management's concern about the consequences of finance-related risks (especially the unavailability of funds from the government). The government of Bangladesh is keen to see the bridge built and is not expected to change laws or regulations in a way that would affect the success of the project. On the other hand, money is a very scarce resource in that country and the government might find it necessary and opportune to shift money allocated to such a project to another activity.

The matrix also shows that when financial risks and acts of God risk are compared, the management was not sure whether to judge it as strongly more important (five on the numerical scale) or very strongly more important (seven on the numerical scale). The judgment in between was therefore chosen. The reason for the low importance of acts of God risks is that the bridge will be designed taking into consideration these kinds of factors. For similar reasons, political risks are judged to be five times more important than acts of God.

This matrix needed only three (in general $n(n-1)/2$) judgments to be made which are enough to fill the triangle above the diagonal. The diagonal elements of the matrix are each equal to one (elements are compared with themselves), and lower triangle elements of the matrix are reciprocals of upper triangle elements.

A close examination of the judgments made to determine the relative importance of the three factors considered shows that management has not been fully consistent. Inconsistency is permissible in AHP so long as it does not exceed a ratio of about 0.10 justified in the theory as a cut-off point. In the case of the matrix comparing the factors, the inconsistency ratio was 0.081.

Similar procedures are followed to elicit judgments on the

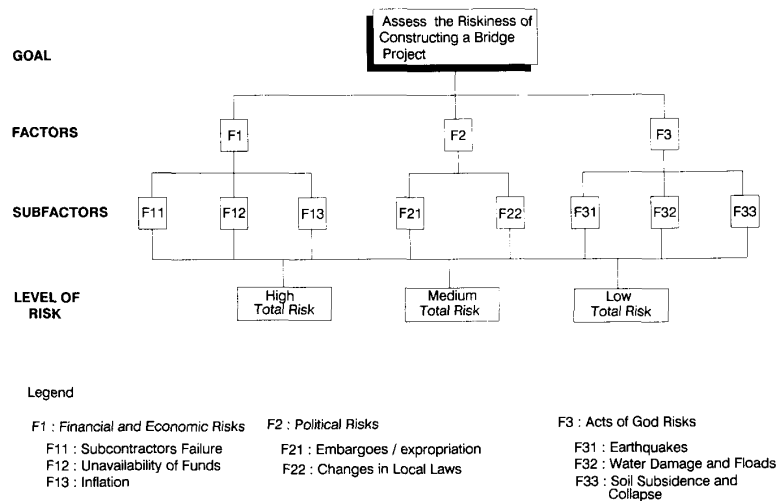


Fig. 3. The AHP risk assessment model.

TABLE I
JUDGMENTS MATRIX AND WEIGHTS OF FACTORS

| With Respect to Goal | F1 | F2 | F3 | Relative Importance |
|----------------------|-----|-----|----|---------------------|
| F1 | 1 | 3 | 6 | 0.635 |
| F2 | 1/3 | 1 | 5 | 0.287 |
| F3 | 1/6 | 1/5 | 1 | 0.078 |

relative importance of the subfactors and the relative likelihood of the levels of risk (high, medium and low total risk). Three matrices of judgments on subfactors and eight matrices on the three levels of risks are formed.

The relative importance of the various factors are then computed as the components of the normalized eigenvectors of the matrices. For example, using the matrix shown in Table I, the relative importance of the factors of risk are computed. Financial risks has the highest relative importance (0.635), followed by political risks (0.287) and finally acts of God with a relative weight of 0.078. The relative importance of the subfactors of Level 3 with respect to the overall goal are shown in column 2 of Table II. The likelihoods of the various levels of risk given the outcome of the subfactors with respect to the overall goal are shown in columns 3-5 of Table II. The results show that unavailability of funds is the most influential subfactor in determining the level of risk of this project with a relative importance of 0.433, followed by changes in local laws subfactors 0.205. Inflation and soil subsidence and collapse are seen by the management as the least important subfactors with priority 0.007.

Step 3: Synthesize and determine likelihoods of levels of risks. In this step, the likelihoods of high, medium, and low total risk are determined by aggregating the relative weights through the hierarchy.

The results show that when all factors are considered with the judgments made by the management of the firm, the project is characterized as low risk (with a likelihood of 0.401) as shown at the bottom of Table II.

Sensitivity Analysis: The outcome of the analysis presented above is highly dependent on the hierarchy established by the management and the relative judgments made about the various elements of the problem. Changes in the hierarchy or the

TABLE II
PRIORITIES OF FACTORS, SUB-FACTORS, AND LEVELS OF RISK

| Factors | Sub-factors | Levels of Risk | | |
|---------|-----------------------------|----------------|--------|-------|
| | | High | Medium | Low |
| F1 | 0.635 | | | |
| | F11 | 0.150 | | |
| | F12 | 0.433 | 0.099 | 0.031 |
| | F13 | 0.052 | 0.041 | 0.121 |
| | | | 0.005 | 0.017 |
| F2 | 0.287 | | | |
| | F21 | 0.082 | | |
| | F22 | 0.205 | 0.008 | 0.019 |
| | | | 0.040 | 0.147 |
| F3 | 0.078 | | | |
| | F31 | 0.022 | 0.005 | 0.015 |
| | F32 | 0.049 | 0.035 | 0.010 |
| | F33 | 0.007 | 0.002 | 0.004 |
| | | | 0.002 | 0.005 |
| | | | 0.002 | 0.001 |
| | | | 0.235 | 0.364 |
| | | | 0.401 | |
| | Likelihood of level of risk | | 0.235 | 0.364 |
| | | | 0.401 | |

judgments may lead to a change in the outcome. Using Expert Choice the sensitivity of the outcome to different changes can be tested. For example, Fig. 4 shows the sensitivity of the outcome to changes in the relative importance of the Financial risks factor. With its current weight of 0.635, the project is judged to be of low total risk. If the relative importance of this factor were judged differently and its weight decreased to 0.55 or less, the project would be described as a medium total risk project. Sensitivity of the decision to other factors can be tested in a similar manner.

V. SUMMARY AND DISCUSSION

In this paper, we have investigated the subject of risk assessment in construction projects. A scheme of classifying the various sources of risk has been developed. The AHP has been introduced and applied in assessing the riskiness of constructing The Jamuna Multipurpose Bridge. Risk factors significant to this project are identified and incorporated in this assessment. Results show that the project is an overall low risk project.

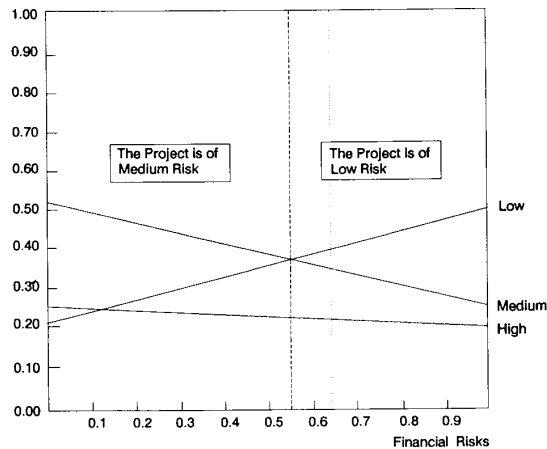


Fig. 4. Sensitivity of the levels of total risk to financial risks.

The AHP provides a valuable support for contractors in the decision making process. It is a comprehensive framework for thinking through the decision problem. The numerical outcomes of the method are less important than the systematic thinking environment it offers. While this paper presents the use of AHP in the risk analysis and assessment stage of the project's risk management process, it can also be used in evaluating alternative responses to risk. The project manager might find the AHP useful to support decision making in bid evaluation, equipment selection, staff selection, corporate stability and competitiveness, and other areas.

Some questions regarding the efficient use of the AHP have been raised. The first concern is related to building the hierarchy and the recommendation of (7 ± 2) elements under any node in order to preserve consistency [11], [16]. This raises the question of how to handle cases where the number of elements is greater than 9. When the number of elements is large, they can be grouped in clusters and then comparable clusters are merged. One can use a first pass to arrange elements in ascending or descending order according to the property at hand. This total ordering is then decomposed into clusters beginning with the largest element (for example) and including only few elements (7 ± 2) in each cluster. Then, the elements in the first cluster are compared. To ensure that elements in two adjacent clusters be comparable, the smallest element of the largest cluster is included as the largest element of the adjacent cluster. The derived values of the elements in the adjacent cluster are then divided by the priority of the common element, and then all are multiplied by the weight of that element in the larger cluster. In this way, the priorities of the elements of both clusters become comparable and the two clusters are then merged. The process is then repeated by using the smallest element of the adjacent cluster as the largest element of the third cluster. This sorting and comparison must be carried out separately for each property. Hypothetical elements may have to be considered to make possible the smooth transition from one cluster to another.

The second source of concern is the number of judgments required to derive relative priorities. From traditional measurement of tangibles, it seems reasonable that AHP needs no more than $(n - 1)$ judgments to relate one element to the remaining $(n - 1)$ from which one can automatically construct all other comparisons by forming ratios. However, when we are dealing with intangible criteria for which we have no measurement, we

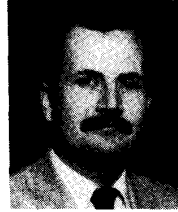
are no longer certain of the precise correspondence of the strength of a judgment to a numerical value, which represents that judgment, nor are we certain of the judgment itself. Therefore, we should use redundant information in more than $(n - 1)$ judgments to improve both the quality of the judgment and the validity of the derived numerical scale. The latter validity of the derived scale can be seen to depend on the amount of information represented in the fundamental scale. Thus we need a way to estimate the cost of information and determine how valuable it is to produce a valid outcome. Harker [7] has developed such a way. It would seem that a complex problem with which one has had to contend for a long period of time, perhaps measured in years, may require longer discussion and a larger number of judgments and redundancy for its solution. Generating these judgments may be a somewhat more protracted process than a simple problem of choice. Therefore, the number of judgments and their quality is an important concern in a complex decision. The participants may have to meet more than once, or their judgment may be canvassed through a carefully designed questionnaire. Eliciting relevant information is a scientific concern not to be abrogated or aborted through slick rationalization.

To the practicing scientist and engineer, the use of personal judgment in the AHP which involves interpretation of stimuli in the form of comparisons may be construed as a limitation. Here the individual uses his mind directly to create scales as outlined in the AHP without the intervention of instruments of measurement. However, every one would agree that whatever its numerical outcome may be, whether in yards or meters, tons or bushels, fahrenheit or celsius, measurement itself must be interpreted by experts. On the other hand, most of the elements in the AHP model are intangibles measured through judgment as there is no other way for their calibration. A fundamental way to check the soundness of such judgments elicited from a diversity of experts is to calculate their consistency. By taking redundant judgments from experts, cooperating together to align their thinking, we can ensure a modicum of validity. The AHP has also been extended to deal with situations where there are conflicts in the judgments of experts [18].

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