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Invited Review

Analytic hierarchy process: An overview of applications

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Abstract

This article presents a literature review of the applications of Analytic Hierarchy Process (AHP). AHP is a multiple criteria decision-making tool that has been used in almost all the applications related with decision-making. Out of many different applications of AHP, this article covers a select few, which could be of wide interest to the researchers and practitioners. The article critically analyses some of the papers published in international journals of high repute, and gives a brief idea about many of the referred publications. Papers are categorized according to the identified themes, and on the basis of the areas of applications. The references have also been grouped region-wise and year-wise in order to track the growth of AHP applications. To help readers extract quick and meaningful information, the references are summarized in various tabular formats and charts.

A total of 150 application papers are referred to in this paper, 27 of them are critically analyzed. It is hoped that this work will provide a ready reference on AHP, and act as an informative summary kit for the researchers and practitioners for their future work.

Keywords: Analytic Hierarchy Process (AHP); Decision analysis; Multiple criteria analysis; Decision making

1. Introduction

Analytic Hierarchy Process (AHP), since its invention, has been a tool at the hands of decision makers and researchers; and it is one of the most widely used multiple criteria decision-making tools. Many outstanding works have been published based on AHP: they include applications of AHP in different fields such as planning, selecting a best alternative, resource allocations,

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resolving conflict, optimization, etc., and numerical extensions of AHP ([137,151]; http://www.expertchoice.com). Bibliographic review of the multiple criteria decision-making tools carried out by Steuer [125] is also important. This review paper is partially dedicated to the AHP applications, which are combined with finance.

The speciality of AHP is its flexibility to be integrated with different techniques like Linear Programming, Quality Function Deployment, Fuzzy Logic, etc. This enables the user to extract benefits from all the combined methods, and hence, achieve the desired goal in a better way.

The present article looks into the research papers with a view to understand the spread of the AHP applications in different fields. The papers considered for discussions describe the extensively used AHP as a developed tool. An attempt is made to explain a few latest applications in a nutshell. Care has been taken to identify the latest references and explain the findings in each category, and also to discuss the papers that have been published in international journals of high repute. The coverage, however, is not exhaustive, and tries to portray only the glimpses of AHP applications.

Papers are discussed in the reverse chronological order, enabling the readers get an overview of the latest trend and the past coverage of the AHP applications. For the instant glimpses, the references are listed alphabetically as well as with the sequence numbers. They are also summarized in a tabular form in each of the area sub-headings.

It is strongly believed that this work will give a quick insight for the future work concerned with AHP, and help the practicing engineers get a view of different facets of AHP.

The following section of the article briefly describes AHP as a multiple criteria decision-making tool. The sections following this covers the discussion of the AHP applications in selected few areas.

2. Analytic Hierarchy Process (AHP): A multiple criteria decision-making tool

Analytic Hierarchy Process [116] is a multiple criteria decision-making tool. This is an Eigen value approach to the pair-wise comparisons. It also provides a methodology to calibrate the numeric scale for the measurement of quantitative as well as qualitative performances. The scale ranges from 1/9 for 'least valued than', to 1 for 'equal', and to 9 for 'absolutely more important than' covering the entire spectrum of the comparison.

Some key and basic steps involved in this methodology are:

1. State the problem.
2. Broaden the objectives of the problem or consider all actors, objectives and its outcome.
3. Identify the criteria that influence the behavior.
4. Structure the problem in a hierarchy of different levels constituting goal, criteria, sub-criteria and alternatives.
5. Compare each element in the corresponding level and calibrate them on the numerical scale. This requires $n(n-1)/2$ comparisons, where n is the number of elements with the considerations that diagonal elements are equal or '1' and the other elements will simply be the reciprocals of the earlier comparisons.
6. Perform calculations to find the maximum Eigen value, consistency index CI, consistency ratio CR, and normalized values for each criteria/alternative.
7. If the maximum Eigen value, CI, and CR are satisfactory then decision is taken based on the normalized values; else the procedure is repeated till these values lie in a desired range.

AHP helps to incorporate a group consensus. Generally this consists of a questionnaire for comparison of each element and geometric mean to arrive at a final solution. The hierarchy method used in AHP has various advantages (see [116]).

3. Analyses of AHP applications

This section of the article analyses different applications of AHP. For the convenience these applications have been classified into three groups, namely: (a) applications based on a theme, (b) specific applications, and (c) applications combined with some other methodology. We collectively call them as 'application based on theme'.

Themes in the first group are selection, evaluation, benefit–cost analysis, allocations, planning and development, priority and ranking, and decision-making. Although a research article may be classified under two headings on the basis of the subject coverage, the best possible suited category is taken into account for the classification purpose in this paper to avoid the duplication. Second group consists of the specific applications in forecasting, and medicine and related fields. AHP applied with Quality Function Deployment (QFD) is covered in the third group.

Papers are also classified on the basis of the area of applications in this paper. Chosen areas of applications are: personal, social, manufacturing sector, political, engineering, education, industry, government, and others which include sports, management, etc.

The following sections describe the theme-wise selected research papers. Each section also contains a table that lists all the theme-specific papers alphabetically. The table also mentions the application area for each of the papers.

3.1. Selection

Lai et al. [83] used AHP for software selection called Multi-media Authorizing System (MAS). They used the group decision-making technique, which included six software engineers. Three products of MAS were evaluated. The hierarchy of the pair-wise comparison was formed that consisted of four levels. The criteria in the level three were evaluated. These criteria were: development interface, graphics support, multi-media support, data file support, cost effectiveness, and vendor support.

The six software engineers were trained about the use of AHP, and then asked to pair-wise compare the different criteria. Expert Choice software was used to felicitate ease in computation. To arrive at a selection consensus, the geometric mean methodology was preferred. The production software, which had a large geometric mean value, was selected.

In the post AHP session, a questionnaire was prepared for the software engineers. This questionnaire was used to determine the contributions of AHP to decision quality, indirect benefits, practical user satisfaction, and economy. Some *t*-test analysis was also done in order to compare the applicability of AHP over conventional Delphi technique. The participants (software engineers) agreed that AHP would be more acceptable over Delphi method. This paper provides an insight for the use of AHP in the group decision-making.

To achieve rapid product development, Kengpol and O'Brien [68] presents a decision tool for the selection of advanced technology. In their proposed model, they integrate cost–benefit analysis model, decision-making effectiveness model, and a common criteria model to choose from Time Compression Technologies (TCT). TCT are the technologies that improve a design and manufacturing process to achieve better quality in short time-period, e.g., rapid prototyping.

In the first stage, sensitivity analysis and neutral line profitability model is worked out. Neutral line profitability model is the anticipated cash flow using the illustrative data for current technology and business practice. This is done considering the fact that companies need to adjust to their own specific data to obtain accurate results for the specific product. This analysis becomes a part of cost–benefit analysis model.

In the second stage, decision-making effectiveness model is framed to investigate to what extent it may be possible to calculate the probability of product success based on the analysis of previous data. In the third stage of the common criteria model, a common criteria and sub-criteria are prepared. All these criteria need to be prioritized based on the company's requirements. There are about three basic line criteria, which are to be prioritized. This was done by AHP and using the Expert Choice software. The proposed model thus helps to monitor the effectiveness of a decision, and the decision model helps in consolidating quantitative and qualitative variables using AHP.

Al Harbi [3] applied AHP in the field of project management to select the best contractor. He constructed a hierarchical structure for the pre-qualification criteria, and the contractors who wish to qualify for the project. In all, five contractors were considered in the case study. They were evaluated based on the criteria of experience, financial stability, quality performance, manpower resources, equipment resources, and current workload. Each of the contractors was compared pair-wise with the other for the different criteria mentioned above. Ranking among the different criteria was also done to find out the 'overall priority' of each contractor. Based on this overall priority, the best contractor was selected. The contractor so selected had a highest overall priority value.

A four-step algorithm for locating and selecting the convenience store (CVS) is presented by Kuo et al. [81]. They extensively used AHP as it certainly has advantage over the conventional methods. The conventional methods provide a set of systematic steps for problem solving without involving the relationships among the decision factors. The authors proposed a new decision support theory using fuzzy steps and AHP. The new theory consists of four steps. The first step consists of the formation of a hierarchical structure that consists of at least three levels. The first level represents the overall objective/focus of the problem. The second level includes the criteria for evaluating the alternatives, while the third level lists sub-criteria. In the case study that used this theory, 34 stores from across the 11 districts were chosen and evaluated for 43 factors/criteria. Thirty-seven criteria were evaluated based on data obtained by the actual investigation. The second step consists of the weight determination. Here a questionnaire was prepared to compare the criteria pair-wise. For ease in answering the questionnaire, a five-point scale based on Fuzzy logic was used although Saaty's nine-point scale is recommended. The third and the final steps constituted data collection and the decision-making. The CVS, which had the highest value, was selected to be the desired location.

Korpela and Tuominen [75] presented an integrated approach to warehouse site selection process, where both quantitative and qualitative aspects were considered. The main objective of the warehouse site selection was to optimize the inventory policies, enable smooth and efficient transportation facilities, and decide on various aspects such as location and size of stocking points etc., as related to logistics system design.

The algorithm constitutes of four phases. The first and the second phase define the problem to set goals for the decision-making and identifies the sites and gather sufficient information to evaluate them respectively. Third phase consists of analysis wherein AHP is used for qualitative analysis, and to compare the alternatives based on intangible criteria. Cost analysis is also done in this phase to evaluate the impact of each alternative on the total logistic cost. Fourth phase combines the outcomes of both analyses to calculate and choose the site based on benefit/cost ratios. The authors described a case wherein a warehouse is selected.

The following couple of papers also use AHP for the selection process. Al Khalil [5] used AHP to select the most appropriate project delivery method as key project success factor. Byun [31] used an extended version of AHP in selection of a car. The paper is focused on two issues: one combines the pair-wise comparison with a spreadsheet method using a five point rating scale; the other applies group weights to consistency ratio. Tam and Tummala [131] have used AHP in vendor selection of a telecommunication system, which is a complex, multi-person, multi-criteria decision problem. They have found AHP to be very useful in involving several decision makers with different conflicting objectives to arrive at a consensus decision. The decision process as a result is systematic and reduces time to select the vendor. For selecting quality-based programs, Noci and Toletti [102] have used AHP along with fuzzy approach.

Jung and Choi [67] presented optimization models for selecting best software product among the alternatives of each module in the development of modular software system. A weight is given to the module using AHP based on access frequency of the modules. Lai et al. [84] presented a paper that explains the use of AHP to select software. Mohonty and Deshmukh [96] proposed a framework applying AHP, for analyzing a firms investment justification problem in advanced manufacturing technologies to take competitive advantage in the liberalized economy and global market. This has facilitated the process of effective management of knowledge as a resource for the value creation and maintenance for an Indian electronics manufacturing company. Schniederjans and Garvin [120] used AHP to select multiple cost drivers for activity based costing with the help of multi-objective programming methodology. Shang et al. [121] used AHP in selecting the most appropriate flexible manufacturing system. This model examines the non-monetary criteria associated with corporate goals and long-term objectives apart from identifying the most efficient flexible manufacturing system. An AHP based heuristic algorithm to facilitate the aircraft selection for the operation on airport pairs was presented by Ceha and Ohta [34]. Kim and Yoon [71] developed a model to identify the quality-based priorities for selecting the most appropriate expert shell as an instructional tool for an expert system course in a business school.

Table 1 lists the references that discuss the application of AHP for the process of selection. Second column specifies the reference number of the article. Column representing 'other tool' lists name of the tool that has been used, if any, alongside the AHP in respective paper.

3.2. Evaluation

Akarte et al. [2] used AHP to select the best casting suppliers from the group of evaluated

Table 1
References on the topic of 'Selection'

Sr. no.	Reference no.	Year	Author/s	Application areas	Other tool/s used
1	[1]	1995	Ahire S L, Rana D S	Social	–
2	[3]	2001	Al Harbi K M Al-S	Personal	–
3	[5]	2002	Al Khalil M I	Social	–
4	[17]	2003	Bahurmoz A M A	Education	–
5	[25]	1986	Brad J F	Manufacturing	–
6	[31]	2001	Byun Dae Ho	Personal	–
7	[34]	1994	Ceha R, Hiroshi Ohta	Political	–
8	[37]	1997	Cheng C H	Social	Fuzzy theory
9	[51]	2003	Ferrari P	Political	
10	[57]	1998	Ghodsypour S H, O'Brien C	Personal	Linear programming
11	[58]	1986	Golden B L, Wasil E A	Engineering	–
12	[64]	1990	Hegde G G, Tadikamalla P R	Social	–
13	[67]	1999	Jung H W, Choi B	Engineering	–
14	[68]	2001	Kengpol A, O'Brien C	Engineering	Cost benefit, statistics
15	[71]	1992	Kim C S, Yoon Y	Education	–
16	[75]	1996	Korpela J, Tuominen M	Social	–
17	[81]	1999	Kuo R J, Chi S C, Kao S S	Political	Artificial neural network, fuzzy set theory
18	[83]	2002	Lai V, Wong B K, Cheung W	Engineering	–
19	[84]	1999	Lai V, Trueblood R P, Wong B K	Engineering	–
20	[92]	1987	Libertore M J	Social	–
21	[96]	1998	Mohanty R P, Deshmukh SG	Manufacturing	–
22	[98]	1990	Murlidhar K, Shantharaman R	Engineering	–
23	[101]	2003	Ngai E W T	Industry	–
24	[102]	2000	Noci G, Toletti G	Industry	Fuzzy linguistic approach
25	[108]	1999	Raju K S, Pillai C R S	Government	–
26	[119]	1991	Schniederjans M J, Wilson R L	Engineering	Goal programming
27	[120]	1997	Schniederjans M J, Garvin T	Personal	Multi-objective programming methodology
28	[121]	1995	Shang J et al.	Manufacturing	Simulation model, accounting procedure
29	[129]	1991	Tadisna S K, Troutt M D, Bhasin V	Education	–
30	[131]	2001	Tam M C Y, Tummala VMR	Personal	–
31	[136]	2003	Vaidya O S, Kumar S	Engineering	Graph theory
32	[148]	1995	Yurimoto S, Masui T	Social	–

suppliers. The authors developed a user-friendly web page so as to carry out the evaluation virtually with 'zero page work'. The evaluation procedure took care of about 18 different criteria. These were segregated into four groups namely: product development capability, manufacturing capability, quality capability, and cost and delivery. Out of 18 different criteria, six were of objective type and twelve were of subjective type. The authors claim to have used most of the important criteria and they state that any criteria can be added/deleted to suit the requirement of the web page user.

The use of AHP in the web page developed has helped the authors to consider multiple criteria and use a common scale for different criteria, apart from considering both the tangible and intangible criteria. All the criteria were structured in three levels, where as the suppliers to be evaluated form the third level. An overall score is computed based on the input given by the suppliers. The objective (quantitative) criteria are evaluated depending on whether the maximum or minimum value is desirable. If the maximum criteria are desirable, then the largest value has the highest performance measure (e.g., maximum part size produced by the supplier has the higher/larger preference), and vice versa. The relative performance measure for each supplier for subjective (qualitative) criteria is obtained by quantifying the ratings expressed in quantitative terms. The supplier who has the maximum score is selected.

Fogliatto and Albin [52] presented a hierarchical method for quantitative sensory panel and expert opinion data. The paper mainly presents two contributions. First is a hierarchical method for computing a weighing or composite performance measures for different products. AHP is applied with its extension to create weights for quantitative, expert opinion, and sensory panel data. These weights, in turn, are used to optimize the level of experimental control factors. The second contribution is a procedure to collect and analyze data using indirect pair-wise comparison method. It is done on a 15 cm linear scale. This method has enabled the panelists to reduce bias. A limitation to this indirect method is that a panelist can compare relatively small number of products due to fatigue. A five step and seven level hierarchical methods (with some minor modifications) are presented, to satisfy the requirements of the methods. In a section of the paper qualitative responses are evaluated and the values normalized. This procedure makes use of desirability function to re-scale the responses onto a zero–one scale.

The authors presented the method with the help of a numerical example. The example, evaluation of powder milk is based on three responses: (a) moisture and fat content; (b) intensity of milk taste; and (c) milkiness for eight products. The seven level hierarchy works from bottom to top. In this methodology, firstly weight vectors of the product for the quantitative responses are computed. Secondly, the panelists judge weight vectors. Thirdly, the expert opinion matrix is used to assess the ability of the panelists; and finally the expert opinion matrix is used to obtain the weight of the products. The method, apart from evaluation of products, helps in selection of the best.

To assess and to evaluate the probability of competitive bidding, Cagno et al. [32] used a simulation approach based on AHP. The paper focuses on the quantitative evaluation and typical uncertainty on the process. A three-layer hierarchy comprising of four criteria and thirteen sub-criteria is presented which forms a part of analysis. Instead of point pair-wise comparison used in AHP, the authors used interval judgments. These judgments represent both uncertainty and depression of decision process. This forms a step to evaluate the 'probability' of winning the bid. Further the authors make use of Monte Carlo simulation approach, as this approach is an easier way to handle the uncertainties regarding the judgments used in AHP. The authors present an example considering an auction for design and construction of a process plant.

A few other research papers in this category are briefly mentioned. Forgionne and Kohli [54] used AHP to evaluate the quality of journals, with a methodology for consolidating the multiple-criteria into an integrated measure of journal quality, with discussion on data collection process. An advanced version of AHP, Analytic Network Process (ANP) is considered by Sarkis [118] for the evaluation of environmentally conscious manufacturing program. The types of programs that could be evaluated range from selection of the product design and material to major disassembly programs that may be implemented in parallel with standard assembly programs. Ossadnik and Lange [104] used AHP to evaluate the quality of three software products supporting AHP, with a view to provide transparency of operative capability of AHP and a generally available method to evaluate AHP software. Liberatore and Stylianou [91] developed a system known as strategic market assessment system, using scoring models, logic tables and AHP. It provides the necessary decision support, so as to evaluate whether or not full-scale development of a candidate product should proceed. The system can function as a stand alone or with association of evaluation system. Weiwu and Jun [143] elaborated the principle and method of comprehensive evaluation and analysis of highway transportation. They used the methods of AHP along with IDS to evaluate the highway with a system engineering perspective. Table 2 lists the references in this category.

3.3. Benefit–cost analysis

Chin et al. [38] used AHP for two basic purposes. They formulated a model to evaluate the success factors, and to develop strategies to implement ISO14001-based environmental management system. The model is used to evaluate the benefit/cost ratios of implementing the ISO-based EMS, and to decide whether to implement it or not. In the first part of this paper, management attitude, organizational change, external and social aspects, and technical aspects are identified as the important success factors. These factors focus on the strategic factors, which are further defined on the operational attributes. The authors have identified the benefits of the ISO based implementation to be

Table 2
References on the topic of 'Evaluation'

Sr. no.	Reference no.	Year	Author/s	Application areas	Other tool/s used
1	[2]	2001	Akarte M M et al.	Engineering	–
2	[26]	1986	Brad J.F	Manufacturing	–
3	[29]	1997	Bryson N, Mololurin A	Education	–
4	[32]	2001	Cagno E, Caron F, Perego A	Personal	–
5	[36]	1999	Cheng C H et al.	Government	Linguistic variable weight
6	[52]	2001	Fogliatto F S, Albin S L	Industry	–
7	[53]	2002	Forgionne et al.	Education	
8	[54]	2001	Forgionne G A, Kohli R	Education	–
9	[62]	2002	Handfielda et al.	Personal	
10	[72]	1990	Klendorfer P R, Partovi F Y	Manufacturing	–
11	[78]	1999	Korpela J, Lehmusvara A	Social	Mixed integer linear programming
12	[80]	1998	Korpela J, Tuominen M, Valoho M	Social	–
13	[86]	1998	Lam K	Education	QFD
14	[90]	2003	Li Q, Sherali H D	Government	–
15	[91]	1994	Liberatore M J, Stylianou A C	Management	Scaling models, logic tables
16	[99]	2001	Murlidharan C et al.	Personal	
17	[104]	1999	Ossadnik W, Lange O	Engineering	–
18	[106]	1999	Poh K L, Ang B W	Government	
19	[118]	1999	Sarkis J	Social	ANP, data envelopment analysis
20	[127]	1992	Suresh N C, Kaparthi S	Manufacturing	Goal programming
21	[130]	2003	Takamura Y, Tone K	Government	
22	[134]	2003	Tavana M	Government	Probability, MAH
23	[140]	1997	Weck M et al.	Manufacturing	
24	[143]	1994	Weiwu W, Jun K	Social	Statistics
25	[150]	1990	Zahedi F	Management	–
26	[153]	1991	Zanakis S H et al.	Engineering	–

of legal, commercial and social. The costs of ISO implementations are said to be of initial set-up cost, long term maintenance cost and improvement costs. The authors have translated the benefit/cost problem into a complementary benefit and cost hierarchies, and have used a pair-wise comparison. This is done in order to quantify the intangible and non-economic factors included in the hierarchy.

The AHP model developed consists of four phases, which include structuring the problem to build up the hierarchy, collecting data through pair-wise comparison, determining the priorities, and analysis for the solution of the problem. The AHP model presented consists of four levels. These are separately done for costs and benefits. For the benefits, the goal forms the first level, the success factors and its further classification forms the second level, the identified benefits forms the third level, whereas the decision to implement the EMS forms the fourth level. In case of the costs hierarchy, the third level parameters from the benefits hierarchy are replaced by the parameters of the costs, other parameters remaining the same. Teams comprising of six members were asked to evaluate the parameters in the hierarchy. This is done with the help of interview rather than following a generalized questionnaire format so as to increase the transparency in the evaluation scheme. After the evaluation process, the combined judgments were formulated and the ratio of the benefits to cost was taken. The ratio of benefits/costs (to implement) was more, and hence a decision to implement the EMS based ISO 14000 were taken.

Tummala et al. [132] applied AHP in a Hong Kong based Electronics Company. AHP was applied to check whether concurrent engineering could be implemented in the organization or not. The benefit/cost analysis was done for this purpose. Costs that were considered include the initial investment, the cost of training and development, cost of new technologies, and the costs of risk and uncertainty. The benefits resulting in the implementation of the concurrent engineering were: effect on the quality, reduced product cost, reduced time to market, customer focus, etc.

Some success factors were identified for the basis of evaluation. These were management attitude, product development, organizational change, and implementation methodologies with there sub-criteria. A five level methodology was presented for computing the benefits and the costs incurred because of the implementation of the concurrent engineering technology. Five representative evaluators were considered from the different areas were asked to carry out the evaluation work. Saaty's geometric mean approach was used to combine the pair-wise comparison. The evaluation for the benefits showed that, if concurrent engineering were implemented properly, the increased product quality and shortened product development time would be the preferred benefits. The cost side of the analysis, the cost of initial change and the cost of the training and development were the dominating cost parameters amongst all. Finally a pair-wise comparison was carried out (from the results of the earlier findings) on the basis of the costs and the benefits hierarchy, and it was inferred that overall the benefits were superseding the costs, and hence the concurrent engineering technology can be implemented.

This paper in real terms does not deal directly with the benefit–cost analysis but deals with performance cost analysis by way of using AHP. The paper is included in this discussion, specifically for two reasons: (a) any benefit–cost analysis can be modified into the desired conditions, and (b) the methodology used in the paper can be suitably modified to benefit–cost analysis on the similar lines.

Angels and Lee [8] presented a methodology using AHP that ties investment decisions to activity based costing. Both the monetary and the non-monetary benefits are included in the analysis. The relationships between goal, activities benefit and cost is also developed. These models are evaluated based on the costs and the performances. The final result is interpreted based on the performance versus cost graph that is plotted. The procedure involved six steps. The first three steps comprehensively make use of AHP. First step determines the relationship between the activities and goals, the second step finds the relationship between the costs and activities, and the third step seeks the different performance measures. Based on this information a model for cost and performance is framed out, these form the fourth and the fifth steps. Finally a graph is plotted to arrive at a decision consensus.

The procedure used is explained with an example in the paper. Some minor modifications are done in the conventional AHP model, like some of the priority weights are negative because the savings allocation is being made. The priority weights are not normalized because they tend to loose the true cost effect. The paper, apart from its extension in the cost performance/cost benefit framework, can be extended for using in ranking considerations.

Wedley et al. [139] used AHP for the scrutiny in cost benefit analysis. It is used as a bridge to connect different situations, which arise due to priority influence, i.e., prioritizing benefit or prioritizing cost or benefit derived from two different hierarchies. Table 3 lists the references in this category.

3.4. Allocations

Badri [15] used AHP as an aid in making location allocation decisions. He claimed that the methodology could help the facility planning personnel to formulate the location strategies in the volatile complex decision environment. The author presented the methodology, by incorporating AHP alone and extended the same with the use of GP. In the stand-alone AHP methodology, a three level hierarchy is defined. This hierarchy is used to select the best location that forms the goal of the hierarchy as the first level. The second level is the criteria, and the third level is the locations. As an example, the author considered a petrochemical company, which is evaluating its plant locations in six Middle-East countries. They are to serve their six distribution centers in six countries. The decision maker's interest is to determine the location site and the quantity of the products to be transported to each location from different sites. In the AHP hierarchy, the second level criteria are the political situations in the countries, global competition and survival, government regulations, and economy related factors. The third level in AHP is formed by the countries as UAE, Saudi Arabia, Bahrain, Qatar and Oman. In order to check whether the results are consistent, Expert Choice software was used, which incorporated composite view of analysis. This was done by a test of performance sensitivity. The author further pointed out the drawbacks of using AHP alone.

To cover the limitations, AHP and GP are combined. Some more objectives were identified apart from the one used in AHP. Some of these are: minimizing the positive deviation, locating where quality of life is satisfactory, minimizing the positive deviation of the total cost above the budgeted amount, minimizing the transportation costs, etc. AHP has permitted flexibility in the use of available data in location allocation, whereas GP model is used so as to consider resource limitations, which are faced during recourse allocations.

In a single item, multi-stage, serial production system, the Manufacturing Block Discipline (MBD) controls materials. Three conflicting objectives prevail during the buffer allocations, namely: (a) the maximization of average throughput rate (b) the minimization of average work in progress, and (c) the minimization of the average system time. Andijani and Anwarul [7] made use of AHP to identify the best possible allocation. They

Table 3
References on the topic of 'Benefit–cost analysis'

Sr. no.	Reference no.	Year	Author/s	Application areas	Other tool/s used
1	[8]	1996	Angels D I, Lee C Y	Manufacturing	–
2	[13]	1990	Azis I J	Social	–
3	[38]	1999	Chin K S, Chiu S, Tammala V M Rao	Management	–
4	[113]	2001	Saaty T L, Chob Y	Government	–
5	[115]	1983	Saaty T L	Political	–
6	[132]	1997	Tummala V M Rao, Chin K S, Ho S H	Manufacturing	–
7	[139]	2001	Wedley W C, Choo E U, Schoner B	Industry	–

also performed sensitivity analysis for allocating the buffer. AHP is used to rank three conflicting objectives, their relative importance, and their preferences simultaneously. The pair-wise comparison methodology is adopted at the criteria (objectives) level. This is done based on the interviews with the experts on the manufacturing systems. A consensus comparison is taken which is preferred over the individual expert judgment. Expert Choice software was used to evaluate the outcome of the process. It was seen that all the cases, which were simulated, gave the highest overall weight to the uniform allocation. In order to know the 'what-if' implications in the developed model, a satisfactory sensitivity analysis was carried out.

Ramanathan and Ganesh [109] used AHP for resource allocation problems. The priorities obtained from AHP are used as a coefficient of the function in the LP format. The benefit/cost ratios are used as coefficients. The authors identified the areas where these approaches fail, and also where they would run true. The authors further proposed a model to overcome the drawbacks seen in the earlier methodologies. The existing model works on the Expected Priority (EP) and Benefit–Cost (BC) approaches. Priorities are obtained by the pair-wise comparison method. The assumption of a single, quantitative criterion is considered, and linear utilities are assumed. It was seen that both the approaches could give correct results when direct criteria were considered. This does not specifically suit to the requirements, and hence, a new methodology consisting of mixed criteria is proposed to serve the purpose.

Korpela et al. [76] integrated AHP and Mixed Integer Programming (MIP) with a view to plan the sales where the limited production capacity is allocated to the customers. This framework takes care of the factors such as risk related customer supplier relationship, the service requirement of the customer, and strategies of supplier companies. Kwak and Changwon [82] applied zero–one goal programming to allocate the resources of the information infrastructure planning in a university. AHP is used to assist the model in assigning proper weights to prioritize project goals. Ossadnik [103] applied AHP to allocate synergy (the difference between capitalized earning powers, the company could expect when operating alone) to the partners according to the impact intensities of their performance potentials on synergistic effect. The three conflicting objectives namely, average throughput rate (to be maximized), the average work in process (to be minimized), and the average flow time (to be maximum) are stochastically system simulated to generate a set of Kanban allocations. AHP was also used to identify most preferred allocation in the paper presented by Andijani [6]. Table 4 summarizes the references in this category.

3.5. Planning and development

Combat ship planning was carried out by Crary et al. [42]. AHP forms a part of the analysis in planning scenario for the 2015 conflicts on the Korean peninsula. Some quantitative methods, AHP, and mixed integer linear programming is

Table 4
References on the topic of 'Allocations'

Sr. no.	Reference no.	Year	Author/s	Application areas	Other tool/s used
1	[6]	1998	Andijani A A,	Manufacturing	–
2	[7]	1997	Andijani A A, Anwarul M	Manufacturing	–
3	[15]	1999	Badri M A	Political	Goal programming
4	[21]	2001	Bitici U S, Suwignjo P, Carrie A S	Manufacturing	–
5	[59]	1994	Greenberg R R, Nunamaker T R	Government	–
6	[76]	2002	Korpela J et al.	Personal	Mixed integer programming
7	[82]	1998	Kwak N K, Changwon L	Education	Goal programming
8	[103]	1996	Ossadnik W	Political	–
9	[109]	1995	Ramanathan R, Ganesh L S	Engineering	Linear programming
10	[114]	2003	Saaty T L et al.	Gen. Management	Linear programming

made use of in the planning. The methodology is derived into three groups. Firstly AHP is used, to treat each decision maker's importance for each mission of each campaign. There are five different missions to be accomplished during the conflict. Based on these observations, a joint distribution for mission importance by phase of the campaign is developed. Again for the war, four phases were identified; experts were asked to compare and rank the importance of each phase. For this purpose, fifteen senior officials in the navy and air force participated in the analysis.

In the analysis, stochastic mission importance parameters are used in mixed integer linear programming to optimize (maximize) the effectiveness. Probability of winning of each fleet is optimized during random sets of weights drawn from Dirichlet distribution in order to obtain a proper mix of the ships. The paper certainly has developed a decision making tool to measure the performance of the ships. This results in optimization and effective planning of the fleet.

Lee and Kwak [88] presented a case study to plan the information resource in a health care system. The case study involved the use of AHP and goal programming. The objective of the planning was to design and evaluate a model to be effective in planning of the health care system. The model, which was proposed by the authors, incorporated goal programming to reflect the multiple conflicting goals, and to provide a solution to the multi-dimensional allocation planning. AHP plays crucial role in decomposing and prioritizing the different goals and criteria in the planning scenario. Effective planning for information resource allocation is the element, which is analyzed. The planning becomes complicated as it involves the quantitative and the qualitative factors. Themes identified during the analysis were: (a) IT resources must be developed and the investments must be continued, and (b) the challenges in front of the planning are advancement, extension and the support of IT.

The model is formulated in three steps; two of the steps extensively use AHP. The first one is the data collection and validity, whereas the second one is the goal prioritization. A group of decision makers are involved in the strategic development process to identify the necessary goals and criteria. The goals and criteria are derived from the strategic plan of the health development system. The decision makers, then, are involved in providing the judgments for the AHP table. They also review the data set and provide the validation. In the goal prioritization phase, the evaluation of the elements is done by the use of AHP. Goal model is formulated in the third phase, and optimized in the given constraints. The authors concluded from the model that the health care system requires re-engineering of the infrastructure. The decision makers need to work closely with other departments, and integrate the efforts of the support personnel to successfully implement the strategic planning in the resource allocation.

Momoh and Zhu [97] presented an integrated approach for reactive power price. Part of the power price, i.e., the variable price is determined on the basis of the capability and contributions to the improvement of system performance as security, reliability and economics. For the variable rate planning, three parallel indices, namely, benefit/cost ratio index, voltage reactive sensitivity index, and the bus voltage security index were considered. AHP is used to comprehensively consider the effects of indices and the network topology. Weistroffer et al. [142] presented a city tax model based on AHP. Opinions from tax experts are used to relate tax plans to decision criteria. Kim [69] attempted to construct an analytic structure of Internet function. AHP was used in order to measure the relative importance of each function to achieve such objectives. The study is based on the survey with three groups of management, namely, top, middle and bottom management. The results were evaluated and implemented to the development of intranet system.

Benjamin et al. [19] used a multi-objective decision model to guide decision making in allocating space when planning facilities in an academic environment. The AHP and LGP (linear goal programming) are used, and explained with an example of computer integrated manufacturing laboratory. Wu and Wu [144] applied AHP for storage for strategic planning model in the first part of the model. The complex strategic problems are broken into a three level AHP model. In the other half, the objective is to process the collected data, analyze and verify. The application of AHP enabled the authors to consider marketing production, quality of life, financial security, personal achievement, and independence in the model. A methodology to assist development planners in a LDC (Low-income Development Countries) in formulating development plan consistent with the national objectives is presented by Ehie et al. [50]. In the methodology proposed, hierarchy of development goals and the objectives are framed from the literature. AHP is used to analyze the judgments from world-bank experts, and a priority structure is developed to assist the main objective. In tax planning, a model that allows city officials to explicitly take into account the existence of multiple decision criteria for selecting new tax options is the need of the hour. The references in this category are summarized in Table 5.

3.6. Priority and ranking

Badri [16] combined AHP and GP to model quality control systems. His work can be utilized in addressing the issues such as 'how to incorporate and decide upon quality control measures in the service industry by the use of AHP?' Five quality measures were identified, and they were weighed accurately and consistently. These were further used in a goal-programming model to select the best set of quality control equipments.

A decision aid is also proposed in the paper that allows the weighing of the firms' service quality measures. The decision level consists of three levels: the goal of the decision at the top, the criterion forms the second level, and the different alternatives at the third level of the hierarchy. There are five different criteria, which are to be prioritized. These are reliability, assurance, responsiveness, empathy, and tangibles. The alternatives (last level) are the options from which the choice is made. The analysis is done in phases. Firstly, pair-wise comparison is made, next are the judgments, and lastly, the synthesis. The synthesis is the adding of weights to the common nodes at the bottom level so as to generate a composite priority of the alternatives across all criteria. These derived priorities are used in a combined model to serve as the contribution each criterion makes to each alternative. The author has applied his proposed methodology to a large departmental store.

Table 5
References on the topic of 'Planning and development'

Sr. no.	Reference no.	Year	Author/s	Application areas	Other tool/s used
1	[10]	1990	Arbel A, Orger Y E	Banking	–
2	[19]	1992	Benjamin C O, Ehie I C, Omurtag Y	Education	Linear goal programming
3	[35]	2003	Chen S J, Lin L,	Industry	–
4	[42]	2002	Crary M et al.	Government	Mixed integer programming
5	[50]	1990	Ehie I C et al.	Banking	–
6	[49]	1993	Ehie I C Benjamin C O	Social	Linear goal programming
7	[69]	1998	Kim J	Engineering	–
8	[73]	1994	Ko S K, Fontane D G, Margeta J	Social	Linear programming, &epsivj; constraint method
9	[77]	2001	Korpela J, Lehmusvaara A, Tuominen M	Engineering	–
10	[87]	1999	Lee M et al.	Industry	
11	[88]	1999	Lee C W, Kwak N K	Social	Goal programming
12	[97]	1999	Momoh J A, Zhu J	Engineering	–
13	[107]	1998	Radasch D K, Kwak N K	Engineering	Goal programming
14	[126]	2003	Su J C Y et al.	Engineering	–
15	[142]	1999	Weistroffer H R, Wooldridge B E, Singh R	Government	–
16	[144]	1991	Wu J A, Wu N L	Personal	–
17	[146]	2003	Yang T, Kuo C	Industry	
18	[154]	1997	Zulch G et al.	Engineering	–

Babic and Plazibat [14] presented a paper for the ranking of the different enterprises using a combined approach of PROMETHEE and AHP. The ranking is based on the achieved level of business efficiency. This work is an attempt to find the financial standing of a particular firm. The final ranking is done by the use of PROMETHEE method whereas the importance of each criteria is determined by the AHP. The evaluation of the criteria, which is the input for the PROMETHEE, is done with the help of AHP. The business analysis is done with a several survey of the efficiency trends of the enterprise. Ten efficiency-related terms are considered for the evaluations, which are classified into four different groups: debt ratio indicator, economy indicator, profitability indicator and productivity indicators. All these are evaluated and ranked based on the 12 different alternatives. The multi-criteria analysis provides a useful tool to answer the question related to the financial standing of a firm.

Lalib et al. [85] proposed a model to help take a maintenance decision using AHP and fuzzy integrated approach. The paper describes the problems in maintenance which arise due to the fact of not having the clear idea, and not having the robust design criteria for the failing equipment. The authors proposed a two-step methodology. Firstly they prioritized the different maintenance criteria to identify crucial machines with their associated faults. In the second step perspective model was formulated with the help of fuzzy logic for the maintenance action. AHP is used in this work because of two basic requirements. Firstly, to prioritize machines and their faults based on different criteria to obtain criticality output. Secondly, to help the decision maker to sense the depth of the problem to give an indication of what values can be considered as low, high or medium. The algorithm presented has three stages. First stage deals with the extraction of the decision support reports to evaluate the different criteria. In the second stage the criteria are prioritized by using AHP. This is done with a six level hierarchy formulation of AHP. The first level is criteria evaluation, whereas the second level is to find the most crucial of the machines. In the third level the failure categories are grouped into the general ones. This helps the decision makers to identify areas where different maintenance skills are essential. The fourth level is concerned with the specific faults related to each fault categories. The final two levels are related to the detail failure component of the major sections. Based on these findings the maintenance program is formulated in the third stage. Table 6 lists the references in this category.

3.7. Decision making

Miyaji et al. [94] solved an education decision problem using AHP. The decision problem tackled by the authors is that of the examination composition. The test results and the selection of questions are utilized for the same. The authors argue that the results of the examination are used to grasp the student's degree of understanding, and to help them to learn individually. It becomes a critical work to choose questions for the examinations from among a huge database. The question selection becomes complicated if content form, correct answer rate, distribution of difficulty degree, size, etc., are to be considered. To overcome this problem, a two-stage decision support system is proposed. Firstly, some plans are presented using branch and bound methods. The teacher then decides on the plan. Two different factors are considered for framing of the different alternatives. They are: whether a student can give an answer within the range of examination content, and whether the students can solve the problem in the given time frame. A hierarchical structure of AHP is formulated for the necessary composition and selection of the examination problem. A three layer hierarchical diagram is composed for the same. The first layer is the decision adopted. The second is the different criteria, namely, answer possibility, necessary time, difficulty balance and appropriateness. The final stage is that of the alternatives. Based on these an optimum framework is selected. The procedure is explained with an example.

In order to opt for new manufacturing technology, Weber [138] used AHP to include non-financial impacts and avoid a bias. A modified version of AHP, which uses support software, is incorporated. This helps to find the best way to automate a machine shop. Four steps are suggested: (a)

Table 6
References on the topic of 'Priority and ranking'

Sr. no.	Reference no.	Year	Author/s	Application areas	Other tool/s used
1	[4]	1996	Alidi A S	Industry	–
2	[11]	1993	Arbel A, Vargas L.G	Personal	–
3	[14]	1998	Babic Z, Plazibat N	Industry	PROMETHEE
4	[16]	2001	Badri M A	Industry	Goal programming
5	[23]	2000	Bodin L, Epstein E	Sports	–
6	[24]	2001	Bolloju N	Personal	–
7	[27]	2000	Braglia M	Manufacturing	Falure mode and criticality analysis
8	[28]	1999	Bryson N, Joseph A	Personal	Goal programming
9	[40]	2001	Chwolka A, Raith M G	Social	–
10	[46]	1999	Dweiri F	Engineering	Fuzzy set theory
11	[48]	2000	Easlav R F et al.	Personal	–
12	[55]	1998	Forman E, Peniwati K	Personal	–
13	[56]	1999	Frei F X, Harker P T	Industry	Tournament ranking
14	[60]	2002	Hafeez K, Zhang Y B, Malak N	Manufacturing	–
15	[85]	1998	Lalib A W, Williams G B, O'Conner R F	Manufacturing	Fuzzy logic
16	[95]	2002	Modarres M, Zarei B	Government	–
17	[117]	1995	Salo A A, Hamalainen R P	Personal	–
18	[122]	1990	Shrinivasan V, Bolster P J	Industry	–
19	[128]	2000	Suwignjo P, Bititci U S, Carrie A S	Manufacturing	Cognitive maps, cause and effect diagrams, tree diagrams
20	[133]	1995	Tan R R	Engineering	–

specify the criteria and alternatives, (b) weigh the criteria, (c) rate alternatives, and (d) compute the overall score. The author modified AHP because of the following two reasons (according to the author): (a) the integer scale proposed by Saaty may be easily misused; and (b) in these applications it is not possible to preserve valid quantitative data, etc. The author applied AHP to a machine shop decision-making problem, which faces certain problems as whether to retrofit the machine, whether to buy a new CNC, or whether to replace the machine with machining center and programmable tool changer. A three level hierarchy is formulated that clubs three major criteria as performance measures, monetary criteria, and strategic considerations. This forms the first level; the sub-criteria forms the second, and the alternatives forms the last. After evaluating each of the criteria and computing overall weighted ratings, the manager can select the highest overall rating and thus decide on the goal.

Beynon [20] used a method combining AHP and DS (Dempster–Shafer) theory. This method allows judgments on groups of decision alternatives, and measure uncertainty of final results. The functions used in this method allow understanding of appropriateness of rating scale. Levary and Wan [89] developed a methodology for ranking entry mode alternatives in firms for foreign direct investment (FDI). AHP is used to solve the decision-making problem in the firm. A simulation approach is incorporated into AHP to handle uncertainty considerations in FDI investments. Decision making in an uncertain environment is done by AHP using point estimates in order to derive the relative weights of criteria, sub-criteria and alternatives, which govern the decision problem. Jain and Nag [66] developed a decision support model to identify successful new ventures. The model integrates the qualitative and quantitative variables through the use of AHP along with the robustness required for the decision-making. Choi et al. [39] stated that AHP could be effectively used to overcome the drawback in the group decision support system of guarantee of value on technical basis. They suggested a group problem-modeling

Table 7
References on the topic of 'Decision making'

Sr. no.	Reference no.	Year	Author/s	Application areas	Other tool/s used
1	[9]	1986	Arbel A, Seidmann A	Manufacturing	–
2	[18]	1993	Baidru A B, Pulat P S, Kang M	Management	–
3	[20]	2002	Beynon M	Engineering	Dempster–Shafer theory
4	[33]	2003	Condon E et al.	Personal	
5	[43]	1998	Crow T J	Industry	
6	[44]	1994	Davis M A P	Personal	–
7	[45]	1990	Dobias A P	Personal	–
8	[47]	1992	Dyer R F, Forman E H	Personal	–
9	[39]	1994	Choi H A, Suh E H, Suh C	Personal	–
10	[61]	1990	Hamalainen R P	Government	–
11	[63]	1996	Hauser D, Tadikamalla P	Personal	–
12	[66]	1996	Jain B A, Nag B N	Engineering	–
13	[89]	1999	Leavary R R, Wan K	Industry	Simulation approach
14	[94]	1995	Miyaji I, Nakagawa Y, Ohno K	Education	Branch and bound theory
15	[110]	2003	Abdi R M	Engineering	
16	[111]	1994	Riggs J L et al.	Management	–
17	[138]	1993	Weber S F	Manufacturing	–
18	[141]	1990	Weiss E N	Social	Dynamic programming
19	[145]	2003	Xu S	Industry	–
20	[147]	2002	Yu C S	Personal	–
21	[149]	1997	Zahedi F M	Engineering	–

tool wherein AHP is applied to real world group problems, and are investigated for values. Table 7 lists the references in this category.

3.8. Forecasting

Korpela and Tuominen [79] used AHP in demand forecasting for inventory. Demand forecasting is very crucial in inventory management as the forecasting is done on the basis of production transportation, and inventory levels. Use of AHP in the forecasting technologies offers a possibility to include both the tangible and the non-tangible factors, and the ability to make some future developments of the environmental factors. The aim of demand forecasting is to estimate the amount of the product and accompanying services that the customers will require. Using AHP, the authors developed a decision support system for demand forecasting. The process involved three basic steps: (a) identifying the factors affecting the demand level and structure the hierarchy, (b) assign priorities, and (c) synthesis the priorities to obtain overall priorities of the elements. A five level hierarchy is proposed in the paper. Goal is the first level; factors describing the actions and the sub-components of the elements are the second and third level respectively. Scenarios defining the possible development paths of the third level elements are located on the fourth level. The decision alternatives form the last level of the hierarchy. During the group consensus, for the comparison method, extensive debate and discussions are preferred. In case, if this system does not work, geometric mean of the group member is used. The procedure was explained with a help of an example.

Kim and Whang [70] used AHP along with growth curve models for technological forecasting. In the study, the element technologies required in industries are classified. This helps to gain the time series data of the technological capabilities. The authors suggest a methodology, to measure and forecast the technical capabilities of the industry, and index them with respect to the time. To obtain relevant time series data, an expert questionnaire is circulated in the experts. This helps in getting the pair-wise comparison of AHP. The authors explain the methodology with the help of a civilian aircraft. The constituent technologies of the aircraft were classified into three streams: fabrication design, testing, and evaluation. They were subgrouped and ranked. In order to interpret the forecasted data, the technology index of each stage was computed. The authors use a weighted average method for the same. The plotted growth curves were used for forecasting of the technological growth capabilities.

In a paper presented by Ulengin and Ulengin [135], the judgments of five experts are applied with AHP to forecast US Dollar/DM exchange rates at two different times. The same forecasting activity using AHP is compared with other forecasting techniques. Table 8 lists the references in this category.

3.9. Medicine and related fields

Rossetti and Selandari [112] used AHP for multi-objective analysis of middle to large size hospital delivery system. The delivery, transportation and distribution services are evaluated to check whether a group of robots can replace the human based system. Technical, economical, social, human, and environmental factors are considered for the evaluation purpose. This methodology is applied to the health centers.

The presented AHP hierarchy considers three main levels. The first level represents the overall goal, which is to select the internal delivery system. The second level is of all concerns in the hospital, consisting of patients, hospital management, doctors, and support staff. The third level is of general criteria for the system evaluation that consists of costs, technical performance, effects on hospital environment, side effects, etc. Depending on the degree of performance, each criterion is then decomposed to assignable and manageable activities. The decision maker in the presented case study was the Director of transportation and distribution services. The prioritization and synthesis was done by comparing each pair of elements. A survey was conducted for preparing the pair-wise comparisons. The local and global priorities were determined according to the preference structure. Expert Choice software was used to felicitate the calculations at each level. The evaluation has proved that the robotic transportation system is the best possible alternatives.

Singpurwalla et al. [123] experimented the use of AHP as a tool to facilitate decision making of two specific healthcare populations. The use of AHP helped to improve physician–patient communication by assisting shared health decision; and helped the patients to evaluate and understand their healthcare options rather than relying completely on the doctor's decision. Table 9 lists the references in this category.

Table 8
References on the topic of 'Forecasting'

Sr. no.	Reference no.	Year	Author/s	Application areas	Other tool/s used
1	[22]	2002	Blair A R et al.	Government	–
2	[70]	1993	Kim S B, Whang K S	Engineering	–
3	[69]	1997	Korpela J, Tuominen M	Management	–
4	[135]	1994	Ulengin F, Ulengin B	Commerce	–

Table 9
References on the topic of 'Medicine and related fields'

Sr. no.	Reference no.	Year	Author/s	Application areas	Other tool/s used
1	[41]	1990	Cook D R et al.	Social	–
2	[93]	2003	Libertore M J et al.	Social	–
3	[112]	2001	Rossetti M D, Selandari F	Social	–
4	[123]	1999	Singpurwalla et al.	Social	–
5	[124]	2003	Sloane E B et al.	Social	–

3.10. AHP as applied with QFD

In order to make the game of soccer more attractive for the soccer enthusiasts, Partovi and Corredoira [105] used quality function deployment techniques with AHP. The market segments, and the sports enthusiast's interests, soccer activities and the rules of the games are the rows and columns in the QFD. AHP is used to determine the intensity of the relationship between the rows and the columns of the matrix. Analytic Network Process (ANP) is also used to determine the intensity of the synergy effects among the column variables. A forecasting technique is also used to suggest the rule change specifications.

The soccer enthusiasts are classified according to their age groups, 8–18 years, 19–34 years, 35–54 years, and 55 and above. The main interests of the enthusiasts which are considered are fun to watch, fun to play, safe to play, and easy to play. A house of quality is build up based on these age groups, and the interests of the enthusiasts. AHP is used for assessing the strengths of the relationships. In another matrix, the enthusiasts' interests are subdivided into eight activities in the game of soccer. The co-relationship between them is carried out by the use of ANP. A third QFD matrix is also formed which considers the important activities, and the laws of the game. AHP is also used to quantify each key-ability to the soccer field players. The authors have presented a model for determining the rule change that are required to make the game more attractive. In addition to this, the analytical method used here makes a powerful tool to implement the changes.

In order to prioritize the team membership based on the customers' requirements and/or products characteristics, Zakarian and Kusiak [152] used AHP and QFD. The QFD is used to organize the different factors in the team, whereas, the information of each team member is determined by the AHP approach. The model is tested on a selection of the teams in concurrent engineering applications. Two basic matrices are planned together. First uses the co-relation of customer requirements and engineering characteristics. The second uses the characteristics and the team members. The team selection is done by the use of AHP. A method is developed for assessing the importance of all possible characteristics or the attributes desired. This is essential for formulation of the team. All the elements, namely customer requirements, engineering characteristics, and the team members, therefore, are depicted in the hierarchy form. A normalized priority value of each team member is computed with the help of AHP. Next, a mathematical model is incorporated to find out the optimum of the teams. The procedure is explained by the authors in a car production scenario.

To prioritize the requirements of the customer in a housing application, Armacost et al. [12] used AHP and QFD. Their study addresses to the industrialized housing manufacturing issues. A number of attributes were considered in the hierarchy. These 42 attributes were then categorized into five groups. The hierarchy so constructed was of four levels. Seven participants evaluated the questionnaire; the answers were summed up by the use of geometric mean method. The ranking of the five important categories was done. These priorities were directly used on the QFD table. The study also gave an insight for the selection of a house.

In order to improve the industrial engineering quality at an educational institute, Koksal and Egitman [74] used QFD and AHP. Requirements from the different groups associated with IE (Industrial Engineering) education are collected with the aid of surveys and interviews. The groups of people associated with IE education are students, faculty members and the future employees of the students. The requirements from them are prioritized by the use of AHP. A group of five represented a particular group of associated people. An AHP questionnaire was prepared, based on which the personnel were asked to compare the importance of the requirements. Geometric mean was then computed to get one value. These values were again combined to arrive at a required consensus. The procedure suggested that, based on these findings necessary modifications in administrative and academic sector can be made. Table 10 lists the references in this category.

Table 10
References on the topic of 'QFD'

Sr. no.	Reference no.	Year	Author/s	Application areas	Other tool/s used
1	[12]	1994	Armacost R L et al.	Social	QFD
2	[30]	1996	Bryson N	Personal	QFD
3	[65]	1999	Ho E S S A et al.	Personal	QFD
4	[74]	1998	Koksal G, Egitman A	Education	QFD
5	[100]	2003	Myint S	Engineering	QFD
6	[105]	2002	Partovi F Y, Corredoira R A	Sports	QFD, Analytic Network Process
7	[152]	1999	Zakarian A, Kusiak A	Personal	QFD

4. Observations and concluding remarks

An attempt has been made in this paper to review and critically analyze the Analytic Hierarchy Process as a developed decision making tool. The paper highlights the application areas in each of the chosen themes. Table 1, for example, lists the research papers in the selection theme. Reviewed papers are further categorized according to the area of applications such as, personal, manufacturing, industry, social, education, etc.

Table 11 shows the references arranged in a matrix form that provides a glimpse of the combinations of themes and application areas to which each of these 150 references belong. A few trends are also obvious from the table. We observe that most of the papers fall in the combination of: (a) engineering and selection, (b) social and selection, and (c) personal and decision making. This highlights the utility of AHP as a decision making tool in engineering as well as in social sector.

It is observed that AHP is being predominantly used in the theme area of selection and evaluation. As far as the area of application is concerned, most of the times AHP has been used in engineering, personal and social categories. This should help researcher judge the applicability of AHP in their area of interest.

Fig. 1 provides a percentage distribution of the review papers arranged theme-wise. Values in the brackets in the figures alongside the legend are the number of papers in that category. Fig. 2 represents application area-wise percentage distribution.

This review brings out an interesting observation that in the earlier phase of usage, AHP was used as a stand-alone tool. As the confidence of the researchers grew with the AHP usage, they started experimenting the combination of AHP with other techniques. Realizing the need to refine their results, the researchers then either used modified versions of AHP, such as fuzzy AHP, or combined AHP with other tools like linear programming, artificial neural network, fuzzy set theories, etc. It does not mean that AHP is no more used in a stand-alone mode. Many more researchers are (e.g., [3,83]), in fact, joining the ever-growing group of people successfully using AHP as a stand-alone tool. What it means is that AHP as a tool comes with a natural flexibility that enables it to be combined with so many different techniques effectively. Thus we conclude that AHP is a flexible multi-criteria decision-making tool. This flexibility is obvious from the fact that some authors have even converted the Saaty's nine-point scale to a convenient five-point scale or even a 100-point scale. Percentage representation of the reviewed papers as displayed in Fig. 3 indicates the growth in the use of AHP over the years. This covers the entire 150 papers reviewed in this article, and clearly supports the claim that the AHP is being adopted as a widely used decision making tool.

Use of AHP increasing with time is also evident by Journals bringing out special issues (European Journal of Operational Research 40(1) 1990, and part special issue Computers and Operation Research 30(10) 2003), and Annual Symposia held on AHP (ASAHPs). We find that the spread of AHP usage is truly global as is evident from Table 12. USA, undoubtedly, is the torchbearer in this field; but we also find an increasing trend of

Table 11
Categorized list of references

	Personal	Social	Manufacturing	Political	Engineering	Education	Industry	Government	Others as specified
Selection	[3,31,57, 120,131]	[1,5,37,64, 75,92,148]	[25,96,121]	[34,81,51]	[58,67,68,84, 83,98,119, 136]	[17,71, 129]	[102,101]	[108]	
Evaluation	[32,62,99]	[78,80, 118,143]	[26,72, 127,140]		[2,104, 153]	[29,54, 86,53]	[52]	[36,106,130, 134,90]	General management [91,150]
Benefit–cost		[13]	[8,132]	[115]			[139]	[108,113]	Environmental management [38]
Allocation	[76]		[6,7,21]	[15,103]	[109]	[82]		[59]	General management [114]
Planning and Development	[144]	[49,73,88]			[69,77,97, 107,126,154]	[19]	[87,146,35]	[42,142]	Banking [10,50]
Priority and Ranking	[11,24,28, 48,55,117]	[40]	[27,60,85,126]		[46,133]		[4,14,16,56,122]	[95]	Sports [23]
Decision making	[33,44,45, 47,39,63]	[141]	[9,138]		[20,66, 149,110]	[94]	[89,43,145]	[61]	General management [18], Project management [111]
Forecasting					[70]			[22]	General management [69], Stock exchange [135]
Medicine		[41,112,123, 124,93]							
QFD	[30,152,65]	[12]			[100]	[74]			Sports [105]

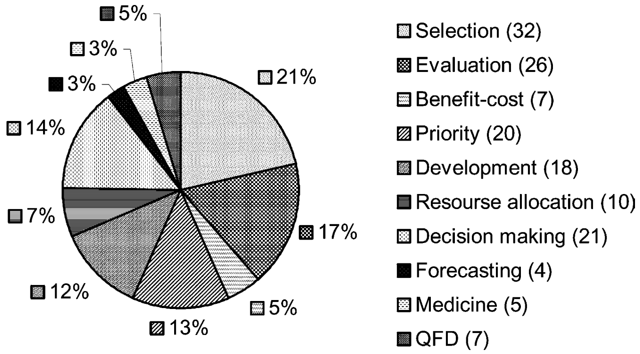

Fig. 1. Theme specific distribution of review papers.

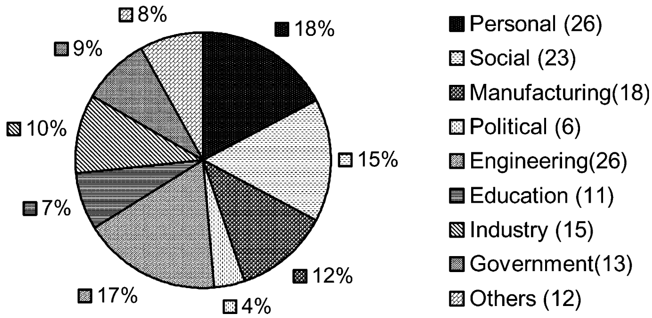

Fig. 2. Application area specific distribution of review papers.

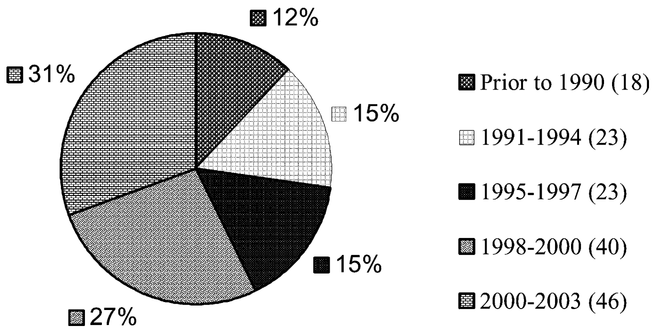

Fig. 3. Distribution of review papers over the years.

AHP applications in developing countries like India. This statement is based on the country mentioned either in the research paper or in the address of the first author.

Developing countries need to use tools like AHP for the evaluation and selection of the complex economic and other systems from different perspectives for development. Viewing the articles from the regional perspective, a glance on the chart as shown in Fig. 4 indicates that AHP applications are catching on in Asian countries. This may be an indication of the importance AHP will gain in future in the developing countries.

Some reviewed articles highlight a few outstanding features like strength, applicability, and flexibility associated with AHP. These are briefly

Table 12
List of country-wise arranged reviewed papers

Sr. No.	Country	No. of articles
1	USA	70
2	Finland	9
3	UK	8
4	Hong Kong	7
5	Korea	7
6	Taiwan	6
7	India	6
8	Germany	5
9	Japan	4
10	China	4
11	Italy	4
12	Saudi Arabia	3
13	Israel	3
14	South Africa	2
15	Turkey	2
16	UAE	2
17	Singapore	2
18	Canada	1
19	Croatia	1
20	Indonesia	1
21	Iran	1
22	Jordan	1
23	Thailand	1

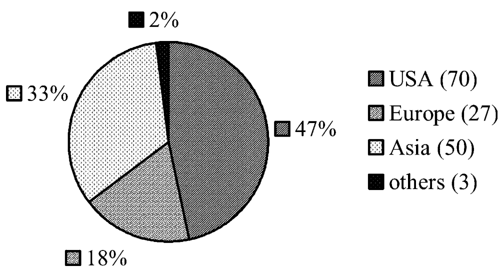

Fig. 4. Region-wise applications of AHP.

mentioned here cutting across the earlier discussed theme in this paper.

Lai et al. [83] applied AHP in group decisions making, which has proved to be more beneficial than the conventional techniques such as the Delphi techniques. This proves AHP as a very powerful tool that can be used in place of Delphi like widely applied technique. AHP can be applied with wide range possibilities. Fogliatto and Albin [52] used AHP for the evaluation purpose ranging as high as seven levels in a hierarchical way. Akarte et al. [2] used AHP to evaluate as large as eighteen alternatives. This certainly proves the versatile nature of AHP, enabling researchers to arrange the different alternatives according to the requirements of the decision/s to be taken.

AHP has also been found useful in considering the 'yes–no' decisions. These decisions generally involve the 'benefit–cost' analyses that are similar to the 'make–buy' decisions. We have classified one of the applications areas as 'benefit–cost' to enable readers have a glance at this type of AHP application.

AHP applications in complex situations may demand the use of professional computer application software. Badri [15] stated that the decisions related to multi-location problems and the problems that involved insufficient resources to support the selected locations etc., cannot be executed with the aid of AHP alone. The authors, in order to overcome the complexity of the situations, have used Expert Choice software.

Based on this review, we feel that the following observations in brief highlight the course of future AHP applications:

1. AHP is going to be used widely for decision making.
2. AHP use is rising in the developing countries. That augurs well with the economic development of this block of countries, such as India, China, etc.
3. Lots of research is going on in the country like US where they have a head start using AHP. Focus there seems to be on combining various other techniques with AHP. This is to take advantage of the versatility of AHP along with the focused use of the supporting techniques.
4. Use of software applications will be more to address the issue of complexities arising out of the integrated applications of AHP and other techniques to represent the real life situations.

Table 13 provides the list of journals with the references in the chronological order arranged theme-wise in order to facilitate the readers a journal-wise search. We feel that this review work will serve as a ready reference for those who wish to

Table 13
Analytic hierarchy process references at a glance

Categories Journals	Selection	Evaluation	Ranking and prioritizing	Development and lanning	Resource allocation	Decision making	Benefit–cost	Forecasting	Medicine	QFD
European Journal of Operational Research	48(1) 77–80, 85(2) 297–315, 91(1) 27–37, 96(2) 343–350, 100(1) 72–80, 112(2) 249–257, 112(3) 613–619, 137(1) 134–144, 150 (1) 194–203	47(2) 214–224, 48(1) 136–147, 96(2) 379–386, 100(2) 351–366, 116(2) 423–435, 118(3) 578–588,141(1) 70–87	48(1) 105–119, 69(2) 200–209, 82(3) 458–475, 108(1) 165–169, 116(2) 436–442, 125(1) 73–83, 128(3) 499–508, 132(1) 176–186	48(1) 27–37, 68(2) 160–172, 76(3) 428–439, 118(2) 375–389, 136(3) 680–695, 147(1) 128–136	80(2) 410–417, 88(1) 42–49, 110(2) 234–242	48(1) 57–65, 48(1) 66–76, 48(1) 28–135, 80(1) 130–138, 90(3) 473–486, 91(1) 27–37, 140(1) 148–164	48(1) 38–48, 133(2) 342–351		48(1) 49–56	137(3) 642–656
International Journal of Production Economics	41(1–3) 411–418, 45(1–3) 169–180, 55(3) 295–307, 56–57(1–3) 199–212, 67(2) 113–133, 69(2) 177–191	56–57 1–3) 303–318, 59 (1–3) 135–146	56–57(1–3) 29–35, 64(1–3) 231–24, 72(1) 27–40, 76(1) 39–51	51(1–2) 123–134, 71(1–3) 145–155	51(3) 155–163, 62(3) 237–248, 69(1) 15–22, 78(2) 187–195	41(10) 2273–2299	49(3) 265–283, 69(2) 193–204	45 (1–3) 159–168		
Information and Management	18(2) 87–95, 20(5) 333–342, 23(5) 249–262, 36(4) 221–232, 38(5) 289–297, 40(4) 233–242	27(4) 221–232, 38(7) 421–435								

Omega	29(2) 171–182	19(6) 639–649, 30(3) 171–183		18(2) 185–194	26(4) 483–493	27(6) 661–677		21(1) 91–98, 22(5) 505–519		
Interfaces	33(4) 70–78	33(3) 40–56		22(4) 95–105		23(4) 75–84	13(6) 68–83			
International Journal of Project Management	19(4) 19–27, 20 469–474	19 313–324	14(4) 205–208							
Computer and Industrial Engineering	27(1–4) 249–252, 37(1–2) 323–326	22(3) 257–252, 27(1–4) 257–259, 36(4) 793–810, 37(3) 507–525	36(1) 1–16	44(3) 435–439, 45(1) 195–204		27(1–4) 167–171			41(3) 309–333	35(3–4) 639–642, 45(2) 269–283
Computers and Operations Research	13(2–3) 146–166	30(10) 1467–1485	26(6) 637–643, 27(3) 205–215	25(12) 1069–1083		30(6) 877–886, 29(14) 1969–200, 30(10) 1435–1445	21(5) 521–533		30(10) 1447–1465, 30(10) 1421–1434	23(1) 27–35
Journal of the Operational Research Society	42(8) 631–638	52(5) 511–522	49 745–757, 53(12) 1308–1326	50 1191–1198		45(1) 47–58				
IIE Transactions		33 1081–1092								26(4) 72–79, 31 85–97, 31 553–567
IEEE Transactions	34(1) 12–18	33(2) 102–111				14(4) 606–617				
Decision Support Systems				23(1) 59–74, 24(3–4) 223 232		8(2) 99–124, 10(1) 1–18				
International Journal of Quality and Reliability Management	12(1) 61–81, 20(9) 1096–1116	15(4) 389–413	17(9) 1017–1033, 12(5) 18–37			15(2) 205–222, 14(8) 791–813	16(4) 341–361			

(continued on next page)

Table 13 (*continued*)

Categories Journals	Selection	Evaluation	Ranking and prioritizing	Development and lanning	Resource allocation	Decision making	Benefit–cost	Forecasting	Medicine	QFD
Socio-Economic Planning Science		37(2) 85–102		33(4) 301–315	28(3) 197–206, 37(3) 169–184		35(4) 243–252	33(4) 277–299, 36(2) 77–91		
Others as specified	Mgt Sc 32(12) 1628–1641	IJOPM 21(10) 1305–1326		IMDS 91(6) 5–9		IJPR 41(10) 2273–2299	IJPR 34(5) 1331–1345			

apply/modify/extend AHP in various applications areas.

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