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Construction management activity scheduling using proposed Analytical Node Activity Hierarchy Process (ANAHP)

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Abstract
In this paper, a new project management technique is proposed, by adapting a modern management practice and integrating it with conventional methods. The method proposed is called Analytical Node Activity Hierarchy Process (ANAHP). The process involves node network analysis along with a provision of decision making of available alternative for an activity based on various criteria defined by the manager or the decision maker. Some of these criteria are cost of the construction, time duration of the completion of work and durability of the component. For devising the method, a model problem of an office building construction is taken with data on activities order and available choices associated with individual activity. The problem is solved with conventional method and modern method, the results are compared to validate that adaptation of modern techniques in management can help in improving the efficiency and dimensionality of the project management process. At the end of the paper a scope of the future studies is also mentioned that opens doors to new and more accurate techniques that can also be adopted or modified as per the need for the construction industry.

Keywords: Construction Management, Node Network, Activity Scheduling, Analytical Hierarchy Process (AHP), Analytical Node Activity Hierarchy Process (ANAHP)

1. Introduction

The study involves an approach to integrate modern management technique in construction management and to study a model problem and validate the proposed model for its flexibility of application. The research also aims to suggest the best alternatives for the project activities on the basis of criteria like cost, durability and time for completion which can provide basic framework for an integrated solution for a generalized model problem for a future adaption in project management practices. The necessity for this study is depicted as a need for increase in dimensionality of the conventional methods of project management. The conventional methods developed for project management are too old and there is scope for introducing new methods to increase the functionality of these existing methods. A requirement of providing efficient solutions to project management problems is necessary. The processes used for project management yield in management aid in various ways. However there is a missing link in several of these methods that can combine these approach for an efficient output. An example for these missing links is in between Decision making techniques and Project management network technique. To introduce choice making process in the Network formation for a project the dimensionality can be increased drastically as per requirement. Conventional methods does not include necessary provisions or parameters that can take care of real life situations in project management practices. This project aims to introduce the technique of decision making in the project management technique to simulate real life scenarios faced in project management.

2. Methods & Materials: Arithmetic Hierarchy Process (AHP) is used for the application of decision making a choice selection. Apart from decision making, a process Node network process is used to solve and integrate the problem parameters. Real life Project Scenario for the problem taken with some parameters is that the data is nearly hypothetical and is taken to approximately simulate real life project management scenario. The fractions of the cost associated with each activity for the project is generalized to most accurate value.

The problem situation taken however gives a framework to apply proposed technique. At the end of the study the conclusion drawn reflects the importance of adapting the modern management techniques and it is shown and proven that integrating several of these techniques can help in increasing the efficiency of project management. At the end of this study a new technique for project management is proposed named as Analytical Node Activity Hierarchy Process (ANAHP), which is an integration of Node Network Process and Decision making technique as Arithmetic Hierarchy Process.

2.1 Modern Management Techniques used: Conventional method of project management involves network formation in a sequential order and connecting all activities with links establishing inter activity relationships. However the process of decision making and active feedback is not included in the network activity diagram. This study aims to introduce an integration of decision making hierarchy process in the Node Network diagram. The process of decision making is a modern technique that uses various modern methods like AHP, Fuzzy decision making, Cheng's Entropy technique, Cheng's Extent analysis & Buckley's Fuzzy AHP method. Introduction and integration of these modern methods will increase the dimensionality of the Node Network management system to decision integrated planning. The managers can schedule and alongside choose alternatives available for any specific activity for maximum efficiency in terms of cost reduction and high quality.
For the study following methods are used and integrated:
1). Node Network Management.
2). Analytical Hierarchy Process.

2.2 Project Definition: The project for the application demonstration is taken as a G+2 office building with various activities. Along with the predecessor relationship, the choice of Contractors, Choice of land & Choice of brand for building components is also taken into consideration.

Table 1: Model problem details

Activity	Specification	Previous Activity	Activity Choices
A	Purchase of Land	-	Choice of Land
B	Plan Preparation	-	Choice of Firm
C	House Construction	A,B	Choice of Contractors
D	Fix Door/Windows	C	Choice of Brand
E	Wiring & Plumbing	C	Choice of Supplier
F	House Painting	D	Choice of Paint Type
G	Polishing Door/Windows	E	Choice of Polish Brand

Activity A: Purchase of Land

For the activity A the manager is provided with 4 land sites namely Site 1, Site 2, Site 3 & Site 4 to choose from based on 3 criteria of cost of land, connectivity from business area and material transportation cost.

Table 2: Parameters for activity A

Activity A) Purchase of Land			
	Cost (Rs)	Connectivity (Km)	Material Transportation Cost (Rs)
Site 1	10125372	1.56	389456
Site 2	8386230	12.34	601647
Site 3	12347390	0.27	436538
Site 3	9137846	9.12	564738

Activity B: Plan Preparation

For the activity B the manager is provided with 3 design firm Firm 1, Firm 2 & Firm 3 to choose from based on 3 criteria of cost of preparation, time of delivery of plan and experience of firm in planning industry.

Table 3: Parameters for activity B

Activity B) Plan Preparation			
	Cost (Rs)	Time (Days)	Experience (Years)
Firm 1	642627	25	10
Firm 2	551929	30	8
Firm 3	767437	15	15

Activity C: House Construction

For the activity C the manager is provided with 4 contractors Contractor 1, Contractor 2, Contractor 3 & Contractor 4 to choose from based on 3 criteria of time proposed for construction, price quoted for the project and experience of contractor in construction field.

Table 4: Parameters for activity C

Activity C) Construction of Office			
	Time (Days)	Price Quote (Rs)	Field Experience (Years)
Contractor 1	190	7224526	12
Contractor 2	180	7594153	8
Contractor 3	200	7884839	9
Contractor 4	210	8183173	15

Activity D: Fix Door/Windows
For the activity D the manager is provided with 3 brand of doors/windows to choose from based on 2 criteria of cost per unit and durability in years.

Table 5: Parameters for activity D

Activity D) Fix Door/Windows		
	Cost (Rs)	Durability (Years)
Brand 1	3823	25
Brand 2	3537	17
Brand 3	3328	15

Activity E: Wiring & Plumbing
For the activity E the manager is provided with 3 suppliers wiring and plumbing material to choose from based on 2 criteria of total cost and durability in years.

Table 6: Parameters for activity E

Activity E) Wiring & Plumbing		
	Cost (Rs)	Durability (Years)
Brand 1	653728	25
Brand 2	582947	18
Brand 3	618832	22

Activity F: House Painting
For the activity F the manager is provided with 3 types of paints to choose from based on 2 criteria of total cost of painting and durability in years.

Table 7: Parameters for activity F

Activity F) Painting the House		
	Cost (Rs)	Durability (Years)
Paint 1	352728	4
Paint 2	380167	5.5
Paint 3	450739	8

Activity G: Polishing Doors/Windows
For the activity G the manager is provided with 2 brand of door/windows polish to choose from based on 2 criteria of total cost of polishing and durability in years.

Table 8: Parameters for activity G

Activity G) Polishing Doors & Windows		
	Cost (Rs)	Durability (Years)
Polish 1	78248	18
Polish 2	62798	13

2.3 Conventional Project Management Process: A project is a well-defined task which has a definable beginning and a definable end and requires one or more resources for the completion of its constituent activities, which are interrelated and which must be accomplished to achieve the objectives of the project. Project management is evolved to coordinate and control all project activities in an efficient and cost effective manner. The salient features of a project are:

- A project has identifiable beginning and end points.
- Each project can be broken down into a number of identifiable activities which will consume time and other resources during their completion.
- A project is scheduled to be completed by a target date.
- A project is usually large and complex and has many interrelated activities.
- The execution of the project activities is always subjected to some uncertainties and risks.

2.3.1 Network Techniques
The network techniques of project management have developed in an evolutionary way in many years. Up to the end of 18th century, the decision making in general and project management in particular was intuitive and depended primarily on managerial capabilities, experience, judgment and academic background of the managers. It was only in the early of 1900's that the pioneers of scientific management, started developing the scientific management techniques. The forerunner to network techniques, the Gantt chart was developed, during World War I, by Henry L Gantt, for the purpose of production scheduling. An example of Gantt chart is shown in Figure 1. The Gantt chart was later modified to bar chart, which was used as an important tool in both the project and production scheduling. The bar charts, then developed into milestone charts, and next into network techniques (such as CPM and PERT).

2.3.2 Network Construction
A network is the graphical representation of the project activities arranged in a logical sequence and depicting all the interrelationships among them. A network consists of activities and events.

2.3.3 Activity
An activity is a physically identifiable part of a project, which consumes both time and resources. Activity is represented by an arrow in a network diagram. The head of an arrow represents the start of activity and the tail of arrow represents its end. Activity description and its estimated completion time are written along the arrow. An activity in the network can be represented by a number of ways: (i) by numbers of its head and tail events (i.e. 10-20 etc.), and (ii) by a letter code (i.e. A, B etc.). All those activities, which must be completed before the start of activity under consideration, are called its predecessor activities. All those activities, which have to follow the activity under consideration, are called its successor activities. An activity, which is used to maintain the pre-defined precedence relationship only during the construction of the project network, is called a dummy activity. Dummy activity is represented by a dotted arrow and does not consume any time and resource. An unbroken chain of activities between any two events is called a path.

2.3.4 Application of Node Activity Process:
The model problem is solved below by conventional Node Network process for finding logical relationship between the activities in a systematic order.

Table 9: Predecessor relation of activity

Activity	Specification	Previous Activity
A	Purchase of Land	-
B	Plan Preparation	-
C	House Construction	A,B
D	Fix Door/Windows	C
E	Wiring & Plumbing	C
F	House Painting	D
G	Polishing Door/Windows	E

Using the predecessor relationship provided, a Node network diagram can be prepared.

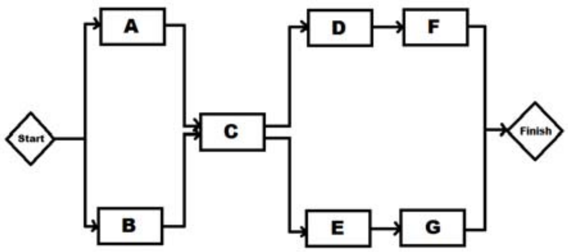

Fig 1: Node network solution of problem

2.3.5 Disadvantage of the conventional process: The method doesn't take care of the choices provided with each activity. The dimensionality of the problem is reduced to 1 (Minimum cost or Minimum time). Dimensional variable like durability and comparison of alternatives is not included in the process.

Introducing the Integration of Hierarchy process in node network process to increase the dimensionality of the whole process.

2.4 Analytic Hierarchy Process (AHP): The analytical hierarchy process was developed primarily by. AHP is a type of additive weighting method. It has been widely reviewed and applied in the literature, and its use is supported by several commercially available, user-friendly software packages. Decision makers often find it difficult to accurately determine cardinal importance weights for a set of attributes simultaneously. As the number of attributes increases, better results are obtained when the problem is converted to one of making a series of pairwise comparisons. AHP formalizes the conversion of the attribute weighting problem into the more tractable problem of making a series of pairwise comparisons among competing attributes. AHP summarizes the results of pairwise comparisons in a "matrix of pairwise comparisons." For each pair of attributes, the decision 8 C. Kahraman maker specifies a judgment about "how much more important one attribute is than the other."

Each pairwise comparison requires the decision maker to provide an answer to the question: "Attribute A is how much more important than Attribute B, relative to the overall objective"

The Analytic Hierarchy Process (AHP) is a multicriteria decision aiding method based on a solid axiomatic foundation. AHP is a systematic procedure for dealing with complex decision making problems in which many competing alternatives (projects, actions, scenarios) exist [Forman and Selly (2002)] [6]. The alternatives are ranked using several quantitative and/or qualitative criteria, depending on how they contribute in achieving an overall goal.

Table 10: Pairwise comparison matrix A of alternatives P_i with respect to criterion K

K	P_1	P_2	…	P_n
P_1	1	a_{12}	…	a_{1n}
P_2	$1/a_{12}$	1	…	a_{2n}
…	…	…	…	…
P_n	$1/a_{1n}$	$1/a_{2n}$	…	1

AHP is based on a hierarchical structuring of the elements that are involved in a decision problem. The hierarchy incorporates the knowledge, the experience and the intuition of the decision-maker for the specific problem. The simplest hierarchy consists of three levels. On the top of the hierarchy lies the decision's goal. On the second level lie the criteria by which the alternatives (third level) will be evaluated. In more complex situations, the main goal can be broken down into sub-goals or/and a criterion (or property) can be broken down into sub-criteria. People who are involved in the problem, their goals and their policies can also be used as additional levels.

The hierarchy evaluation is based on pairwise comparisons. The decision maker compares two alternatives A_i and A_j with respect to a criterion and assigns a numerical value to their relative weight. The result of the comparison is expressed in a fundamental scale of values ranging from 1 (A_i, A_j contribute equally to the objective) to 9 (the evidence favoring A_i over A_j is of the highest possible order of affirmation). Given that the n elements of a level are evaluated in pairs using an element of the immediately higher level, an n × n comparison matrix is obtained (Table 2). If the immediate higher level includes m criteria, m matrixes will be formed. In every comparison matrix all the main diagonal elements are equal to one ($a_{ii} = 1$) and two symmetrical elements are reciprocals of each other ($a_{ij} \times a_{ji} = 1$).

Since n(n-1)/2 pairwise comparisons are required to complete a comparison matrix, mn(n-1)/2 judgments must be made to complete the evaluation of the n elements of a level using as criterion the m elements of the immediately higher level. For large evaluations, the number of comparisons required by the AHP can be somewhat of a burden. For example, if 5 alternatives are to be evaluated, in a model containing 20 criteria, at least 10 × 20 = 200 judgments must be made.

The decision-maker's judgments may not be consistent with one another. A comparison matrix is consistent if and only if $a_{ij} \times a_{jk} = a_{ik}$ for all i, j, k. AHP measures the inconsistency of judgments by calculating the consistency index CI of the matrix

$$CI = \frac{\lambda_{max} - n}{n-1} \qquad \text{Eq.1}$$

Where λ_{max} is the principal eigenvalue of the matrix.

The consistency index CI is in tum divided by the average random consistency index RI to obtain the consistency ratio CR.

$$CR = \frac{CI}{RI} \qquad \text{Eq.2}$$

The RI index is a constant value for an nxn matrix, which has resulted from a computer simulation of n × n matrices with random values from the 1-9 scale and for which $a_{ij} = 1/a_{ji}$. If CR is less than 5% for a 3 × 3 matrix, 9% for a 4 × 4 matrix, and 10% for larger matrices, then the matrix is consistent.

Once its values are defined, a comparison matrix is normalized and the local priority (the relative dominance) of the matrix elements with respect to the higher level criterion is calculated. The overall priority of the current level elements is calculated by adding the products of their local priorities by the priority of the corresponding criterion of the immediately higher level. Next, the overall priority of a current level element is used to calculate the local priorities of the immediately lower level which use it as a criterion, and so on, till the lowest level of the hierarchy is reached. The priorities of the lowest level elements (alternatives) provide the relative contribution of the elements in achieving the overall goal.

Note that the AHP also allows group decision making. Each member of the group provides separately his own judgments according to his experience, values and knowledge. If the group has achieved consensus on some judgment, only that judgment is registered. If during the process it is impossible to arrive at a consensus on a judgment, the group may use some voting technique, or may choose to take the "average" of the judgments, that is the geometric mean of the judgments. The group may decide to give all group members equal weight, or the group members could give them different weights that reflect their position in the project.

2.5 Application of AHP on problem: The decision component of model problem is solved using Arithmetic Hierarchy Process (AHP) for ranking the best alternatives.

Table 11: Model problem with decision choice parameters

Activity	Specification	Previous Activity	Activity Choices
A	Purchase of Land	-	Choice of Land
B	Plan Preparation	-	Choice of Firm
C	House Construction	A,B	Choice of Contractors
D	Fix Door/Windows	C	Choice of Brand
E	Wiring & Plumbing	C	Choice of Supplier
F	House Painting	D	Choice of Paint Type
G	Polishing Door/Windows	E	Choice of Polish Brand

Table 12: Decision parameter for activities

Activity A) Purchasing Land			
	Cost (Rs)	**Connectivity (Km)**	**Material Transportation Cost (Rs)**
Site 1	10125372	1.56	389456
Site 2	8386230	12.34	601647
Site 3	12347390	0.27	436538
Site 3	9137846	9.12	564738
Sum	39996838	23.29	1992379
Activity B) Preparing Plan			
	Cost (Rs)	Time (Days)	Experience (Years)
Firm 1	642627	25	10
Firm 2	551929	30	8
Firm 3	767437	15	15
Sum	1961993	70	33
Activity C) Construction of Office			
	Time (Days)	Price Quote (Rs)	Field Experience (Years)
Contractor 1	190	7224526	12
Contractor 2	180	7594153	8
Contractor 3	200	7884839	9
Contractor 4	210	8183173	15
Sum	780	30886691	44
Activity D) Fixing Doors/Windows			
	Cost (Rs)	Durability (Years)	
Brand 1	3823	25	
Brand 2	3537	17	
Brand 3	3328	15	
Sum	10688	57	
Activity E) Wiring/Electrical & Plumbing			
	Cost (Rs)	Durability (Years)	
Brand 1	653728	25	
Brand 2	582947	18	
Brand 3	618832	22	
Sum	1855507	65	
Activity F) Painting the House			
	Cost (Rs)	Durability (Years)	
Paint 1	352728	4	
Paint 2	380167	5.5	
Paint 3	450739	8	
Sum	1183634	18	
Activity G) Poishing Doors & Windows			
	Cost (Rs)	Durability (Years)	
Polish 1	78248	18	
Polish 2	62798	13	
Sum	141046	31	

By the process of normalizing the scores of each alternatives the aggregate score of each alternative can be calculated by multiplying them with their respective weightages.

Table 13: Normalized scores for all alternatives with applied Sign convention

Activity A) Purchasing Land			
	Cost (Rs)	**Connectivity (Km)**	**Material Transportation Cost (Rs)**
Site 1	-0.253154312	-0.066981537	-0.195472849
Site 2	-0.209672325	-0.529841134	-0.301974173
Site 3	-0.308709153	-0.011592958	-0.219103895
Site 3	-0.22846421	-0.391584371	-0.283449083
Sum	-1	-1	-1

2.6 Weight Calculation: For the weight calculation of each criteria the process of Analytical Hierarchy is applied by pairwise comparison. The decision maker can be the expert or manager controlling the project. The Eigen values of the pair wise comparison matrix made by Satty scale gives the relative weightages for the criteria of comparison.

Table 14: Ranking for alternative for activity A

Activity A) Purchasing Land						
Deciding Factors Comparison					**Score**	**Rank**
	Cost	Conn.	M.T.C.	Weightage	-0.21348	1
Cost	1.00	5.00	7.00	0.731	-0.27734	4
Conn.	0.20	1.00	3.00	0.188	-0.24559	2
M.T.C	0.14	0.33	1.00	0.081	-0.26358	3

Table 15: Ranking for alternative for activity B

Activity B) Preparing Plan						
Deciding Factor Comparison						
	Cost	**Time**	**Exp.**	**Weightage**	**Score**	**Rank**
Cost	1.00	3.00	1.00	0.429	-0.06159	2
Time	0.33	1.00	0.33	0.143	-0.07797	3
Exp.	1.00	3.00	1.00	0.429	-0.00345	1

Table 16: Ranking for alternative for activity C

Activity C) Construction of Office						
Deciding Factor Comparison					**Score**	**Rank**
	Time	Price	F.Exp.	Weightage	0.086321	2
Time	1.00	3.00	0.33	0.258	0.030463	4
Price	0.33	1.00	0.20	0.105	0.037337	3
F.Exp.	3.00	5.00	1.00	0.637	0.119879	1

Table 17: Ranking for alternative for activity D

Activity D) Fixing Doors/Windows					
Factor Comparison				**Score**	**Rank**
	Cost	Durab.	Weightage	-0.0925272	1
Cost	1.00	2.00	0.667	-0.1214158	3
Durab.	0.50	1.00	0.333	-0.120057	2

Table 18: Ranking for alternative for activity E

Activity E) Wiring/Electrical & Plumbing					
Factor Comparison				**Score**	**Rank**
	Cost	Durab.	Weightage	-0.106919	1
Cost	1.00	2.00	0.667	-0.1173369	3
Durab.	0.50	1.00	0.333	-0.1097441	2

Table 19: Ranking for alternative for activity F

Activity F) Painting the House					
Factor Comparison				**Score**	**Rank**
	Cost	Durab.	Weightage	-0.1247689	3
Cost	1.00	2.00	0.667	-0.1124812	2
Durab.	0.50	1.00	0.333	-0.1059999	1

Table 20: Ranking for alternative for activity G

Activity G) Polishing Doors & Windows					
Factor Comparison					
	Cost	Durab.	Weightage	Score	Rank
Cost	1.00	2.00	0.667	-0.1766763	2
Durab.	0.50	1.00	0.333	-0.1573237	1

The rankings for the alternatives in each activity is obtained based on their score performance in each of the criteria category.

3. Analytical Node Activity Hierarchy Process (ANAHP): The results from both the process can be integrated in this newly introduced ANAHP technique. This allows the introduction of decision making in the process of node activity process.

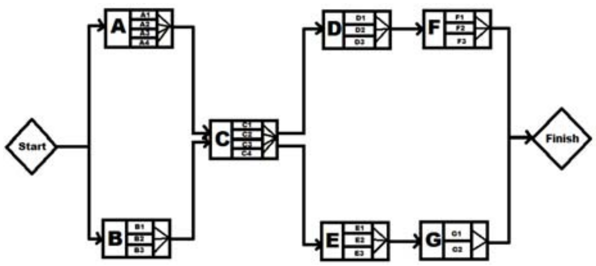

Fig 2: Integrated Analytical Node Activity Hierarchy Process for problem

The ranks obtained from the AHP technique is used to choose only one best alternative for the individual activity. This converges the output for the ANAHP technique to that of the Node network process. After the convergence of the ANAHP network, conventional operations to find Critical path and project duration can be applied for efficient project management.
The converged output of ANAHP technique is shown in below figure:

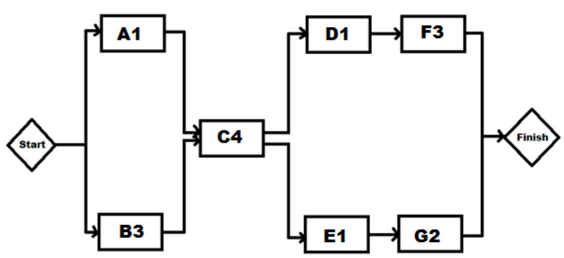

Fig 3: Converged output of ANAHP as a conventional node network

4. Conclusion & Future Scope: Although this method is being introduced for the first time as an integrated process, this can only be applied for Node Network process. There is no provision for arrow network integration as of now. The Analytical Node Activity Hierarchy Process (ANAHP) can be used to develop hybrid software that can handle activity scheduling and decision making process parallel in a single and integrated way. Various more method can be used as a substitute for Analytical Hierarchy Process, some of these methods are:

1. Cheng's Entropy Method.
2. Buckley's Fuzzy AHP.
3. Van Loorvan Fuzzy AHP.
4. Cheng's Extent Analysis.

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