ISSN 2229-5518

An Integrated Approach of AHP-GP and Visualization for Software Architecture Optimization: A case-study for selection of architecture style

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Abstract— Software Architecture has emerged as an important sub-discipline of software engineering. A key aspect of the design of any software is its architecture styles, i.e. components and connectors and their relationships. Selecting the best style is difficult because there are multiple factors such as project risk, corporate goals, limited availability of resources, etc. Therefore this study presents a methodology for selection of software architecture styles. In this paper we explore the Analytic Hierarchy Process (AHP) within a zero-one goal programming (ZOGP) model for selection of architecture styles. AHP is applied to the decision problem involving multiple alternatives and criteria and aims at selecting an alternative from a known set of alternatives. Then Goal programming model is used to optimize the objective function while simultaneously satisfying all the constraints. Further, AHP-GP Visualization framework and visualization tool (SAVE Tool) are applied to evaluate the selected software architecture style.

Index Terms— Software Architecture, Selection of Software Architecture Styles, Multi-Criteria Decision Making, Analytic Hierarchy Process (AHP), Zero-One Goal Programming (ZOGP), Visualization.

1 Introduction

Nowadays, decision-making has become more complex due to reasons related to (1) the alternatives, (2) the goals and (3) the environment in which decisions are being made. First, for almost any decision the number of alternatives has grown dramatically. Second, the number and the nature of the goals, criteria or constraints, have changed. When making decisions, the goals are not limited to related objectives. The third set of reasons for the increased complexity of decisions refers to the environment. The changing alternatives, goals, and environment enlarge the complexity of decisions and call for effective decision support. The basic approach of mathematical programming models is to optimize the objective function while simultaneously satisfying all the constraints that limit the activities of the decision maker.

Software architectures significantly impact software project success [1]. However, creating architectures is one of the most complex activities during software development [2]. When creating architectures, architecture styles narrow the solution space: First, styles define what elements can exist in architecture (e.g. components, connectors). Second, they define rules on how to integrate these elements in the architecture. Moreover, styles address functional and non-functional issues [3]. This paper focuses on two mathematical methods, Analytic Hierarchy Process and Goal Programming. Further, AHP-GP-Visualization framework and Visualization Tool (SAVE Tool) are applied to evaluate the selected software architecture style.

The contributions of this paper are as follows:

1. This paper presents a methodology for selection of software architecture style which uses two mathematical techniques Analytic Hierarchy Process and Goal Programming.
2. Analytic Hierarchy Process (AHP) is used to determine the degree of relative importance among the alternatives and criteria.
3. It provides a way of collecting expert group opinion along with stakeholders interests (e.g. reliability, performance)
4. Goal Programming (GP) to determine the desired level of attainment for each goal and penalty weights for over or under achievement of each goal [4]
5. AHP-GP Visualization Framework and Visualization Tool are used to evaluate the selected software architecture style.

In AHP, pairwise comparisons matrix is formulated and then the relative priority of each alternative is calculated. After obtaining the overall priorities of alternatives and using the goal constraints, zero-one goal programming (ZOGP) model formulated. The combined use of the AHP and GP approaches extended the use of Multi Criteria Decision-Making approach.

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2 INTEGRATED APPROACH OF AHP-GP AND VISUALIZATION

2.1 Analytic Hierarchy Process

The initial study identified the multi-criteria decision technique known as the Analytic Hierarchy Process (AHP) to be the most appropriate for solving complicated problems. Decision-making involving multiple objectives and/or criteria is called Multi Criteria Decision-Making (MCDM) [5]. Often the criteria include both qualitative and quantitative factors, whereas the quantitative criteria may be measured in incomparable units (for example, the market share and the price of a software package). T.L. Saaty introduced AHP to solve the problem of independence on alternatives and/or criteria. AHP allows better, easier and more efficient identification of selection criteria, their weighting and analysis [6]. It reduces drastically the decision cycle and allows organization to minimize common mistakes by using the expert group decision [7].

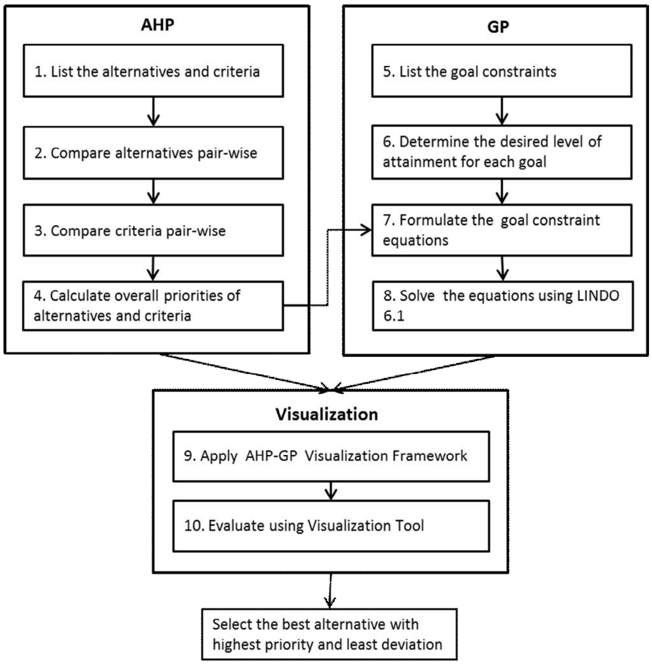

Figure 1. Process Model for architecture style selection using AHP-GP Visualization

Thus, AHP is "a method of breaking down a complex, unstructured situation into its components parts; arranging these parts, or judgments on the relative importance of each variable; and synthesizing the judgments to determine which variables have the highest priority and should be acted upon to influence the outcome of the situation" [8]. In Analytic Hierarchy Process, a first pairwise comparison matrix for alternatives and criteria are formulated and then the relative priority of each alternative and criterion is calculated. In Figure 1, step 1 to step 4 depict AHP model.

2.2 Goal programming

After obtaining the overall priorities of alternatives using AHP, with these priorities and goal constraints, Goal Programming (GP) model is formulated [9] as illustrated in figure 1, step 5 to step 6.
The GP model for architecture style selection can be stated as follows:

Minimize $$Z = P_K(w_j d_i^+, w_j d_i^-) \quad (1)$$

Subject to $$a_{ij}x_j + d_i^- - d_i^+ \le b_i$$

for i = 1, 2, …, m, j = 1, 2, …, n (2)

$$x_j + d_i^- = 1$$

for i = m+1, m+2, …m+n, j = 1, 2, …, n (3)

$$x_j = 0 \text{ or } 1 \text{ for } \forall j \quad (4)$$

where m is the number of goals to be considered in the model, n is the pool of architecture styles from which the optimal set will be selected, = the AHP mathematical weight on the j =1, 2,…, n architecture style, = some k priority pre-emptive priority , for i =1, 2,…, m goals, = the ith positive and negative deviation variables for i = 1, 2,…, m goals, = a zero-one variable, where j = 1, 2,…, n possible projects to choose from and where = 1, then select the jth architecture style or when =0, then do not select the jth architecture style, = the jth parameter of the ith resources, and = the ith available resource or limitation factors that must be considered in the selection decision. In Figure 1, steps 5 to step 7 depict GP model.

The presented GP formulation can easily be rearranged or modified depending on the priorities of the decision makers and circumstances of the decision environment. The GP objective function includes the positive and negative deviational variables which represent the deviations from the desired goal levels (i.e., over-achievement of a goal is represented by d+ and underachievement of a goal is shown as d-). Resource limitations are considered more important. The solution of the GP model will minimize the objective function and satisfy the goal constraints.

2.3 AHP-GP Visualization Framework for Architecture Style Selection

Visualization is used to enhance information understanding by reducing cognitive overload. The proposed AHP-GP Visualization Model as shown in Figure 2, overcome the limitations of the AHP-GP model as AHP-GP model address the non-functional requirements of the software architecture as desired by the stakeholder. The visualization techniques address the functional key areas only.

The proposed model is the best model to choose architecture style suitable for a given application as per both the functional and non-functional requirements [10] as in figure 1, step 9.

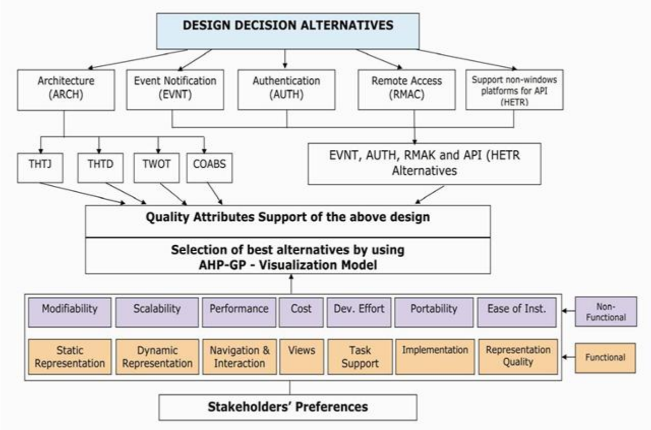

Figure 2. AHP-GP-Visualization Framework for the selection of architecture style [10]

2.4 Evaluating the Architecture Style using Visualization Tool (SAVE Tool)

Fraunhofer SAVE [11] (Software Architecture Visualization and Evaluation) is a tool for analyzing and optimizing the architecture of implemented software systems. Using this tool the functional criteria as specified in the AHP-GP-Visualization Framework can be evaluated effectively as depicted in figure 1, step 10. Even from the source code, the architecture styles used in the project can be visualized and the functional criteria can be evaluated. Also SAVE supports reverse engineering, quality assurance, and maintenance tasks for systems implemented in Java, C/C++ and the extracted information can be visualized, analyzed, manipulated or used to modify system artifacts.

3 A CASE-STUDY FOR SELECTION OF SOFTWARE ARCHITECTURE STYLE

A case study to illustrate the advantages of the integrated AHP-GP based on the expert opinion of an organization is taken. The problem consisted of prioritizing three architectures styles [12] on the basis of seven criteria deemed to be important for an organization. The criteria used are (1) Modifiability (M), (2) Scalability (S), (3) Performance (P), (4) Cost (C), (5) Effort (E), (6) Portability (Pr) and (7) Ease-of-use (Eu). However, we are of the opinion that there is an existence of relative importance among these seven criteria. The attribute of criteria P influence criteria C, the attribute of criteria E influence criteria Eu, S, Pt, C and so on. In order to check relationship of criteria or alternative, we need to have group discussion because the type of network or relationship depends on the stakeholders' judgment.

3.1 Decision Hierarchy Formulation

The decision hierarchy formulation is very important as the export group agreed that the evaluation criteria in the decision criteria are comprehensive and also agreed that the criteria should be expressed in fairly general terms and should be understood by all stakeholders. They concerned both managerial and technical factors were critical decision criteria. Based on the functional and non-functional requirements, stakeholders and export group opinion and previous project information are considered to in the formulation of decision hierarchy [13].

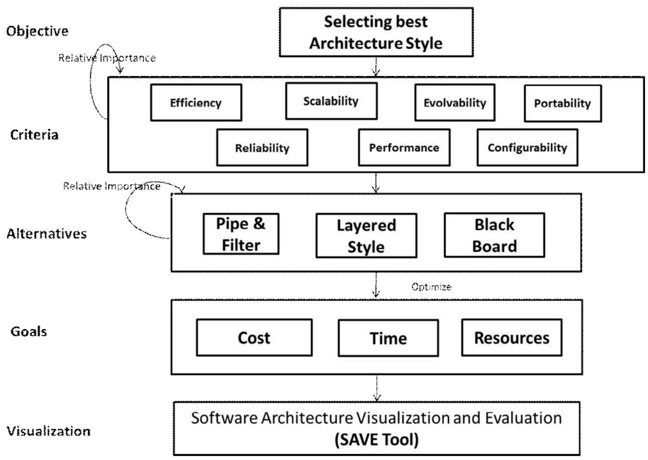

Figure 3. AHP-GP-Visualization Decision Hierarchy for the selection of architecture style

3.2. Pairwise Comparisons

This section focuses on the comparison of the alternatives, with respect to the other alternatives in the hierarchy. The judgment of the importance of one of the alternative over the other can be made subjectively. The subjective judgment that is achieved can then be converted to a numerical value using a satty scale of 1-9 , where 1 denotes equal importance and 9 denotes the highest degree of importance. For this pair wise comparison, we follow bottom up method. In this pair wise comparison process, all the obtained comparison results are evaluated by the expert group to better reflect their perception and understanding of the issues.

3.3. Decision Weight calculation

This is the main step in the selection procedure. This step focuses on getting the input from the Expert's group, i.e., comparison of matrices. Then the relative weights for the available alternatives with respect to the available criteria are calculated.

1. Pair wise comparison with respect to Modifiability

Modifiability	PF	LA	BB
PF	1	3	5
LA	1/3	1	3
BB	1/5	1/3	1
PF	0.6521	0.6923	0.5555
LA	0.2174	0.2307	0.3333
BB	0.1304	0.0769	0.1111

Relative Priorities for Modifiability is w_{11} (0.6333, 0.2604, 0.1061)

2. Pair wise comparison with respect to Scalability

Scalability	PF	LA	BB
PF	1	3	7
LA	1/3	1	3
BB	1/7	1/3	1
PF	0.6774	0.6923	0.6363
LA	0.2258	0.2307	0.2727
BB	0.1428	0.0769	0.0909

Relative Priorities for Scalability is w_{12} (0.6686, 0.2431, 0.1035)

3. Pair wise comparison with respect to Performance

Performance	PF	LA	BB
PF	1	7	5
LA	1/7	1	3
BB	1/5	1/3	1
PF	0.7446	0.8400	0.5556
LA	0.1063	0.1200	0.3333
BB	0.1489	0.0400	0.1111

Relative Priorities for Performance is w_{13} (0.7134, 0.1865, 0.1000)

4. Pair wise comparison with respect to Cost

Cost	PF	LA	BB
PF	1	3	5
LA	1/3	1	7
BB	1/5	1/7	1
PF	0.6521	0.7241	0.3846
LA	0.2173	0.2413	0.5384
BB	0.1304	0.0344	0.0769

Relative Priorities for Criterion Cost is w_{14} (0.5869, 0.3324, 0.0806)

5. Pair wise comparison with respect to Dev. Effort

Development Effort	PF	LA	BB
PF	1	3	7
LA	1/3	1	3
BB	1/7	1/3	1
PF	0.6774	0.7142	0.5384
LA	0.2258	0.2380	0.3846
BB	0.0967	0.0476	0.0769

Relative Priorities for Dev. Effort is w_{15} (0.6433, 0.2828, 0.0737)

Pair wise comparison with respect to Probability

Probability	PF	LA	BB
PF	1	1/7	3
LA	7	1	1/5
BB	1/3	5	1
PF	0.1200	0.0232	0.7142
LA	0.8400	0.1627	0.0476
BB	0.0400	0.8139	0.2380

Relative Priorities for Probability is w_{16} (0.2858, 0.3501, 0.3640)

6. Pair wise comparison with respect to Ease of Use

Ease of Use	PF	LA	BB
PF	1	7	3
LA	1/7	1	7
BB	1/3	1/7	1
PF	0.6774	0.8596	0.2727
LA	0.0967	0.1228	0.6363
BB	0.2258	0.0175	0.0909

Relative Priorities for Ease of Use is w_{17} (0.6032, 0.2853, 0.1114)

Relative Importance Matrix Calculations for the above stated criteria:

Pair wise comparison for Criteria

W	M	S	P	C	E	Pr	Eu
M	1	3	3	5	7	3	7
S	1/3	1	3	5	3	7	3
P	1/3	1/3	1	3	5	5	7
C	1/5	1/5	1/3	1	5	7	3
E	1/7	1/3	1/5	1/5	1	7	5
Pr	1/3	1/7	1/5	1/7	1/7	1	3
Eu	1/7	1/3	1/7	1/3	1/5	1/3	1

Normalized Pair-wise Comparison Matrix:

W	M	S	P	C	E	Pr	Eu
M	0.4022	0.5614	0.3808	0.3406	0.3279	0.0989	0.2413
S	0.1340	0.1871	0.3808	0.3406	0.1405	0.2307	0.1034
P	0.1340	0.0623	0.1269	0.2044	0.2342	0.1648	0.2413
C	0.0804	0.0124	0.0423	0.0681	0.2342	0.2307	0.1034
E	0.0574	0.0623	0.0084	0.0136	0.0468	0.2307	0.1724
Pr	0.1340	0.0017	0.0084	0.0019	0.0066	0.0329	0.1034
Eu	0.0574	0.0623	0.0012	0.0006	0.0013	0.0109	0.0344

Relative Importance Matrix:

W	M S P C E Pr Eu	RowAvg
M	0.4022+0.5614+0.3808+0.3406+0.3279+0.0989+0.2413 / 7	0.3361
S	0.1340+0.1871+0.3808+0.3406+0.1405+0.2307+0.1034 / 7	0.2167
P	0.1340+0.0623+0.1269+0.2044+0.2342+0.1648+0.2413 / 7	0.1668
C	0.0804+0.0124+0.0423+0.0681+0.2342+0.2307+0.1034 / 7	0.1102
E	0.0574+0.0623+0.0084+0.0136+0.0468+0.2307+0.1724 / 7	0.0845
Pr	0.1340+0.0017+0.0084+0.0019+0.0066+0.0329+0.1034 / 7	0.0412
Eu	0.0574+0.0623+0.0012+0.0006+0.0013+0.0109+0.0344 / 7	0.0240

ISSN 2229-5518

1.3. Weight Aggregation

After all the relative weights are calculated, a composite weight for each decision choice is determined by aggregating the weights over the hierarchy for decision choice.

Calculation of Relative Priorities:

$$\begin{bmatrix} 0.6333 & 0.6686 & 0.7134 & 0.5869 & 0.6433 & 0.2858 & 0.6032 \\ 0.2604 & 0.2431 & 0.1865 & 0.3324 & 0.2828 & 0.3501 & 0.2853 \\ 0.1061 & 0.1035 & 0.1000 & 0.0806 & 0.0737 & 0.3640 & 0.1114 \end{bmatrix} \times \begin{bmatrix} 0.3361 & 0.3361 & 0.3361 \\ 0.2167 & 0.2167 & 0.2167 \\ 0.1668 & 0.1668 & 0.1668 \\ 0.1102 & 0.1102 & 0.1102 \\ 0.0845 & 0.0845 & 0.0845 \\ 0.0412 & 0.0412 & 0.0412 \\ 0.0240 & 0.0240 & 0.0240 \end{bmatrix}$$

$$= \begin{bmatrix} 0.6220 & 0.6220 & 0.6220 \\ 0.2531 & 0.2531 & 0.2531 \\ 0.1075 & 0.1075 & 0.1075 \end{bmatrix}$$

Normalized Priority Matrix:

$$\begin{bmatrix} 0.6220 & 0.6220 & 0.6220 \\ 0.2531 & 0.2531 & 0.2531 \\ 0.1075 & 0.1075 & 0.1075 \end{bmatrix}$$

Relative Priority Vector:

Pipes & Filters : 0.6220+0.6220+0.6220 / 3 = 0.622

Layered Style : 0.2531+0.2531+0.2531 / 3 = 0.253

Black Board : 0.1075+0.1075+0.1075 / 3 = 0.101

The final results obtained in the AHP Phase are (PF, LS, BB) = (0.622, 0.253, 0.101). These weights are used as priorities in goal programming formulation. That is (PF, LS, BB) = (w_1, w_2, w_3) = (0.622, 0.253, 0.101) are the values of the three architecture styles.

The weight vector obtained from the above AHP model is used to optimize the solution further by zero-one goal programming as follows: There exist several obligatory and flexible goals that must be considered in the selection from the available pool of three architecture styles. There are three obligatory goals: (1) a maximum time of 24 working days is required to select the best architecture style, (2) a maximum duration of 35 months is required to complete the software project and (3) a maximum budget of $ 20,000 is allocated to develop the project [14]. In addition to the obligatory goals of selecting the best architecture style, there are two other flexible goals, stated in order of importance: (1) allocation of budget is set at $20,000 and (2) allocation of miscellaneous fees is set at $4200, deviation from this allocation is not allowed. In the following table, the cost and resource usage information for each of the three styles is presented.

Table. Cost and resources usage information

	Project resource usage (a_{ij})			
	x_1	x_2	x_3	b_i
Planning and design days	10	24	18	24 days
Construction months	32	34	30	35 months
Budgeted cost (00)	$150	$300	$280	$300
Misc cost (00)	$18	$24	$15	$42

Based on the weight vector computed using AHP, we can formulate the goal constraints in the following table. This ZOGP model is solved using LINDO Ver 6.1. The results are summarized as follows:

Table. ZOGP model formulation

ZOGP model formulation	Goals
Minimize Z =	
$pl_1(d_1^+ + d_2^+ + d_3^+)$	Satisfy all obligatory goals
$pl_2(0.622d_5^- + 0.253d_6^- + 0.101d_7^-)$	Select highest AHP weighted architecture styles
$pl_3(d_8^- + d_8^+)$	Use $20,000 for all architecture styles selected
$pl_4(d_4^- + d_4^+)$	Use $4200for all architecture styles selected
Subject to	
$10X_1 + 24X_2 + 18X_3 + d_1^- - d_1^+ = 24$	Avoid over utilizing max. planning and design days
$32X_1 + 34X_2 + 30X_3 + d_2^- - d_2^+ = 35$	Avoid over utilizing max. construction months
$150X_1 + 300X_2 + 280X_3 + d_3^- - d_3^+ = 30($	Avoid over utilizing max. budgeted dollars
$X_1 + d_5^- = 1$	Select Layered Style (LS)
$X_2 + d_6^- = 1$	Select Pipe & Filter (PF)
$X_3 + d_7^- = 1$	Select Blackboard Style (BB)
$18X_1 + 24X_2 + 15X_3 + d_4^- - d_4^+ = 42$	Avoid over or under utilizing misc cost
$150X_1 + 300X_2 + 280X_3 + d_8^- - d_8^+ = 300$	Avoid over or under utilizing expected budget
$Xj = 0$ or $\forall j = 1,2,3$	

$$x_1 = 0\ x_2 = 1,\quad x_3 = 0$$

$$d_1^- = 0,\ d_1^+ = 0,\ d_2^- = 1,\ d_2^+ = 0,\ d_3^- = 0,\ d_3^+ = 0,\ d_4^- = 18,\ d_4^+ = 0,$$
$$d_5^- = 1,\ d_6^- = 0,\ d_7^- = 1,\ d_8^- = 0,\ d_8^+ = 0.$$

Architecture Style Pipe & Filter (PF) is chosen as it consumes the total budgeted cost of $30,000 and use 24 days of time for decision. Also, the selected style will save one month construction time (total time is 35 months) as . Compliance checking is to be executed for every single modification made to source code using the SAVE Tool.

4 Discussion

As organizations are infusing more technologies to support business operations and enhance organizational competitiveness, they are like to find that the traditional methods such as scoring, ranking methods, Fuzzy logic, etc analyses are unsatisfactory for evaluating emerging technologies for adoption of decisions.

The objective of this paper is to provide a systematic process to sort out the available alternatives by applying the decision analysis model, the AHP. However, the comparison of the AHP and other method like scoring and ranking methods may be inappropriate as the AHP is a multi criteria decision technique. Another extension of this research could test the wide range of decision problem is a group setting. This study of AHP has evaluated in the context of Software Architecture selection. A more comprehensive list of multi criteria problems, including varied level of difficulty and problem types, should be prepared to guide the systematic evaluation of the strengths and weakness of AHP. It would perhaps be better if multiple multi criteria methods, alongside multiple decision problems, be employed to derive a reference model for the effectiveness of multi criteria models.

Table Different Techniques and Methods

Method	Multiple Criteria	Resource Feasibility	Optimization required
Ranking [14]	Yes	No	No
Scoring [15]	Yes	No	No
AHP [16]	Yes	No	No
Goal Programming [17]	No	Yes	Yes
DynamicProgramming[18]	No	Yes	Yes
AHP-GP [This Paper]	Yes	Yes	Yes

According to experts, in selecting a style there is no single decision involved but in the decisions consideration may be better or worse but still significant. For example, a style with a low weight might be selected over a style with a high weight if developers are more familiar with the style which has a lower score. The weight vector obtained using AHP for the above example is (0.622, 0.253, 0.101) [19]. Table 18 shows the comparison among the AHP and AHP-GP approaches.

Table Comparison of AHP and AHP-GP approaches

Method	Resources Used			
	Planning and design days	Construction months	Budgeted cost (00)	Misc cost (00)
AHP	24	35	300	42
AHP-GP	24	34*	300	24**

* We will save one month construction time as $d_2^- = 1$

** We will use only Misc cost $1800 (<$4200) more than the initial Budgeted cost as $d_4^- = 18$.

The proposed model, AHP-GP is to demonstrate the procedure of finding weight that considers interdependence among criteria or alternatives [20] which has highest weight wj. The ZOGP model selects the best architectural style for which the weight wj is derived from AHP which has maximum value and minimum deviation dj. Finally, architecture Style 2 is chosen which is optimum as it is consumes the total budget cost of $30,000 and use exactly 24 days of time for decision. The selected style will save one month construction time (total time is 35 months) as $d_2^- = 1$

5 Conclusions

This paper proposes a goal programming approach to the selection of software architecture style. This approach can simultaneously handle the multiple and conflicting goals characteristic of the decision problems such as quality, limited availability of resources. The integrated AHP-GP-Visualization model applied in three subsequent stages: the first part of the analysis provided the priority levels for the different alternatives (pipe&filter, layered , blackboard) with respect to the criteria (modifiability, scalability, performance, cost, effort, portability and ease of use). In the second step, the Goal Programming model equations are formulated for the selection of the optimal architecture style based of the goals. In the third step, compliance checking is to be executed for every single modification made to source code using the SAVE Tool for quality assurance. The application of the GP technique combined with AHP methodology proved to be a flexible tool to select the best architecture style.

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