eXclusive e-JOURNAL
ISSN: 1339-4509 (Online) Journal homepage: http://www.exclusiveejournal.sk
ECONOMY & SOCIETY & ENVIRONMENT

Semester Evaluation of Students Tasks Using the Analytic Hierarchy Process Method (AHP)

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Abstract: Decision making is an integral part of the teacher's work as part of students´ evaluation. The teacher can use the hierarchical decision making method to exclude subjective impacts. The paper describes the decision making method, the Analytic Hierarchy Process (AHP), constructing the matrix of pair-wise comparison and calculation of the eigenvector of the pair-wise matrix. The steps of the AHP method are described on short examples relating to the consistency of the pair-wise matrix

Keywords: AHP; hierarchy; decision making; consistency

JEL Classification: C02

Introduction

Present economic conditions put higher demands on the quality of managerial decisions. Faulty decisions can cause big losses and even bankruptcy of the firm. That is why it is necessary to re-establish the importance of mathematics and its applications within the preparation of managers of the 21st century, e.g. in decision making processes. This approach can be beneficial to the work of teachers as well. It is sometimes difficult for the teacher not to be influenced by the subjective feeling when evaluating students. The described Saaty method can be used even at such a type of decision-making. To divide the process of decision-making hierarchy is the ideal way for decision makers to find the optimal variant.

The goal of decision making is a certain future state of the decision maker following from the necessity to realize certain needs or to fulfil certain functions. The goal should be reached by the realization of some variant of decision making. The goal of decision making is usually hierarchically divided into partial goals, which are being transformed into the form of decision making criteria (RAMÍK, 2010).

People make three general types of judgments to express importance, preference, or likelihood and use them to choose the best among alternatives in the presence of environmental, social, political, and other influences. They base these judgments on knowledge in memory or from analyzing benefits, costs, and risks. From past knowledge, we sometimes can develop standards of excellence and poorness and use them to rate the alternatives one at a time. This is useful in such repetitive situations as student admissions and salary raises that must conform to established norms. Without norms one compares alternatives instead of rating them. Comparisons must fall in an admissible range of consistency. The analytic hierarchy process (AHP) includes both the rating and comparison methods. Rationality requires developing a reliable hierarchic structure or feedback network that includes criteria of various types of influence, stakeholders, and decision alternatives to determine the best choice (SAATY, 1994).

1. Decision making

Analytic hierarchy process (SAATY, 1980, 1990, 2008) is one of the most commonly used utility-based methods for multi-criteria decision making (WANG, 2011). The AHP uses objective mathematics to process the subjective and personal preferences of an individual or a group in decision making. In Saaty's hierarchical analysis, a decision maker is asked to provide his/her ratios A_{ij} for each pairwise comparison between issues (alternatives, candidates, etc.) A_l, A_2, ..., A_n for each criterion (objective) in a hierarchy and also between the criteria. To make comparisons, a scale of numbers should be used to indicate how many times more important or dominant one element is over another element with respect to the criterion or property being compared. In Saaty's fundamental nine-scale measurement used in making a comparison, the numbers for the ratios are usually taken from the set 1, 2, ..., 9. It consists of verbal judgments that range from equal to extreme (equal, moderately more, strongly more, very strongly more, extremely more). The numerical judgments 1,3,5,7,9 correspond to the verbal judgments and compromises between these values. For example, if a person considers A_1 to be moderately more important than A_2, then a_{l2} is equal to 3/l. The ratio a_{ij} indicates the strength with which Ai dominates A_j. The nine-scale measurement is widely applied in AHP. However, the language description disagrees with the numerical values of the scale division in various aspects (YANG, 2010, 2013).

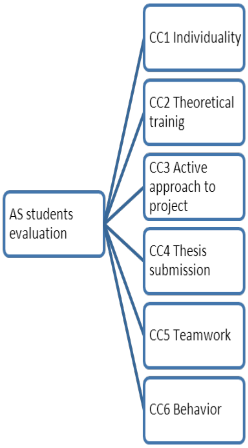
The AHP consists of following five steps: 1) break down a decision problem into component factors. 2) arrangement of these factors in a hierarchic order. 3) assignment of numerical values (SAATY, 1977) to determine the relative importance of each factor according to their subjective relevance. 4) set up of a comparison matrix. 5) computation of the normalized principal eigenvector, which gives the weight of each factor (SAATY&VARGAS, 2012).

AHP is widely used across industries for dealing with multiple criteria decision-making problems involving subjective judgment. However, AHP is often criticized for its inability to adequately accommodate the inherent uncertainty and imprecision associated with mapping decision-maker perceptions to an exact number (SOMSUK, 2013).

To make decisions is a common task of every teacher; here he is in the role of the decision maker. The task of the decision maker is to choose one or more variants from the feasible variants set. The decision maker is defined as subject, who has to make a decision, chose a variant, which is rated most, the optimal variant. The multi-criteria analysis facilitates the choice from set m of possible variants. The multi-criteria decision-making process enables hierarchical structuring of variants, the description of individual criteria of decision making, their quantification and rating. The decision maker concentrates only on assessment per one criterion and his decision is not influenced by his view concerning other criteria. Assessment of the variant becomes comparing the variants per one criterion. If the decision maker feels insecure, he can set up a team of decision makers who compare the individual variants through discussion or brainstorming method.

In our case we structured the semester rating of students into the evaluation of individual students according to the stated criteria. Each criterion has been rated separately by the decision makers.

Figure 1: **Hierarchy for students' evaluation**



Source: Author

In the following text Variants (individual students) are indicated as V (for i = …, m).

Points of view, according to which the decision maker evaluates are called criteria, indicated CC_n (for i = 1, 2 …,n). Criteria can be either qualitative or quantitative. Qualitative criteria cannot be objectively measured, and that is why we determine in the decision making process mostly according to the point scale by so-called scaling or by comparing the variants by the pair-wise comparison. With quantitative criteria for example price, salary, etc. we work directly as with values. In our case we do not have quantitative criteria in the decision making hierarchy.

2. Saaty AHP method

The pair-wise comparisons allow for the production of the relative importance value, which is called weight, and the importance value is computed using the eigenvalue method. (ESLAMIPOOR, 2013).

The mathematical model used in multi-criteria decision-making method follows from setting criteria between the individual factors which influence decision-making. If the manager decides among more variants, it is necessary to set criteria for each variant, respectively the relation among the individual factors. To get as many probability values of criteria is the most difficult part of the decision making process. Everything which follows is only mathematics.

The AHP Analytic Hiearchy Process was described by Prof. Dr. Thomas L. Saaty, professor at the University of Pitsburgh, where he teaches at the Joseph M. Katz Graduate School of Business. Professor Saaty described the multi-criterial decision-making method which today bears his name.

The preference of individual variants is evaluated by a scale of odd numbers from 1 to 9 which express the intensity scale of importance of the variant. To create Saaty matrix we have to assign absolute importance to the individual variants, according to preferences of the decision maker or the team of decision makers and to use the listed nine point scale for a more sensitive expression of the individual variants it is possible use an intermediate stage, even numbers 2, 4, 6, 8. To assign the importance of individual variants can be carried out by a team of decision makers by brainstorming method, for each criterion separately. In that way the subjective factor is ruled out of the decision making process. The AHP method of pair-wise comparison is used for writing down preferences.

Table 1. Saaty's AHP pair-wise comparison scale

Numeric scale	meaning	explanation
1	both variants have equal importance	two activities contribute equally to the object
3	variant has more moderate importance than another one	slightly favors one over another
5	variant has stronger importance than another one	strongly favors one over another
7	variant has demonstrated importance than another one	dominance of the demonstrated in practice
9	variant has extremely importance than another one	evidence favoring one over another of highest possible order

Source: compiled by the author according (Ho, 2012), (Deng, 2014), (Ramík, 2010)

Saaty´s analytic hierarchy process is a mathematical method; we can say also mathematical method. It uses pair-wise matrix and mathematical methods to find the best variant for decision making. Eigenvector for matrix is used for calculation.

We put values from the column Numeric scale into Saaty‘s matrix S.:

1. matrix S is squared type n x n,
2. matrix S is reciprocal, that means Sji = 1 / Sij,
3. in matrix S are odd numbers on the numeric scale or 1 divided by an odd number from the numeric scale,
4. diagonal of the matrix is always number 1 because it is true that Sji = Sij = 1 for i=j, any variant compares to itself has equal importance,
5. Eigenvalue for matrix S type n × n is a complex number λ which satisfies the equation det $(S - \lambda I) = 0$, when I means identity matrix. Equation det $(S - \lambda I) = 0$ is called characteristic equation of matrix S.

2.1 Rating of qualitative criteria

At the rating of qualitative criteria, we apply comparison scale. At qualitative criteria we rate the individual variants according to Saaty´s numeric scale of importance (Table 1). Using the scale enables the decision makers to compare variants always only according to one criterion, and that factually, without trying to compare different elements (RAMÍK, 2010).

Individually rated variants are listed into the table and the values of pair-wise comparison are listed, the relation of significance of one variant to another. For example the second variant is according to criterion 1 slightly more important than the first variant, $v_2 / v_1 = 3 / 1$ and according to the principle of reciprocity $v_1 / v_2 = 1 / 3$. In the second line of the form of pair-wise comparison is the first variant according to criterion 1 expressively more important than the third variant, $v_3 / v_1 = 1 / 7$ a $v_1 / v_3 = 7 / 1$. The importance is written in the Saaty matrix S.

Following Table 1 every variant scaling number is written into a form. Non red numbers were erased for better clarity of the table. Table 2 shows complete pair-wise form for criterion Individuality:

Table 2: Pair-wise form table for criterion Individuality
Pair-wise form

	9	7	5	3	1	3	5	7	9	
student 1				3						student 2
student 1			5							student 3
student 1				3						student 4
student 1							5			student 5
student 1						3				student 6
student 2						3				student 3
student 2				3						student 4
student 2							5			student 5
student 2					1					student 6
student 3							5			student 4
student 3						3				student 5
student 3				3						student 6
student 4						3				student 5
student 4				3						student 6
student 5					1					student 6

***Source*: Author**

Saaty´s pair-wise matrix S is:

Table 3: Saaty pairwise matrix S.

Saaty matrix S

		v1	v2	v3	v4	v5	v6
student1	v1	1	3	5	3	1/5	1/3
student2	v2	1/3	1	1/3	3	1/5	1
student3	v3	1/5	3	1	1/5	1/3	3
student4	v4	1/3	1/3	5	1	1/3	3
student5	v5	5	5	3	3	1	1
student6	v6	3	1	1/3	1/3	1	1

***Source*: Author**

For pair-wise matrix S we have to compute eigenvalue λ_{max} and then normalized eigenvector for max number λ_{max}. We use mathematical modeling in Microsoft Excel and solve equation using matrix formula and function =MDETERM.

We have to solve equation det $(S - \lambda I) = 0$, when I means identity matrix. To solve the equation, we use iteration Goal seek tool in Excel. We have to insert great number to cell λ, because we are seeking the greatest eigenvector number λmax. Solving equation det $(S - \lambda I) = 0$ is converging to value 3,83 10-8, we can say it is zero. λmax for our pair-wise matrix is 8,691. Several methods have been proposed for estimating the weights from the pair-wise matrix. For example, logarithmic least squares, weight logarithmic least square, fuzzy preference programming and others. We decided to use the classical eigenvector method which is being described here.

2.2 Consistency index

The AHP method is based on the principle of pair-wise comparison. The formed matrix is according to the above mentioned square, reciprocal, the diagonal of the matrix is formed by number 1 and it would be ideal for accuracy of the method that the matrix was consistent.

Consistency of of pair-wise comparison matrix S = (s_{ij}) can be defined as follows: let us say that element xi je s_{iq} is-times more important than element s_q (according to the rating criterion f), and element s_q is s_{qj}-times more important than element x_j, then element xi je $s_{ij} = s_{iq} \bullet s_{qj}$- times more important than element x_j. When comparing qualitative criteria the pair-wise comparison matrix is perfectly consistent, it holds that scales, the values of qualitative criterion are known $v_i > 0$ a $v_j > 0$ and for the elements of the matrix of pair-wise comparison it holds that $S_{ji} = v_i / v_j$. If the given relation matrix holds, the S = (s_{ij}) is reciprocal and consistent (RAMÍK, 2000).

For the success of the AHP method the consistency index is important. It holds, that the maximal own number of the square matrix of pair-wise comparison S = (s_{ij}) of the type m x m, which is always reciprocal, but does not need to be consistent S = (s_{ij}) is bigger or equals m. If the matrix S = (s_{ij}) is consistent, it always holds that λ_{max} = m. Consistence index is the number CI counted from the relation $C_I = \frac{\lambda_{max} - m}{m - 1}$

Consistency index CI for consistency matrix is close to zero. Inconsistency matrix expresses the size of the deviance CI from value 0.

We have set the consistency index of matrix S, according to the above shown relation, its value is 0,5382 and that indicates little inconsistence of matrix S. It preponderantly means that the decision maker or he decision makers are in contradiction concerning some criteria.

Saaty's methodology with the eigenvector will be marked **w**. According to definition we multiply identity matrix I and λ_{max} and then the matrix expression (S - λ_{max} I). We seek the solution of the equations (S - λ_{max} I) **w** = 0. We have solved the system of equations with the analytic tool Solver in Microsoft Excel, another common way could be used too.

Eigenvector w for matrix S corresponding to value λ_{max} is

w = (1,999; 1,508; 1,224; 1,645; 3,297; 1,470), normalized vector

w = (0,187; 0,099; 0,114; 0,154; 0,308; 0,138)^T.

Max value in eigenvector for matrix S λ_{max} is 0,308. The best result by criterion Individuality has student student5.

For better clarity of our results tables we use style of pair-wise matrix in normalized form with λ_{max}, CI and CR indexes in the last row and eigenvector in the last column (ZHANG, 2013). In next text there are described only last rows and last columns of tables with our results.

2.2.1 Criterion CC1 Individuality

Table 4: Normalized matrix for criterion Individuality.

				Normalized matrix CC1				
variant:		v1	v2	v3	v4	v5	v6	priorities
student1	v1	1	3	5	3	1/5	1/3	0,187
student2	v2	1/3	1	1/3	3	1/5	1	0,099
student3	v3	1/5	3	1	1/5	1/3	3	0,114
student4	v4	1/3	1/3	5	1	1/3	3	0,154
student5	v5	5	5	3	3	1	1	**0,308**
student6	v6	3	1	1/3	1/3	1	1	**0,138**
λ_{max} = 8,691	C_I = 0,538		C_R = 0,434					

***Source*: Author**

The best result by criterion Individuality, the highest value of priority, the highest value in normalized eigenvector, has student5 (it has shown by bold number in the last column of the table). Value of consistency index CI = 0,538 indicates that pair-wise matrix is a non-consistency, index is proposed to be less than 0,1 by many authors (HO, 2012), (ESLAMIPOOR, 2013), (AMINBAKHSH, 2013), (DI GIRONIMO, 2013).

2.2.2 Criterion Theoretical training

Table 5: Normalized matrix for criterion Theoretical training.

Normalized matrix CC2

variant:		v1	v2	v3	v4	v5	v6	priorities
student1	v1	1	5	7	3	3	3	**0,404**
student2	v2	1/5	1	3	1/3	1/3	1	0,101
student3	v3	1/7	1/3	1	1	3	3	0,129
student4	v4	1/3	3	1	1	3	5	0,193
student5	v5	1/3	3	1/3	1/3	1	3	0,115
student6	v6	1/3	1	1/3	1/5	1/3	1	**0,057**
λ_{max} = 7,213	C_I = 0,243		C_R = 0,196					

***Source*: Author**

The best result per criterion Theoretical training, the highest value in the normalized own vector, has been achieved by student2 (illustrated in bold letters in the last column of the table). The value of index consistence CI = 0,243 indicates good results of the comparison. It can be seen from the results that student2, according to criterion Theoretical training, significantly exceeds his colleagues.

2.2.3 Criterion Active approach to project

Table 6: Normalized matrix for criterion Active approach to project.

Normalized matrix CC3

variant:		v1	v2	v3	v4	v5	v6	priorities
student1	v1	1	1/3	3	3	1	1	0,198
student2	v2	3	1	1/3	1	1	1/3	0,136
student3	v3	1/3	3	1	1/3	3	3	0,201
student4	v4	1/3	1	3	1	3	1/5	0,157
student5	v5	1	1	1/3	1/3	1	1	0,093
student6	v6	1	3	1/3	5	1	1	**0,215**
λ_{max} = 8,205	C_I = 0,441		C_R = 0,356					

***Source*: Author**

The best result according to criterion Active approach to project has been achieved by student6. The value of index consistence CI = 0,441 indicates that the student according to this criterion shows a certain inconsistency and it would be appropriate for the teacher to reconsider his original comparison of the student according to this criterion. Especially the tight results of student6 and student3 are the evidence.

2.2.4 Criterion Thesis submission

Table 7: Normalized matrix for criterion Thesis submission.

Normalized matrix CC4

variant:		v1	v2	v3	v4	v5	v6	priorities
student1	v1	1	7	5	5	3	3	**0,405**
student2	v2	1/7	1	1	3	3	1/7	0,090
student3	v3	1/5	1	1	1/3	3	1/7	0,062
student4	v4	1/5	1/3	3	1	3	1/5	0,082
student5	v5	1/3	1/3	1/3	1/3	1	1/7	0,043
student6	v6	1/3	7	7	5	7	1	**0,318**
λ_{max} = 7,002	C_I = 0,200		C_R = 0,162					

***Source*: Author**

The best result per criterion Thesis submission to project has been achieved by student1. The value of index consistence CI = 0,200 shows a good result.

2.2.5 Criterion Teamwork

Table 8: Normalized matrix for criterion Teamwork.

		Normalized matrix CC5						
variant:		v1	v2	v3	v4	v5	v6	priorities
student1	v1	1	1	5	3	1/3	1/3	0,176
student2	v2	1	1	1	3	3	1	0,187
student3	v3	1/5	1	1	1/3	3	1/3	0,098
student4	v4	1/3	1/3	3	1	5	1/5	0,143
student5	v5	1/3	1/3	1/3	1/5	1	1/3	0,106
student6	v6	3	1	3	5	3	1	**0,290**
λ_{max} = 8,026	C_I = 0,405		C_R = 0,326					

***Source*: Author**

The best result according to criterion Teamwork to project has been achieved by student6. The value of index consistence CI = 0,405 indicates inconsistence of pair-wise comparison matrix. The significantly lower results of other students do not require re-evaluation by a of teacher team.

2.2.6 Criterion Behaviour

Table 9: Normalized matrix for criterion Behaviour.

		Normalized matrix CC6						
variant:		v1	v2	v3	v4	v5	v6	priorities
student1	v1	1	1	1	3	3	5	**0,305**
student2	v2	1	1	1	3	3	1	0,194
student3	v3	1	1	1	1/3	3	1/3	0,127
student4	v4	1/3	1/3	3	1	3	1/3	0,128
student5	v5	1/3	1/3	1/3	1/3	1	1/3	0,052
student6	v6	1/5	1	3	3	3	1	**0,195**
λ_{max} = 7,024	C_I = 0,205		C_R = 0,165					

***Source*: Author**

The best result according to criterion Behaviour to project has been achieved by student1. The value of the index consistence CI = 0,205 indicates a good result.

3. Result analysis and discussion

With the individual results of student comparison of each criterion a synthesis will be carried out to get an overall evaluation. The team of decision makers in this final step evaluates by the *pair-wise comparison* method the importance of individual criteria among themselves. The same scale as with individual criteria a *pair-wise comparison* matrix for individual criteria has been set up and by the same eigenvector method the final normalised eigenvector has been found. The most important criteria are CC2 closely followed by CC5.

Table 10: Normalized matrix for synthesis the Assessment of students.

					Normalized matrix AS			
variant:		v1	v2	v3	v4	v5	v6	priorities
CC1	v1	1	1	1/3	3	1	1	0,140
CC2	v2	1	1	1	5	3	5	0,288
CC3	v3	3	1	1	3	1/5	3	0,186
CC4	v4	1/3	1/5	1/3	1	1/5	1	0,048
CC5	v5	1	1/3	5	5	1	3	0,271
CC6	v6	1	1/5	1/3	1	1/3	1	**0,067**
λ_{max} = 6,949	C_I = 0,189		C_R = 0,153					

***Source*: Author**

After comparison of individual students per each criterion a synthesis of partial results was carried out. From the normalized own vectors a matrix was set up so that each normalized own vector forms a column of the matrix synthesis S_k. For our criteria, it will be S_k.

Table 11: Matrix of normalized eigenvectors of individual criteria S_k.

			Synthesis of own vector criteria CC1 - CC6			
1	0,187	0,099	0,114	0,154	0,308	0,138
2	0,404	0,101	0,129	0,193	0,115	0,057
3	0,198	0,136	0,201	0,157	0,093	0,215
4	0,405	0,090	0,062	0,082	0,043	0,318
5	0,176	0,187	0,098	0,143	0,106	0,290
6	0,305	0,194	0,127	0,128	0,052	0,195

***Source*: Author**

We can see that according to the opinion of pedagogues – *decision-makers* the most important criterion is CC2 Teamwork. The matrix of normalized vectors is transposed and multiplied from the right by normalized own vector matrix AS of the importance of individual criteria as evaluated by the pair-wise comparison method by the evaluators. The resulting matrix determines the best student. It is Student1.

Table 12: Multiplying S_k matrix from the right by normalized eigenvector

			Multiplying S_k matrix from the right by normalized eigenvector			
	1	2	3	4	5	6
V1	0,187	0,404	0,198	0,405	0,176	0,305
V2	0,099	0,101	0,136	0,090	0,187	0,194
V3	0,114	0,129	0,201	0,062	0,098	0,127
V4	0,154	0,193	0,157	0,082	0,143	0,128
V5	0,308	0,115	0,093	0,043	0,106	0,052
V6	0,138	0,057	0,215	0,318	0,290	0,195

***Source*: Author**

w = (0,140; 0,288; 0,186; 0,048; 0,271; 0,067), normalized vector

w = (0,267; 0,136; 0,129; 0,157; 0,128; 0,183)^T.

4. Conclusions

The AHP method has been used on a short example, the set-up of a pair-wise comparison matrix and setting the highest eigenvector of pair-wise comparison matrix in the decision-making process and the importance of the auxiliary criterion consistency matrix of pair-wise comparison. There are appearing still new criteria in nowadays complex development of technologies and business environment. In practice, they often appear as tangled and sometimes rational decision-making is substituted by an intuitive procedure or inclination to experience. The experience of a manager can project into setting the scales of the individual criteria. Among the main advantages of the AHP method the possibility of setting at work with qualitative and quantitative criteria can be shown. It helps a better orientation at decision-making and optimization of profit in consistency and inconsistency to introduce the elegant joining of exact procedures and experience of managers. The AHP method is a good contribution, its results can indicate the spheres of student evaluation per individual variants, concentrating only on one criterion, which helps the teacher to suppress subjective feelings. Mathematical elaboration of pair-wise comparison matrix and the overall synthesis of results are then independent of subjective feelings.

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