Educational Microsoft Excel Add-ins
Solving Multicriteria Decision Making Problems

Radomir Perzina and Jaroslav Ramik
Silesian University in Opava, School of Business Administration in Karvina,
University sq. 1934/3, Karvina, Czech Republic

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Abstract: There exists wide range of software products to support decision making. Main disadvantage of those software products is that they are commercial and relatively expensive and thus it prevents them to be used by students or researchers. Also they are not suitable from pedagogical point of view. This paper introduces two Microsoft Excel add-ins DAME and FVK that were developed for students to help them understand basic principles of Multicriteria Decision Making. They don't behave as a black box but display all results of all intermediate calculations which are very important for educational purposes. The proposed software packages are demonstrated on couple of illustrating examples of real life decision problems.

1 INTRODUCTION

Decision making in situations with multiple variants is an important area of research in decision theory and has been widely studied e.g. in (Fishburn, 1971), (Gass, 2004), (Ramik, 2006), (Ramik, 2014), (Saaty, 1978), (Saaty, 1991), (Saaty, 2001). When teaching decision making theory it is essential to support it with appropriate computer program that demonstrates its basic principles. There exists wide range of computer programs that are able to help decision makers to make good decisions, e.g. Expert Choice (http://www.expertchoice.com), Decisions Lens (http://www.decisionlens.com), Mind Decider (http://www.minddecider.com), MakeItRational (http://makeitrational.com) or Super Decisions (http://www.superdecisions.com). Main disadvantage of those programs is that they are commercial and relatively quite expensive and thus it prevents them to be used by students, researchers or small companies. Also they are not suitable from pedagogical point of view because they generally displays just final results not the intermediate ones which are essential to help students to understand decision making theory.

Here we introduce two Microsoft Excel add-in named DAME – Decision Analysis Module for Excel and FVK which were mainly designed to support the learning of the decision making theory. Comparing to other software products for solving multicriteria decision problems, DAME is free, able to work with scenarios or multiple decision makers, allows for easy manipulation with data and utilizes capabilities of widespread spreadsheet Microsoft Excel. Users can structure their decision models into three levels – scenarios/users, criteria and variants. Standard pair-wise comparisons are used for evaluating both criteria and variants. For each pair-wise comparison matrix there is calculated an inconsistency index. There are provided three different methods for the evaluation of the weights of criteria, the variants as well as the scenarios/users - Saaty's Method (Saaty, 1991), Geometric Mean Method (Aguaron, 2003) and Fuller's Triangle Method (Fishburn, 1971). Multiplicative and additive syntheses are supported. FVK incorporates possibility for expressing uncertainty by fuzzy numbers and also takes into account interdependences between criteria.

2 DAME

DAME works with all current versions of Microsoft Excel from version 97. It consists of four individual files:

- DAME.xla – main module with user

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interface, it is written in VBA (Visual Basic for Applications),

- DAME.dll – it contains special functions used by the application, it is written in C#,
- DAME.xll – it contains library for linking C# modules with Excel called Excel-DNA (http://exceldna.codeplex.com),
- DAME.dna – configuration file.

All four files must be placed in the same folder and macros must be permitted before running the module (see Microsoft Excel documentation for details). DAME itself can be executed by double clicking on the file DAME.xla. After executing the add-in there will appear a new menu item “DAME” in the Add-ins ribbon (in older Excel versions the menu item “DAME” will appear in the top level menu). A new decision problem can be generated by clicking on “*New problem*” item in the main DAME menu, see figure 1.

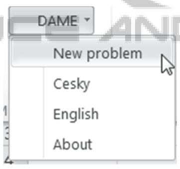

Figure 1: New problem menu.

Then there will be shown a form with main problem characteristics, see figure 2.

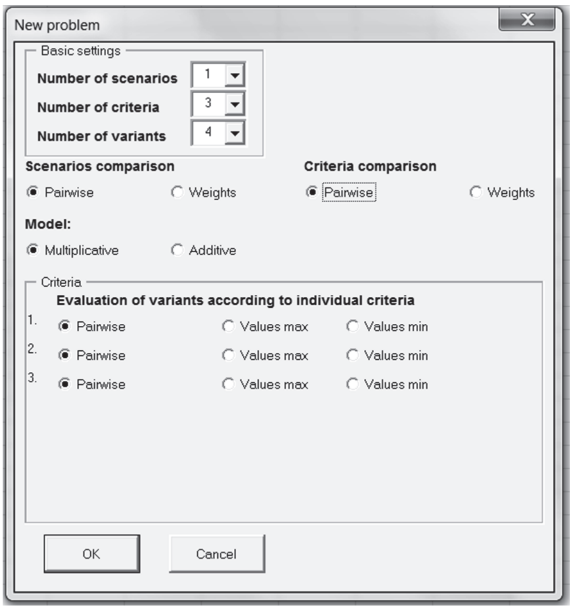

Figure 2: New problem characteristics.

In the top panel there are basic settings: number of scenarios, criteria and variants. In case a user doesn’t want to use scenarios or there is just a single decision maker, the number of scenarios should be set to one. In the second panel we can set how we want to compare scenarios/users and criteria either using pairwise comparison matrix or set weights directly. Here we can also choose multiplicative or additive synthesis model. In the last panel users can chose how they want to evaluate variants according to individual criteria. There are three options: Pairwise – each pair of variants is compared individually, Values max – indicates maximization criterion where each variant is evaluated by single value, e.g. price and Values min – indicates minimization criterion where each variant is evaluated by single value, e.g. costs. When user confirms his options a new Excel sheet with forms is created, where user can set names of all elements and evaluate criteria and variants using pairwise comparison matrices as shown on figure 3.

Criteria	Crit 1	Crit 2	Crit 3	0.000	*Criteria weights*	
Crit 1	1					0.333333
Crit 2	0	1				0.333333
Crit 3	0	0	1			0.333333

Figure 3: Pairwise comparison matrix.

In the pairwise comparison matrix users enter values only in the upper triangle. The values in the lower triangle are reciprocal and automatically calculated. If criterion (variant) in the row is more important than the criterion (variant) in the column user enters values from 2 to 9 (the higher the value is the more important is the criterion in the row). If criterion (variant) in the row is less important than the criterion (variant) in the column user enters values from 1/2 to 1/9 (the less the value is the less important is the criterion in the row). If criterion (variant) in the row is equally important to the criterion (variant) in the column user enters value 1 or leaves it empty. In the top right corner there is calculated inconsistency index which should be less than 0.1, if it is greater we should revise our pairwise comparisons, so that they are more consistent. In the very right column there are calculated weights of individual criteria (variants) based on the values in the pairwise comparison matrix and selected evaluation method. The weights w_k based on geometric mean method are calculated using the equation (1).

$$w_k = \frac{\left(\prod_{j=1}^{n} a_{kj}\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} a_{ij}\right)^{1/n}},\ k = 1,2,\ldots,n \tag{1}$$

where w_k is weight of k-th criterion (variant), a_{ij} are values in the pairwise comparison matrix, and n is number of criteria (variants).

The inconsistency index is calculated using the formula (2).

$$GCI = \frac{2}{(n-1)(n-2)}\sum_{i<j}\log^2\left(a_{ij}\cdot\frac{w_j}{w_i}\right) \tag{2}$$

When we are entering values in individual pairwise comparison matrices all weights are being instantly recalculated, so we can see immediate impact of our each individual entry. Matrix and graph with total evaluation of variants is then shown at the bottom of the sheet. The resulting vector of weights of the variants **Z** is given by the formula (3).

$$\mathbf{Z} = \mathbf{W}_{32}\mathbf{W}_{21}, \tag{3}$$

where $\mathbf{W}_{21}$ is the $n\times1$ matrix (weighing vector of the criteria), i.e.

$$\mathbf{W}_{21} = \begin{bmatrix} w(C_1) \\ \vdots \\ w(C_n) \end{bmatrix}, \tag{4}$$

and $\mathbf{W}_{32}$ is the $m\times n$ matrix:

$$\mathbf{W}_{32} = \begin{bmatrix} w(C_1,V_1) & \cdots & w(C_n,V_1) \\ \vdots & \cdots & \vdots \\ w(C_1,V_m) & \cdots & w(C_n,V_m) \end{bmatrix}, \tag{5}$$

where $w(C_i)$ is weight of the criterion C_i, $w(V_r,C_i)$ is weight of variant V_r subject to the criterion C_i.

3 CASE STUDY – DAME

Here we demonstrate the proposed add-in DAME on a decision making situation buying an "optimal" refrigerator with 3 decision criteria and 3 variants. The goal of this realistic decision situation is to find the best variant from 3 pre-selected ones according to 3 criteria: price (minimization criterion), efficiency (pairwise) and design (pairwise). At this stage we have just single decision maker, so the parameter "Number of scenarios" is set to one. Setting of parameters can be seen on the figure 4.

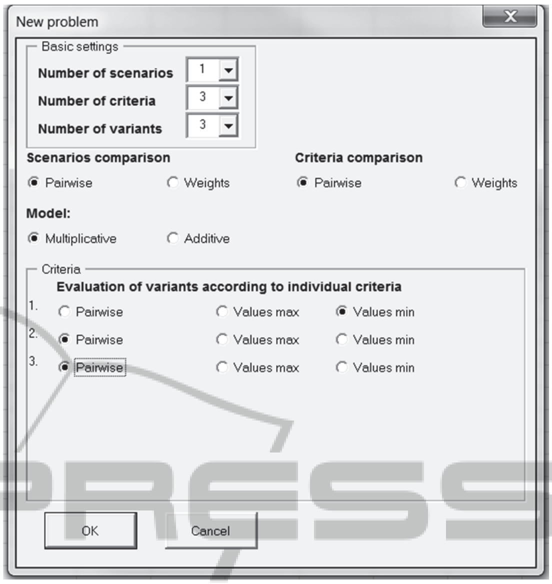

Figure 4: Case study – setting of parameters.

When we submit the form a new sheet is generated. First we set names of criteria and variants, for simplicity we use default names for variants (Var 1, Var 2 and Var 3), see figure 5.

Names of criteria:		
Price	**Efficiency**	**Design**
Names of variants:		
Var 1	**Var 2**	**Var 3**

Figure 5: Case study – names of criteria and variants.

Next step is comparison of individual criteria using pairwise comparison matrix with elements saying how much more important is criterion in the row than the criterion in the column, see figure 6.

Criteria	Price	Efficiency	Design	0.010	*Criteria weights*
Price	1	4	2		0.558425
Efficiency	0.25	1	1/3		0.121957
Design	0.5	3	1		0.319618

Figure 6: Case study – criteria comparison.

We can see that inconsistency index is less than 0.1 therefore we can say that our pairwise comparisons are consistent. In the very right column we can see calculated weights of individual criteria.

Final step is evaluation of variants according to individual criteria. Variants according the first criterion (price) will be evaluated by actual price and variants according the other two criteria (efficiency and design) will be evaluated using pairwise comparisons), see figure 7.

Price	Value	Variants weights		
Var 1	19	0.339705	0.163424	0.648329
Var 2	17	0.37967	0.539615	0.12202
Var 3	23	0.280626	0.296961	0.229651

Efficiency	Var 1	Var 2	Var 3	0.005
Var 1	1	1/3	1/2	
Var 2	3	1	2	
Var 3	2	0.5	1	

Design	Var 1	Var 2	Var 3	0.002
Var 1	1	5	3	
Var 2	0.2	1	1/2	
Var 3	0.333333	2	1	

Figure 7: Case study – evaluation of variants.

As we can see both pairwise comparison matrices are consistent, because their inconsistency indexes are less than 0.1. In the top right matrix we can see calculated weights of all variants (rows) according to individual criteria (columns). At this stage synthesis is calculated and we can see total evaluation of variants in the last table on figure 8 and graphical representation on figure 9. We can say that the best variant is Var 3 with weight 0.40 followed by Var 1 with weight 0.34 and the last one is Var 2 with weight 0.25.

CZn=	Weight	Rank
Var 1	0.416848	1
Var 2	0.316827	2
Var 3	0.266325	3

Figure 8: Case study – total evaluation of variants.

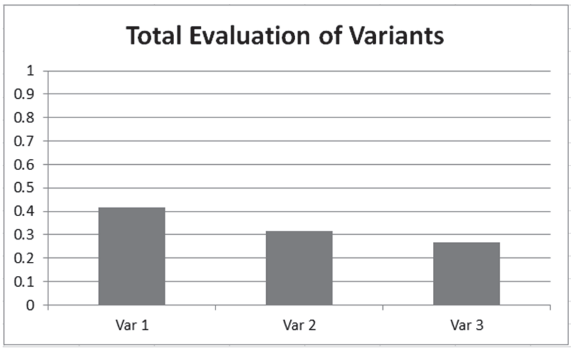

Figure 9: Case study – total evaluation of variants - graph.

4 FVK

When applying Analytic Hierarchy Process (AHP) in decision making one usually meets two difficulties: when evaluating pair-wise comparisons on the nine point scale we do not incorporate uncertainty or when decision criteria are not independent as they should be. In this paper these difficulties are solved by a proposal of the new method which incorporates uncertainty using pair-wise comparisons by triangular fuzzy numbers, and takes into account interdependences between criteria.

The first difficulty is solved by fuzzy evaluations: instead of saying e.g. “with respect to criterion C element A is 2 times more preferable to element B” we say “element A is possibly 2 times more preferable to element B”, where “possibly 2” is expressed by a triangular fuzzy number. In some real decision situations, dependency of the decision criteria occur quite frequently, e.g. the criterion price is naturally influenced by the quality criterion. Here, the dependency is modeled by a feedback matrix, which expresses the grades of influence of the individual criteria on the other criteria.

The interface between hierarchies, multiple objectives and fuzzy sets have been investigated by the author of AHP T.L. Saaty (Saaty, 1978). Later on, (Laarhoven, 1983) extended AHP to fuzzy pairwise comparisons. Saaty extended AHP to a more general process with feedback called Analytic Network Process (ANP) (Saaty, 1991), (Saaty, 2001). In this paper we extend the approaches from (Buckley, 1985), (Chen, 1992), (Saaty, 2001) to the case of feedbacks between the decision criteria as it was specified in (Ramik, 2006) and (Perzina, 2008), moreover we also supply an illustrating realistic example to demonstrate the proposed method, documented by the outputs from Microsoft Excel add-in FVK that was developed for students to help them understand and solve the proposed model.

FVK works with all current versions of Microsoft Excel from version 97. It consists of two individual files which must be place in the same folder:

- FVK.xla – main module with user interface, it is written in VBA (Visual Basic for Applications),
- xlwVisio.xll – it contains special functions used by the application which are linked with Excel by module called XLW (http://xlw.sourceforge.net).

FVK itself can be executed by double clicking on the file FVK.xla. After executing the add-in there will appear a new menu item “FVK” in the Add-ins ribbon (in older Excel versions the menu item “FVK” will appear in the top level menu). A new decision problem can be generated by clicking on “*New problem*” item in the main FVK menu. Then there will be shown a form with main problem characteristics, see figure 10.

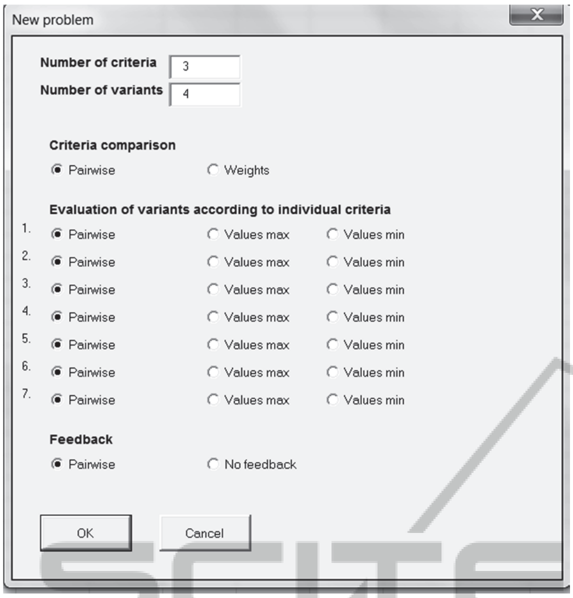

Figure 10: New problem characteristics.

In the top part there are basic settings: Number of criteria and variants. In the second part we can set how we want to compare criteria either using pairwise comparison matrix or set weights directly. In the next part users can chose how they want to evaluate variants according to individual criteria. There are three options: Pairwise – each pair of variants is compared individually, Values max – indicates maximization criterion where each variant is evaluated by single value, e.g. price and Values min – indicates minimization criterion where each variant is evaluated by single value, e.g. costs. In the last part we can specify if we want to use dependency among criteria. When user confirms his options a new Excel sheet with forms is created, where user can set all elements.

5 CASE STUDY – FVK

Here we analyze similar decision making situation as we analyzed with DAME, but now using the fuzzy ANP algorithm with a help of FVK

First we express the importance of the criteria that is given by the pair-wise comparison matrix **C**:

C =	Crit 1			Crit 2			Crit 3		
Crit 1	1	1	1	2	4	5	1	2	2
Crit 2	0,2	0,25	0,5	1	1	1	1/4	1/2	1
Crit 3	0,5	0,5	1	1	2	4	1	1	1

Figure 11: Pair-wise comparison matrix C.

Then we calculate the corresponding triangular fuzzy weights, i.e. the relative fuzzy importance of the individual criteria that are given in matrix $\mathbf{W_{21}}$:

W21 =			
0,360	0,571	0,616	- C1 (Price)
0,105	0,143	0,227	- C2 (Design)
0,227	0,286	0,454	- C3 (Efficiency)

Figure 12: Matrix W_{21}.

Next step is to make fuzzy evaluations of the variants according to the individual criteria that are given by the following 3 pair-wise comparison matrices **A1**, **A2**, **A3**:

A1 =	Var 1			Var 2			Var 3		
Var 1	1	1	1	1/3	1/2	1	1/3	1/3	1/2
Var 2	1	2	3	1	1	1	1/2	1/2	1
Var 3	2	3	3	1	2	2	1	1	1

A2 =	Var 1			Var 2			Var 3		
Var 1	1	1	1	1/4	1/3	1/2	2	2	4
Var 2	2	3	4	1	1	1	1/4	1/2	1
Var 3	0,25	0,5	0,5	1	2	4	1	1	1

A3 =	Var 1			Var 2			Var 3		
Var 1	1	1	1	4	5	6	3	3	5
Var 2	0,167	0,2	0,25	1	1	1	1/3	1/2	1
Var 3	0,2	0,333	0,333	1	2	3	1	1	1

Figure 13: Pair-wise comparison matrices A1, A2, A3.

The corresponding fuzzy matrix $\mathbf{W_{32}}$ of fuzzy weights is calculated as

W32 =									
0,143	0,163	0,236	0,263	0,289	0,417	0,602	0,648	0,817	- Variant 1
0,236	0,297	0,428	0,263	0,379	0,526	0,100	0,122	0,166	- Variant 2
0,374	0,540	0,540	0,209	0,331	0,417	0,154	0,230	0,263	- Variant 3

Figure 14: Matrix W_{32}.

In order to evaluate fuzzy feedback between the criteria we apply again pair-wise comparison method, then we obtain the following 3 pair-wise comparison matrices **B1**, **B2**, **B3**:

B1 =	Crit 2			Crit 3		
Crit 2	1	1	1	1	2	3
Crit 3	0,333	0,5	1	1	1	1

B2 =	Crit 1			Crit 3		
Crit 1	1	1	1	1/5	1/3	1/2
Crit 3	2	3	5	1	1	1

B3 =	Crit 1			Crit 2		
Crit 1	1	1	1	2	3	5
Crit 2	0,2	0,333	0,5	1	1	1

Figure 15: Matrices B1, B2, B3.

Then we obtain the fuzzy feedback matrix $\mathbf{W_{22}}$:

W22 =									
0,000	0,000	0,000	0,194	0,250	0,306	0,612	0,750	0,968	- C1 (Price)
0,471	0,667	0,816	0,000	0,000	0,000	0,194	0,250	0,306	- C2 (Design)
0,272	0,333	0,471	0,612	0,750	0,968	0,000	0,000	0,000	- C3 (Efficiency)

Figure 16: Fuzzy feedback matrix W_{22}.

Finally we calculate the synthesis – the aggregated triangular fuzzy values of the individual variants **Z**. The situation is graphically depicted in Figure 18.

Z =	L	M	U
Var 1	0,182	0,346	0,870
Var 2	0,112	0,264	0,649
Var 3	0,149	0,390	0,733

Figure 17: Synthesis.

In the last step we rank the evaluations of the above

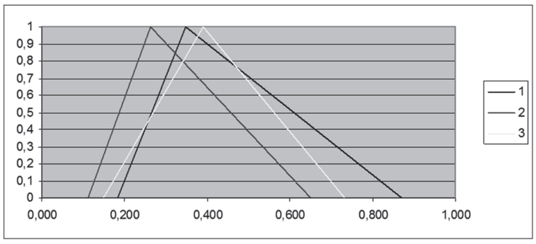

Figure 18: Total evaluation of fuzzy variants.

fuzzy variants resulting in the best decision. Here we use ranking methods as described in section 4.3., i.e. Center of gravity, *L* domination and *R* domination. For the last two methods level $\alpha = 0.7$ was used. The results are in the following table.

Variant	xgi	Rank		
		Center of gravity	*L* dominantion	*R* dominantion
Var 1	0,466	1	2	1
Var 2	0,342	3	3	3
Var 3	0,424	2	1	2

Figure 19: Rank of variants.

6 CONCLUSIONS

In this paper we have proposed two Microsoft Excel add-ins DAME and FVK which were developed for students to help them understand and solve decision making problems. Comparing to other decision support programs they are free, able to work with scenarios or multiple decision makers, allow for dependency among criteria, can work with fuzzy numbers, allows for easy manipulation with data and utilizes capabilities of widespread spreadsheet Microsoft Excel. On a realistic case study we have demonstrated their functionality in individual steps. These add-ins are regularly used by hundreds of students in the course Decision Analysis for Managers at the School of Business Administration in Karvina, Silesian University in Opava. The feedback from students is mostly positive and also teachers of this subject observed increased students' understanding of the decision support theory by using these add-ins.

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