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Software Support for Multiple Criteria Decision Making Problems

Summary

Data envelopment analysis (DEA) and multiple criteria decision making (MCDM) models are one of the most often used modelling techniques in managerial practice. Both techniques evaluate the given set of alternatives by several decision making criteria. Availability of appropriate simple software tools for mentioned models is a necessary condition for their wider real application. The paper presents two freeware software systems that are available for downloading on the author's web pages. The first system is the DEA Excel solver and the second one is Sanna – application of multi-criteria evaluation of alternatives. DEA Excel solver covers all basic DEA models and uses internal MS Excel optimization solver. The application includes standard envelopment models with constant and variable returns to scale including super-efficiency models. As the second software system the paper presents a simple MS Excel based application Sanna for multiple criteria evaluation of alternatives using several main MCDM methods (WSA, ELECTRE I and III, PROMETHHEE, ORESTE, TOPSIS and MAPPAC).

Key words

Multiple criteria decision making, data envelopment analysis, optimization, MS Excel.

Introduction

Spreadsheets belong among software products with very wide possible applications in decision making. Unfortunately their properties are used just for working with tables, simple recalculations by means of standard mathematical operators and functions in everyday practice. Spreadsheets have much wider usage – they contain tools for financial decisions, statistical analyses, working with databases, graphical representation of data and, last but not least, for optimisation and mathematical modelling. Due to their user-friendliness and wide-spread they are an ideal tool for managerial decision making in many fields. In this paper we will discuss how it is possible to use spreadsheets for mathematical modelling and optimisation. In the next sections of the paper we consider the typical spreadsheet product, which is MS Excel.

Linear programming, project management, supply chain management, waiting lines analyses, simulation, etc. belong among the most often used operational research fields. Each of the mentioned fields needs its own tools for solving various problems. It is not possible to discuss more than one or two fields within this paper. That is why we will show how it is possible to solve data envelopment analysis (DEA) models and problems of multiple criteria decision making. Both mentioned models belong to one of the most often used decision making approaches in practice. DEA models are used as a tool for evaluation of

efficiency, productivity and performance of decision making units. They are based on solving linear programming optimisation problems. Multiple criteria decision making (MCDM) problems (evaluation of alternatives) are very simple to understand even for non-expert persons in modelling, and that is why they find very frequent usage. MS Excel can be used for solving analytical problems in several ways. We can see the following three ones:

1. The standard way, characterised by using built-in tools in MS Excel (mathematical operators, functions, add-in applications coming with common MS Excel installation, etc). It is the easiest way that may suppose some advanced experience in using add-ins and other tools.
2. Linking spreadsheets to modelling languages such as *LINGO*, *MPL for Windows*, *GAMS* and others. The advantage of this approach consists in the possibility to use modelling and solving features of such products that are much more powerful than the same ones included directly in MS Excel or other spreadsheets.
3. Building end-user applications by means of VBA (Visual Basic for Applications) or by using other programming tools.

In the next two sections of the paper we will show the possibility of solving DEA and/or

MCDM problems by using our original end-user applications *DEA Excel Solver* for DEA models and *Sanna* for multicriteria evaluation of alternatives.

DEA Excel Solver

Let us consider the set of homogenous units $U_1, U_2, \ldots, U_n$ that is described by r outputs and m inputs. Let us denote $\mathbf{X} = \{x_{ij}, i = 1, 2, \ldots, m, j = 1, 2, \ldots, n\}$ the matrix of inputs and $\mathbf{Y} = \{y_{kj}, k = 1, 2, \ldots, r, j = 1, 2, \ldots, n\}$ the matrix of outputs. The *DEA Excel Solver* covers all basic DEA models and uses their formulation as follows:

Input oriented models		Output oriented models	
min	$z = \theta - \varepsilon\left(\sum_{i=1}^{m} s_i^- + \sum_{k=1}^{r} s_k^+\right)$,	max	$g = \phi + \varepsilon\left(\sum_{i=1}^{m} s_i^- + \sum_{k=1}^{r} s_k^+\right)$,
st	$\sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta x_{iq}$,	st	$\sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = x_{iq}$
	$\sum_{j=1}^{n} \lambda_j y_{kj} - s_k^+ = y_{kq}$,		$\sum_{j=1}^{n} \lambda_j y_{kj} - s_k^+ = \phi y_{kq}$
	$\lambda_j \geq 0, s_i^+ \geq 0, s_i^- \geq 0,$		$\lambda_j \geq 0, s_i^+ \geq 0, s_i^- \geq 0,$
CRS	$\sum_{j=1}^{n} \lambda_j - free,$	CRS	$\sum_{j=1}^{n} \lambda_j - free,$
VRS	$\sum_{j=1}^{n} \lambda_j = 1$,	VRS	$\sum_{j=1}^{n} \lambda_j = 1$,
NDRS	$\sum_{j=1}^{n} \lambda_j \leq 1,$	NDRS	$\sum_{j=1}^{n} \lambda_j \leq 1,$
NIRS	$\sum_{j=1}^{n} \lambda_j \geq 1,$	NIRS	$\sum_{j=1}^{n} \lambda_j \geq 1,$

where $\lambda_j, j = 1, 2, \ldots, n$ are weights of all decision making units, $s_i, i = 1, 2, \ldots, m$ are slack variables of particular inputs and $s^+_k, k = 1, 2, \ldots, r$ are surplus variables of particular outputs. Index q represents the index of evaluated unit and θ, φ are plain variables expressing the level of efficiency. The evaluated unit q is recognised as efficient in input oriented model if $\theta = 1$ and all slack and surplus variables equal to zero. Except this standard formulation there were formulated many modifications but the mentioned ones are the most often used. Detailed information about theory of DEA models can be found in: Cooper, Seiford, & Tone, 2000; Jablonský & Dlouhy, 2004; and Zhu, 2003.

Software tools for DEA models are widely offered on the software market, but they are usually commercial products and that is why their wider usage is limited. The following list contains some of the most often referenced software tools for DEA models:

- Saitech DEA Solver Pro (www.saitech-inc.com),
- Banxia Frontier Analyst (www.banxia.com),
- KonSi DEA Software (www.dea-analysis.com),
- Warwick Performance Improvement Management DEA Software (www.deazone.com),
- Joe Zhu's DEA Excel Solver (www.deafrontier.com) – software is included as a demo version in book [5],
- EMS: Efficiency Measurement System (http://www.wiwi.uni-jena.de/Mikro/pdf/ems.pdf) is the MS Excel application written by H. Scheel.

A more extensive description of DEA software can be found in Barr, R.S. (cited in Cooper, W.W. et al. (2000.)) or Zhu, J. (2003).

DEA Excel Solver developed at the University of Economics Prague belongs to freeware MS Excel add-in application. That is why it is quite widely used in managerial applications, research and education not only in the Czech Republic. In its first version the *DEA Excel Solver* was described in Jablonský, J. & Dlouhy, M. (2004). Further we deal with the modified version for MS Excel 2007. After the application DEAExcel.xla is once installed, the new item „DEA" is added to the main menu of MS Excel. This new menu contains just two items – *Settings* and *Model selection*. The *Settings* item contains the possibility to specify several parameters of the system. The most important among them is setting one of the three language versions of the system.

Input data set for DEA analysis can be prepared in any sheet of a MS Excel file. Figure 1 shows how data for evaluation of efficiency of 12 decision making units can be arranged (pension funds in the Czech Republic) described by 4 inputs and 3 outputs by means of model (1). After the input data set is prepared and the parameters are set up, it is possible to continue by the model selection – Figure 2, where, among others, the ranges with data sets and the model types are specified.

Figure 1 Input data sheet for DEA analysis

The dialog window *Model selection* consists of the following items:

- *DMU's labels* – a range with labels of the evaluated units (not obligatory – when it is not specified the system works with default labels DMU1, DMU2,...);

- *Inputs/outputs labels* – ranges with labels of the inputs and outputs (not obligatory – when it is not specified the system works with default labels INP1, INP2,...and OUT1, OUT2...);

- *Matrix of inputs and outputs* – two continuous ranges containing the matrix of inputs and the matrix of outputs – in our example it is the range B3:D17 for the inputs and F3:G17 for the outputs;

- *Model orientation* – one of the two choices – input- or output-oriented model;

- *Returns to scale* – one of the four choices – CRS, VRS, NIRS, NDRS;

- *Super efficiency* – a switch which sets up the selection of the super-efficiency model;

- *Optimisation in two steps* – a switch which specifies whether the optimisation will be realised in one or two steps (the first step is the optimisation of the reduction variable θ or the expansion variable ϕ and the second one is the maximisation of the slack and surplus variables;

- *Detailed/brief output of results* – two choices which switch on/off a brief and/or detailed output of results – for both the outputs the system generates a single sheet with output information.

Figure 2 Input data and model selection

The current version of the *DEA Excel Solver* supports the most often used DEA models. Among them are the following:

- Standard radial models with constant, variable, non-decreasing or non-increasing returns to scale with input or output orientation (see the mathematical formulation at the beginning of this section];

- Additive models often denoted as SBM models. This group of models measures the efficiency by means of slack variables only;

- Models with uncontrollable inputs or outputs. In many applications some of the inputs or outputs cannot be directly controlled by the decision maker. In this case the uncontrollable characteristics have to be fixed;

- Models with undesirable inputs or outputs. In typical cases inputs are to be minimised and outputs are to be maximised in DEA models, i.e. the lower value of inputs and higher value of outputs lead to higher efficiency score. It is not difficult to formulate problem where some of the inputs and outputs will be of reverse nature. Such characteristics are denoted as undesirable inputs or outputs. The models with undesirable characteristics are included in the DEA Excel Solver too.

Most of the mentioned models can be extended by super-efficiency option. This option allows discriminate among efficient units that reach 100% efficiency score in standard DEA models.

The brief output information sheet for our example is presented on Figure 3. This sheet contains the following information:

- specification of the DEA model used in the analysis (CRS_I is input oriented model with constant returns to scale);
- DMU labels and the efficiency scores computed by the model (the efficient units are marked by red colour);
- values of virtual inputs and outputs (target values for reaching the efficient frontier);
- non-zero weights of the units (their linear combination of units using these weights gives the virtual inputs and outputs).

In addition to this information, the detailed output sheet contains the optimum values of slack and surplus variables and original values of inputs and outputs.

Figure 3 Output information sheet

SANNA – a spreadsheet based tool for solving MCDM problems

Sanna is an Excel based system for multiple criteria evaluation of alternatives. The problem solved by *Sanna* can be formulated by criterion matrix very easily as follows:

$$\begin{array}{cccc} & Y_1 & Y_2 & \ldots & Y_k \end{array}$$
$$\begin{array}{c} X_1 \\ X_2 \\ \vdots \\ X_n \end{array} \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1k} \\ y_{21} & y_{22} & \cdots & y_{2k} \\ \vdots & & \ddots & \vdots \\ y_{n1} & y_{n2} & \cdots & y_{nk} \end{bmatrix}$$

where $X_1, X_2,\ldots, X_n$ are alternatives, $Y_1, Y_2,\ldots, Y_k$ are criteria and y_{ij}, $i = 1,2,\ldots n$, $j = 1,2,\ldots k$, are criterion values. The aim of the analysis is to find the "best" (compromise) alternative or rank the alternatives. In the previous section several more or less professional software products for DEA models are mentioned. The situation is different with software products for multicriteria decision making support. There are several systems available, covering isolated methods, e.g. Expert Choice (www.expertchoice.com) for AHP models, D-SIGHT (www. promethee-gaia.com) for PROMETHEE class methods, etc. *Sanna* system described below is a system covering several most often used multicriteria decision methods and there are even other attempts to create similar systems in the Czech Republic (e.g. [5]), *Sanna* remains the most popular one, with many hundreds of downloads.

Sanna is a standard ms excel add-in application. The system consists of five basic modules plus simple help tool (each module corresponds to one item of *sanna* menu):

1. *Data management module.*

Sanna works with standard .xlsx files. Data management module either opens a new data sheet (if it does not already exists) based on the specification of the basic parameters of the problem (the number of alternatives and criteria), or deals with the current data sheet. The basic functions for dealing with the current data set cover adding the new alternative or criteria or removing the alternative or criteria.

2. *Non-dominance filter.*

This module makes it possible to test the non-dominance of alternatives in the current data set. The alternatives are marked according to the results of the test as dominated or non-dominated. Another feature of the module is the possibility to remove the dominated alternatives from the data set. Removing dominated alternatives is non-reversible.

3. *Estimation of weights module.*

The decision maker can specify the weights of the criteria either directly by their setting in the data sheet or by means of three simple well-known methods supported by estimation of weights module. The decision maker can use the following techniques:

- scale method (weights are set in any numerical scale and normalised);
- Fuller's method (based on paired comparisons of the criteria and selection one of the following: one of the criteria is more important or both the criteria are equally important);
- AHP (based on the standard Saaty's scale) – uses either eigenvector calculation or logarithmic least square method (approximation of the eigenvector); the consistence of the comparison matrix is checked.

The estimation weights module contains functions for moving weights calculated by above mentioned methods into the data sheet and their graphical representation.

4. *Methods for multi-criteria evaluation of alternatives.*

The current version of the *Sanna* system supports several basic methods for multi-criteria evaluation of alternatives (WSA, TOPSIS, ELECTRE I and III, PROMETHEE I and II, MAPPAC and ORESTE). All the methods need the knowledge of the weights of criteria. ELECTRE and PROMETHEE class methods require specification of some additional parameters. The following overview provides very brief information about available methods:

WSA

The WSA method is based on linear utility function. This method computes the global utility of the alternatives as the weighted sum of normalised criterion values. The method provides complete ranking of alternatives according to their global utilities.

TOPSIS

The TOPSIS method is based on the computation of global utilities of alternatives according to their relation to the ideal criterion values and distance from the nadir criterion values. The TOPSIS method provides complete ranking of alternatives according to their global utilities.

ELECTRE I and III

The basic output of the ELECTRE I method is the split of the set of alternatives into two disjoint subsets of efficient and inefficient alternatives. Except the criterion matrix and weights of the criteria the user must specify a concordance and discordance thresholds. The extension of ELECTRE I method is ELECTRE III which offers to users complete ranking of alternatives.

PROMETHEE I and II

The PROMETHEE methods require the knowledge of criterion matrix, weights of the criteria and preference functions of criteria with their parameters for measuring the strength of the preference of the pairs of alternatives with respect to the given criterion. PROMETHEE I method provides partial ranking of alternatives, while PROMETHEE II method offers complete ranking according to the net flow values.

MAPPAC

The MAPPAC method works with the criterion matrix and weights of the criteria only. The method splits the alternatives into several preference groups. The evaluation of alternatives by this method can be very long for problems with a high number of alternatives compared to other supported approaches.

ORESTE

The ORESTE method uses ordinal information for ranking alternatives based on several parameters and thresholds.

5. *Report wizard.*

The successfully completed evaluation by any of the methods adds a new sheet into the active worksheet, with basic information about the results. With report wizard, the user of the application can build his/her own output sheet with the results in the user-defined form. The user selects required items for the report from the set of items associated to the current method (including simple graph presentations of results).

The application can solve multi-criteria decision problems with maximum 100 alternatives and 50 evaluation criteria. Figure 4 presents an illustrative example with 6 alternatives and 6 criteria including the menu of the application. Working with *Sanna* is very simple and the interested user can analyse quite large problems by several methods in very short time. In the future, the application will be extended by other methods and by a module for comparison of results obtained by several different methods.
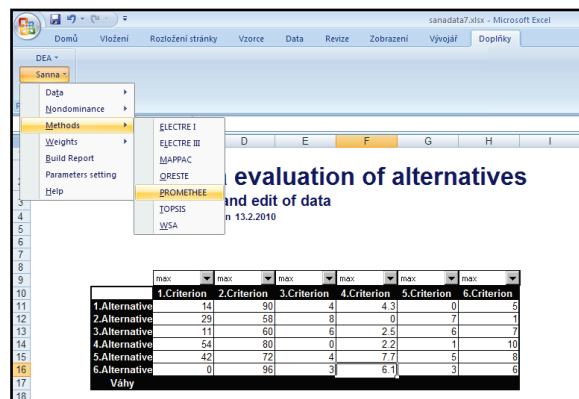

Figure 4   *Sanna* – data sheet

Conclusions

Spreadsheets are powerful and popular software products that can be used for solving problems of mathematical modelling and optimisation. The paper presented two original MS Excel add-in applications for solving DEA models on one side, and multiple criteria evaluation of alternatives on the other. The *DEA Excel solver* allows solving problems of evaluation of efficiency by means of standard DEA models of the size up to 200 decision making units and 20 inputs and outputs. The second application is *Sanna,* which analyses

problems of multiple criteria evaluation of alternatives (100 alternatives is maximum). Both applications are written in VBA, are user-friendly, controlled by pull down menus and dialog windows, and do not suppose any other software tools installed (except MS Excel including MS Excel solver needed for DEA Solver). The user-friendliness of both applications is an important feature that allows their wide using in real-world cases. The hundreds of downloads and many positive feedbacks prove the applications are well accepted by teachers, students and other professionals. The applications can be downloaded on the web page http://nb.vse.cz/~jablon/.

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