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MS Excel based software support tools for decision problems with multiple criteria

Josef Jablonsky*

University of Economics, Prague, W. Churchill Sq. 4, 13067 Praha 3, Czech Republic

Abstract

Decision making in real practice is usually connected with multiple criteria. Multiple criteria decision making (MCDM) and data envelopment analysis models, even they solve different problem classes, belong to the most often used modeling techniques in this field. Their wider using is often limited by availability of appropriate software tools. The paper presents two freeware software systems that are available for downloading on the author's web pages. The first system is *DEA Excel Solver* and the second one is *Sanna* – application for multi-criteria evaluation of alternatives. *DEA Excel Solver* covers 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. *Sanna* is a simple MS Excel based application for multi-criteria evaluation of alternatives using several important MCDM methods (WSA, ELECTRE I and III, ORESTE, PROMETHEE, TOPSIS, and MAPPAC).

1. Introduction

Spreadsheets belong among software products with wide possible applications. Unfortunately, their properties are used in everyday practice usually only for working with tables, simple recalculations by means of standard mathematical operators and functions, etc. Spreadsheets have much wider usage – they contain tools for financial

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* Corresponding author. Tel.: +420-224-095-403; fax: +420-224-095-423.
  E-mail address: jablon@vse.cz

decisions, statistical analyses, working with databases, graphical representation of data and finally for optimisation and mathematical modelling. This paper is focused on information about software applications for solving one important class of decision making problems – problems with multiple criteria.

The paper aims at two groups of models of the mentioned class. First of them is data envelopment analysis (DEA) that belongs among one of the modelling tools that deals with multiple criteria. This group of models is used as a tool for evaluation of efficiency, productivity and performance of decision making units (DMUs). They are based on solving linear programming optimization problems. The second group of problems discussed in this paper covers multiple criteria decision making (MCDM) problems (multi-criteria evaluation of alternatives). MCDM problems are very simple to understand even for non-expert decision makers and that is why they can find very frequent usage in practice.

MS Excel can be used for solving decision problems of two mentioned groups in several ways. The following three ones can be emphasized:

1. A conventional way that is characterized 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 supposes some more advanced experience in using add-ins and other tools.
2. Linking spreadsheets with modelling languages as *LINGO*, *MPL for Windows*, *GAMS* and others. The advantage of this approach consists in 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 other programming tools. This way is the most difficult and requires a certain level of programming skills but allows building end-user applications for a wide group of problems. *DEA Excel Solver* and *Sanna* that are further introduced in this paper are applications that were built using VBA.

The paper is organized as follows. Section II contains basic information and formulation of DEA models and MCDM problems. Section III informs how to solve DEA and/or MCDM problems by using our original end-user applications *DEA Excel Solver* for DEA models and *Sanna* for MCDM problems or better expressed for multicriteria evaluation of alternatives. Final part of the paper summarizes the results and discusses possibilities how to extend and improve current versions of the applications.

2. Theoretical background

DEA is a tool for evaluation and measuring the relative efficiency of a set of DMUs that consume multiple inputs and produce multiple outputs. Efficiency score that is one of the main information given by DEA models reflects efficiency of transformation of multiple inputs into multiple outputs. Fundamentals of DEA models were formulated by Charnes et al. (1978) and since 80's of the last century DEA models become one of the main modelling tool for efficiency analysis.

Let us suppose that the set of DMUs contains n elements. The DMUs are evaluated by m inputs and r outputs with inputs and outputs values x_{ij}, $i = 1, 2, \ldots, m$, $j = 1, 2, \ldots, n$ and y_{kj}, $k = 1, 2, \ldots, r$, $j = 1, 2, \ldots, n$, respectively. The efficiency of the DMU_q can be expressed as the weighted sum of outputs divided by the weighted sum of inputs with weights reflecting the importance of particular inputs/outputs v_i, $i = 1, 2, \ldots, m$ and u_k, $k = 1, 2, \ldots, r$ as follows:

$$\theta_q = \frac{\sum_{k=1}^{r} u_k y_{kq}}{\sum_{i=1}^{m} v_i x_{iq}}. \tag{1}$$

Conventional CCR output oriented DEA model consists in maximization of efficiency score of the DMU_q subject to constraints that efficiency scores of all other DMUs are lower or equal than 1. The linearized form of this model is as follows:

minimize

$$\theta_q = \sum_{i=1}^{m} v_i x_{iq},$$

subject to (2)

$$\sum_{k=1}^{r} u_k y_{kq} = 1,$$

$$\sum_{k=1}^{r} u_k y_{kj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0, \qquad j = 1,2,...,n,$$

$$u_k, v_i \geq \varepsilon, \qquad k = 1,2,...,r, i = 1,2,...,m,$$

where ε is a non-Archimedean constant that ensures positive weights u_k and v_i. If the optimal value of model (1) $\theta_q^* = 1$ then the DMU$_q$ is CCR efficient and it is lying on the CCR efficient frontier. $\theta_q^* > 1$ shows that the DMU$_q$ is not CCR efficient – higher value indicates lower efficiency. This measure is often presented as its reciprocal value, i.e. $1/\theta_q^*$, which is more understandable for decision makers – the higher value is assigned to more efficient units in this case.

Model (2) is often referenced as primal CCR output oriented model. Its dual form is sometimes more convenient from computational points of view and its mathematical model is as follows:

maximize

$$\theta_q + \varepsilon \left(\sum_{i=1}^{m} s_i^- + \sum_{k=1}^{r} s_k^+ \right),$$

subject to (3)

$$\sum_{j=1}^{n} x_{ij} \lambda_j + s_i^- = x_{iq}, \qquad i = 1,2,...,m,$$

$$\sum_{j=1}^{n} y_{kj} \lambda_j - s_k^+ = \theta_q y_{kq}, \qquad k = 1,2,...,r,$$

$$\lambda_j \geq 0, \qquad j = 1,2,...,n,$$

where $\lambda_j, j = 1, 2, …, n$ are weights of DMUs, $s_i^-, i = 1, 2, …, m$, and $s_k^+, k = 1, 2, …, r$ are slack (surplus) variables and θ_q is the efficiency score of the DMU$_q$ that expresses the improvement rate of outputs in order this unit reaches the efficient frontier. Model (3) is usually solved in two phases. The first phase consists in maximization the efficiency score θ_q. If the optimal value $\theta_q^* > 1$ then the evaluated unit is not efficient and the second phase is not necessary. Otherwise, the second phase maximizes the sum of all slack and surplus variables s_i^- and s_k^+ with keeping the optimal value of θ_q from the first phase. The unit DMU$_q$ is efficient when $\theta_q^* = 1$ and all slack (surplus) variables are zero.

Models (2) and (3) are output oriented DEA models, i.e. they for inefficient units propose how to increase the outputs in order to reach the efficient frontier and the efficiency score $\theta_q^* > 1$ expresses the rate of this increasing. In the similar way it is possible to formulate input oriented DEA models where the efficiency score $\theta_q^* < 1$ expresses the rate for reduction of inputs in order the DMU under evaluation becomes efficient – see e.g. Cooper et al. (2000) or Zhu (2003).

Models (2) and (3) assume constant returns to scale (CRS). In model (3) it is ensured by no restrictions (except non-negativity) for lambda variables. By considering their unit sum the model changes into the models with variable returns to scale (VRS). Sum of lambdas greater (lower) than 1 leads to models with non-increasing (non-decreasing) returns to scale.

Envelopment models (2) or (3) split DMUs into two categories – efficient with efficiency score 1 and inefficient with efficiency score greater than 1 (in output oriented models). In order to rank all DMUs a class of so called super-

efficiency models was developed. They assign to efficient units efficiency scores lower than 1 which allows their ranking. First model of this class was formulated in Anderen and Petersen (1993).

More information about DEA models including super-efficiency models can be found in books Cooper et al. (2000) or Zhu (2003). They contain not only formulation of standard DEA models formulated above but except them they discuss how to rank DMUs, how to deal with undesirable outputs, uncontrollable inputs and outputs, etc. Some of them are covered by the application described in the next section of the paper.

MCDM problems deal with analysis of the set of alternatives using several criteria with objective to choose a "best" (compromise) alternative, rank alternatives or split them into several disjoint sets (we do not consider MCDM problems where the set of alternatives is given by general constraints as e.g. in linear programming problems). This problem can be formulated by criterion matrix very easily as follows:

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

The criterion values y_{ij}, $i = 1,2, \dots, n$, $j = 1,2,\dots, k$, must usually be given as numerical values and most of the MCDM methods suppose that numerical expression of criteria importance (weights of the criteria) is known. The weights of criteria are given as positive values v_j, $j = 1, 2, \dots, k$. They can be entered directly by decision maker or estimated by one of the available support techniques.

Many methods were proposed in the past in order to solve MCDM problems as formulated above. Main methodological principles used in these methods are application of utility functions (WSA, MAUT, AHP), and outranking methods (ELECTRE and PROMETHEE class methods, ORESTE, MAPPAC, etc.). A nice survey of MCDM theory and methods can be found in Ishizaka and Nemery (2013).

3. Software tools for DEA and MCDM models

This section contains a brief introduction of two original software tools written using VBA (Visual Basic for Applications) in MS Excel environment. They can be easily used for most of the decision problem of the mentioned two classes – DEA models and multi-criteria evaluation of alternatives.

3.1. DEA Excel Solver

DEA Excel Solver is a simple support tool that uses the internal MS Excel optimization solver for solving several basic DEA models. Its first version was described in Jablonsky (2005) and now the current version is available for MS Excel 2013. The size of problems that can be solved using this application is limited by capacity of MS Excel solver − maximum number of evaluated units is 200 and the number of inputs and outputs together cannot exceed 30.

Input data set for DEA analysis can be prepared in any sheet of MS Excel file according to decision maker's preferences. Decision making units must be organized in rows and the inputs/outputs in columns of the sheet. At first the decision maker must choose a DEA model that will be used for the analysis. The application supports the following models:

- Conventional radial models with constant, variable, non-decreasing or non-increasing returns to scale with input or output orientation.
- Additive models often referenced as SBM models. This group of models measures the efficiency by means of slack/surplus variables only.
- Models with uncontrollable inputs or outputs. In many applications some of the inputs or outputs cannot be directly controlled by 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 minimized and outputs are to be maximised, i.e. the lower values of inputs and higher values of outputs lead to higher efficiency score of the unit

under evaluation. In many cases the inputs and outputs can be of a reverse nature. Such characteristics are denoted as undesirable inputs and/or outputs. The models with undesirable characteristics are included in our application too.

After the selection of the model the main dialog window of the application appears. For radial models it is presented in Fig. 1. The decision maker must specify:

- DMU's labels – a range with names of the units (not obligatory – in case it is not specified the application assigns default names DMU1, DMU2, etc.).
- Inputs/outputs labels – ranges with names of inputs and outputs (not obligatory – in case it is not specified the application assigns default names INP1, INP2,... or OUT1, OUT2...).
- Matrix of inputs and outputs – two continuous ranges containing the matrix of inputs and the matrix of 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 check box for selection of super-efficiency option. This option is available for radial models only and thesuper-efficiency is measured by means of Andersen and Petersen model.
- Optimisation in two steps – a check box that determines whether the optimisation is realized in one or two steps (the first step is the optimisation of the efficiency score θ_q and the second one is the maximisation of slack and surplus variables).
- Detailed/brief output of results – two check boxes that allow selection of a form of output information given by the application (detailed or short output).

Fig. 1. DEA Excel solver – dialog window.

The results of the analysis are organized into the MS Excel sheet and contain all necessary information for further analysis:

- Information about the DEA model used, e.g. CRS_I is the input oriented DEA model with constant returns to scale.
- The efficiency scores for all DMUs. The efficient units are highlighted in red colour.
- Values of virtual inputs and outputs, i.e. target values how to improve the inputs/outputs for inefficient units.
- Non-zero weights of the units – lambda variables in model (3).
- The optimal values of slack and surplus variables – see model (3).

3.2. Sanna application

Sanna is a standard MS Excel add-in application that consists of five basic modules (each module corresponds to one item of Sanna menu):

a. *Data management module*

Sanna works with standard MS Excel (*.xlsx) files. Data management module either opens a new data sheet (if it does not already exist) based on specification of 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 allow adding a new alternative or criterion or removing an alternative or criterion.

b. *Non-dominance filter*

This option makes it possible to test the non-dominance of alternatives in the current data set. The alternatives are highlighted according to the results of the test as dominated or non-dominated. Another feature of this option is the possibility to remove the dominated alternatives from the data set but the removal of dominated alternatives is non-reversible.

c. *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 normalized),
- Fuller's method (based on pairwise comparisons of the criteria; the decision maker must specify whether one criterion is more important than the second one or both of them are equally important,
- AHP (based on Saaty's scale) – uses either eigenvector calculation or logarithmic least square method. The consistency of the comparison matrix is tested.

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

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

The current version of 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 these methods need the knowledge of weights of criteria. ELECTRE and PROMETHEE class methods further require a specification of some additional parameters. The following survey brings very brief information about available methods:

WSA

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

TOPSIS

TOPSIS method is based on the computation of global utilities of alternatives according to their distance from ideal and basal alternatives. TOPSIS gives complete ranking of alternatives according to their global utilities.

ELECTRE I and III

ELECTRE I methods splits the set of alternatives into two disjoint subsets containing efficient and inefficient alternatives. Except the criterion matrix and the weights of the criteria the decision maker must specify the concordance and discordance thresholds. The extension of ELECTRE I method is ELECTRE III that offers complete ranking of alternatives.

PROMETHEE I and II

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

MAPPAC

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 using this method can take a quite long time (comparing to other supported approaches) for problems with a high number of alternatives.

ORESTE

ORESTE method uses ordinal information for ranking of alternatives. It is based on several parameters and thresholds.

More information about selected methods for solving MCDM problems can be found e.g. in Ishizaka and Nemery (2013).

e. Report wizard

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

Sanna can solve MCDM problems with up to 200 alternatives and 50 criteria. Using Sanna is a simple task and decision makers can analyse quite large problems by various methods in a very short time. In the future Sanna will be extended by other MCDM methods and by the module for comparison of results given by different methods.

4. Conclusions

Spreadsheets are powerful and popular software products that can be used not only for simple re-calculations of source data but they can deal as powerful tools for solving problems of mathematical modelling and optimization. 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 side. *DEA Excel Solver* is the application that allows solving problems of evaluation the efficiency by means of standard DEA models of the size up to 200 decision making units and 30 inputs and outputs. The second application is *Sanna* that allows to analyze problems of multiple criteria evaluation of alternatives (200 alternatives is maximum). Both applications are written in VBA, they 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 Excel Solver*). They can be downloaded for free from download section of the web page http://nb.vse.cz/~jablon and used by any interested professionals.

Both applications described in previous sections of the paper seem to be very useful tools for analysis of real/world problems as well as for teaching purposes. DEA models find their applications in analysis of efficiency in public sector (health care, education, regional comparisons and analyses), performance analyses within financial institutions (bank branches, insurance companies), and many other public or private areas. Application of DEA models requires a certain (higher) level of professional experiences. In the contrary, MCDM models can be applied very easily and their application supposes only introductory knowledge. That is why *Sanna* is an ideal tool for almost anybody (students, researchers, analysts, and practitioners). *DEA Excel Solver* is mostly for researchers and analysts that are more or less familiar with this class of models.

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