MODELS FOR EFFICIENCY EVALUATION IN EDUCATION

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Outline

• Introduction
• Modelling tools for efficiency evaluation – DEA, MCDM
• Review of DEA applications in education
• Resource allocation among university departments
• Software support for DEA and MCDM models
• Conclusions
Evaluation of efficiency in education is an important task which is widely discussed by many researchers. Performance and efficiency evaluation of the set of homogenous decision making units in education, i.e. primary, secondary schools, faculties of the same subject, universities, university departments, etc., can significantly contribute to the improvement of educational system within the given region. Due to continuing discussion about changes in educational system in the Czech Republic (especially in higher education) modelling in this field is of a high importance.
The aim of the presentation is:

• To give a short review of data envelopment analysis (DEA) and multiple criteria decision making (MCDM) applications in education. It is focused especially on evaluation of relative teaching and research efficiency of universities, university departments, and study programmes.
• To present an original procedure for evaluation of university departments and resource allocation based on comparison of their teaching and research performance.
• To inform about software support for DEA and MCDM models developed at the University of Economics Prague.
Modelling tools for efficiency evaluation

1. Data Envelopment Analysis (DEA) measures relative efficiency of a set of alternatives (decision making units - DMUs) that consume multiple inputs and produce multiple outputs. Basics of DEA models were formulated by Charnes, Cooper and Rhodes (1978) and since 80’s of the last century DEA models become one of the main modelling tool for efficiency analysis.

2. Multiple Criteria Decision Making (MCDM) methods were developed mainly in 70’s and 80’s of the last century. They can be used for multicriteria comparison of alternatives, selection of the „best“ alternative, ranking of alternatives, etc and that is why can be applied in problems of efficiency evaluation in education.
Data envelopment analysis

- **Decision making units** – $U_1, U_2, \ldots, U_n$
- **Inputs** (resources) – $X = \{x_{ij}, i=1,2,\ldots,m, j=1,2,\ldots,n\}$
- **Outputs** (effects) – $Y = \{y_{ij}, i=1,2,\ldots,r, j=1,2,\ldots,n\}$

- **Measure of efficiency** – $\text{outputs}/\text{inputs}$
DEA – Data envelopment analysis

output

y'

y

U'

U''

U1

efficient frontier

production possibility set

U2

U3

U6

U4

U8

U5

U7

0

x'

x

input
CCR (Charnes, Cooper, Rhodes) model

constant returns to scale (conic frontier)

maximise

\[ \sum_i u_i y_{iq} \]

subject to

\[ \frac{\sum_j v_j x_{jq}}{\sum_j v_j x_{jk}} \leq 1, \]

\[ k = 1, 2, \ldots, n, \]

\[ u_i \geq \varepsilon, v_j \geq \varepsilon. \]
CCR (Charnes, Cooper, Rhodes) model

Primal model: 

minimise \( z = v^T x^q \) 
subject to 
\( u^T y^q = 1 \) , 
\( u^T Y - v^T X \leq 0 \) , 
\( u \geq \varepsilon, v \geq \varepsilon \).

Dual model: 

max \( f = \theta + \varepsilon (e^T s^+ + e^T s^-) \) , 
s.t. 
\( Y \lambda - s^+ = \theta y^q \), 
\( X \lambda + s^- = x^q \), 
\( \lambda, s^+, s^- \geq 0 \).

\( U_q \) is efficient:
1. Radial scalar variable \( \theta = 1 \),
2. All the slack variables \( s^+ \) and \( s^- \) equal to 0.

Virtual unit (target values of inputs and outputs):
\( x^{\prime q} = X \lambda^* \),
\( y^{\prime q} = Y \lambda^* \), where \( \lambda^* \) are optimal values of variables of dual model.
BCC (Banker, Charnes, Cooper) model
variable returns to scale (convex frontier)

maximise

\[ g = \theta + \varepsilon (e^T s^+ + e^T s^-) , \]

subject to

\[ Y\lambda - s^+ = \theta y^q , \]
\[ X\lambda + s^- = x^q , \]
\[ e^T \lambda = 1 , \]
\[ \lambda, s^+, s^- \geq 0. \]
Basic DEA models

\[
\begin{align*}
\text{min} & \quad z = \theta - \varepsilon \left( \sum_{i=1}^{m} s_i^- + \sum_{i=1}^{r} s_i^+ \right) \\
\text{max} & \quad g = \phi + \varepsilon \left( \sum_{i=1}^{m} s_i^- + \sum_{i=1}^{r} s_i^+ \right) \\
\text{st} & \quad \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta x_{iq} \\
\text{st} & \quad \sum_{j=1}^{n} \lambda_j y_{ij} - s_i^+ = y_{iq} \\
\text{CRS} & \quad \sum_{j=1}^{n} \lambda_j = \text{free}, \\
\text{VRS} & \quad \sum_{j=1}^{n} \lambda_j = 1, \\
\text{NDRS} & \quad \sum_{j=1}^{n} \lambda_j < 1 \\
\text{NIRS} & \quad \sum_{j=1}^{n} \lambda_j > 1
\end{align*}
\]
maximise
\[ z = \theta + \varepsilon(e^T s^+ + e^T s^-) , \]
subject to
\[ Y\lambda - s^+ = \theta y^q , \]
\[ X\lambda + s^- = x^q , \]
\[ (e^T \lambda = 1) , \]
\[ \lambda, s^+, s^- \geq 0. \]
Multicriteria evaluation of alternatives

\[
\begin{bmatrix}
X_1 & y_{11} & y_{12} & \cdots & y_{1k} \\
X_2 & y_{21} & y_{22} & \cdots & y_{2k} \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
X_n & y_{n1} & y_{n2} & \cdots & y_{nk}
\end{bmatrix}
\]

\[w = (w_1, w_2, \ldots, w_k)\]
MCDM methods

- **WSA** evaluates the alternatives by values of their utility functions which are supposed to be linear in this case – only information about the weights of criteria are required.
- **TOPSIS** is based on minimization the distance from the ideal alternative and maximization from the basal alternative - only information about the weights of criteria are required.
- **ELECTRE I, III** decides whether the alternative is efficient or not - information about the weights of criteria and preference and dispreference thresholds are required.
- **PROMETHEE I and II** uses preference functions to express the intensity of preference for each pair of alternatives and for each criterion. The decision maker can choose among six types of intensity preference functions for each criterion; except this the weights of criteria are required.

The paper presents an extensive survey of frontier efficiency applications in education from 1981 until 1998. This survey contains information about approx. 30 studies of different nature and motivation. The applications in this survey aim at evaluation of school districts, local educational authorities, elementary and secondary schools, efficiency of study programmes, university departments, etc. Main motivation for the studies is ranking of the DMUs, identification of inefficiencies, allocation of resources among DMUs, analysis of educational systems within the given region, etc. There are used various inputs and outputs depending on the nature of the studies. Among the inputs are often teaching and non-teaching expenditures, teaching salaries, number of staffs, operational costs in different structures, structure of students (pupils), and the outputs are measured by the level of successfulness of students (test scores, grades, etc.).

The authors aim in their study at evaluation of research efficiency and performance of 36 economic departments of UK universities in five year period since 1984. This study uses many DEA runs with different combinations of input and output characteristics. Staffs that perform both teaching and research functions, that perform research functions only and the number of grants per capita are considered as the main inputs. The outputs are measured by the number of publications of different types (papers in academic journals, professional journals, popular journals, authored books, edited books, published official reports and contributions to edited works). The study results in ranking of the departments.

Beasley (1995) evaluates both teaching and research efficiency of chemistry and physics departments of 52 UK universities. He formulates an original joint DEA model with weight restrictions which combines teaching and research efficiency. General expenditures (majority are staff salaries), equipment expenditures and research income are the inputs in this study, and number of undergraduates, number of taught postgraduates, number of research postgraduates, research income and research rating of the department (A++, A+, A, A–) are the main outputs. The key point of the presented model is a non-linear approach for apportioning resources between teaching and research. This study aims with physics and chemistry departments but the model can be used without any changes for economic or other departments.
This paper presents a methodology for efficiency assessment and allocation of resources among university departments and applies it to one of the departments of the University of Warwick. Departments are firstly evaluated against those of the same discipline in other universities to ensure comparability. Then the performance from the first phase is compared to the other departments of the same university. The methodology proposed enables the university authorities to allocate resources among departments and enhance its performance as a whole. A different approach will be presented further in our study.

Martin (2006) studies technical teaching and research efficiency and performance of 52 departments of the University of Zaragoza (Spain). The problem of this study consists in an attempt to compare all departments in very different scientific fields. He runs four DEA models with always the same set of inputs (academic and research personal – doctors and non-doctors, budgetary assignment, material resources (annual pay-off rate). The set of outputs was slightly modified in particular runs – they are credits registered by students, PhD credits offered by the department, PhD theses per year, research activity incomes and research activity compute. Main conclusion of the study consists in differentiation among departments of particular scientific fields.

The study uses output oriented DEA models for efficiency analysis of educational systems in 31 world, mainly European, countries. The two outputs considered in the study are academic performance in mathematics and in the sciences. The inputs include short-term controllable variables (intensity of teaching resource, index of facility availability and index of material consumption), long-term controllable variables (quality of teaching staff) and contextual variables reflecting economic situation of the countries (family income level, availability of resources at home, etc.). The study shows good results of former Communist countries among the other ones included in the study.
Review of DEA applications (7)


The aim of the study (Thanassoulis et al., 2011) is to investigate the structure of costs in the UK higher education in the period 2000/2001–2002/2003 in light of the fact that the UK government at the time wanted to increase substantially the number of students attending university. This extensive study is based on 363 observations and uses one input (total operation costs including depreciation). The outputs considered measure the number of undergraduate and postgraduate students, quality related funding and research grants, and income from other services.
Kuah and Wong (2011) analyse technical teaching and research efficiency of 30 universities. Unfortunately the study is not based on the set of real data but on hypothetical data only. There are formulated two DEA models separately for teaching and research efficiency. The model for teaching efficiency contains four inputs (total university expenditures, number of academic staffs, number of taught course students and average qualification of students) and four outputs (graduation rate, graduate’s employment rate, number of graduates from courses and average graduate’s results). The model for research efficiency takes into account research staffs, research grants, expenditures, and number of research students as inputs, and quality and quantity of research as outputs. Except two particular efficiency measures a model for overall efficiency is proposed.
Measuring of research performance by $h$-index


A scientist has index $h$ if $h$ of his/her $N$ papers have at least $h$ citations each and the other ($N - h$) papers have no more than $h$ citations each.

An interesting analysis of research contribution of academics is presented by Mingers (2009). It is not a DEA application but this paper deals with applicability and improvement of Hirsch-index ($h$-index), discusses their advantages and disadvantages. The common version of $h$-index measures the intensity of research contribution of academics by citations of their research outputs. The author compares $h$-index with which similar other indices defined by several authors (g-index, hc-index and h-rate). All definitions are compared on a set of real data.
Let us suppose that each department is described by three output characteristics of the last planning period:

- re-calculated direct teaching hours,
- indirect teaching (exams, theses, etc.), and
- research measured in publication points.

Only input is amount of allocated resources to the department. The aim of the model is find the amount of resources that ensure the maximum efficiency of all units. Of course the sum of resources allocated to departments is fixed.

The basic idea for application of DEA models for allocation of resources consists in modification of the input in order all the units will be efficient after this modification.
Allocation of resources among departments - a DEA model (2)

minimize

\[ \sum_{j=1}^{n} \frac{(\alpha_j + \beta_j)}{x_j} \]

subject to

\[ \sum_{j=1}^{n} y_{kj} \lambda_{qj} = y_{kq}, \quad k = 1,2,3, \quad q = 1,2,...,n, \]

\[ \sum_{j=1}^{n} (x_j - \alpha_j) \lambda_{qj} = x_q - \alpha_q, \quad q \in U_n, \]

\[ \sum_{j=1}^{n} (x_j + \beta_j) \lambda_{qj} = x_q + \beta_q, \quad q \in U_e, \]

\[ \lambda_{qj} \geq 0, \quad \alpha_j \geq 0, \quad \beta_j \geq 0, \]
Due to the computational problems with solving of the DEA model a simple iteration procedure that can be described in the following steps is proposed:

1. The efficiency score for inefficient units and super-efficiency score for efficient ones $\theta_j^*, j = 1, 2, ..., n$, is computed by solving the problem (3). It is either lower than 1 for inefficient units or greater than 1 for efficient ones in input oriented models.

2. The $\theta_j^*$ value is used as a rate for increasing/reducing the input of the unit DMU$_j$. All inputs are proportionally modified in order to keep the original budget.

3. Original inputs are replaced by the modified ones and efficiency (super-efficiency) scores are computed again.

4. The steps 2 and 3 are repeated until the limit set of inputs is reached.
### Allocation of resources among departments - an example (4)

\[ \sum_{j=1}^{n} (\alpha_j + \beta_j) / x_j \]

<table>
<thead>
<tr>
<th>Dept.</th>
<th>Resources [thous. CZK]</th>
<th>Direct [hours.]</th>
<th>Indirect [hours]</th>
<th>Research [points]</th>
<th>( \theta*_{q} )</th>
<th>Modif. res. step 1</th>
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<td>\textbf{25000}</td>
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</table>
Allocation of resources among departments - results (5)

\[ \sum_{j=1}^{n} (\alpha_j + \beta_j) x_j \]

<table>
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<tr>
<th>Dept.</th>
<th>Resources final step</th>
<th>MCDM</th>
<th>Deviation [%]</th>
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<td>1200</td>
<td>808</td>
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<td>D5</td>
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<td>2907</td>
<td>-26.65</td>
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<tr>
<td>Sum</td>
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<td>25000</td>
<td>xxx</td>
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</table>
Software support - MS Excel DEA solver (1)

- the application uses internal MS Excel solver; that is why it can be used on any computer with MS Excel,
- very simple and user-friendly environment,
- 250 DMUs, 20 inputs and 20 outputs,

Covers the following groups of models:
- envelopment models with constant, variable, non-decreasing and non-increasing returns to scale including super-efficiency option,
- additive models (slack based models),
- models with uncontrollable inputs and outputs, and
- models with undesirable inputs and outputs.
Software support - MS Excel DEA solver (2)
### DEA Excel Solver (4)

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<th>B</th>
<th>C</th>
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<th>G</th>
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### DEA Excel Solver – results (5)

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<th>B</th>
<th>C</th>
<th>D</th>
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<td>Virtual inputs Assets</td>
<td>Virtual inputs Equity</td>
<td>Virtual inputs Employees</td>
<td>Virtual outputs Revenue</td>
<td>Virtual outputs Profit</td>
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Software support MCDM – Sanna (1)

- Up to 100 alternatives by 40 criteria,
- Enables to solve MCDM problems by means one of the 7 different methods:
  - WSA
  - TOPSIS
  - ELECTRE I and III
  - ORESTE
  - PROMETHEE I and II
  - MAPPAC
- Support for estimation of weights (Saaty, Fuller)
- Non-dominance filters.
Multicriteria evaluation software
input/edit of the data set
date 27.6.2000

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Weights: 0.07000, 0.24000, 0.33000, 0.19000, 0.09000, 0.08000
Conclusions

- Education belongs among the most often applied fields in evaluation of efficiency using DEA and MCDM models – number of more or less cited papers in OR and other journals is huge.
- The aim of this paper was to inform about past and current main directions in evaluation of efficiency especially in higher education.
- An additional aim of the paper was to contribute to more information and wider extension of DEA methodology in efficiency and performance evaluation in education in the CR.
- The original contribution is a procedure for allocation of resources among university departments based on their teaching and research performance.
- DEA methodology seems to be an suitable tool for efficiency analysis (not only) in education.
- A simple MS Excel software tools for DEA and MCDM models can be downloaded from http://nb.vse.cz/~jablon.