DOI: 10.18515/dBEM.M2012.n01.ch25

Tamás Koltai, Judit Uzonyi-Kecskés

3.11 DATA ENVELOPMENT ANALYSIS AND ITS APPLICATION FOR MEASURING THE PERFORMANCE OF STUDENTS IN A PRODUCTION SIMULATION GAME

Summary: The paper presents a solution for the evaluation of student groups in a production simulation game when decisions have to be made in several consecutive periods. The result of the game is influenced by the utilization of several resource types and there is no any unique measure of performance. The traditional ratio based evaluation fails to capture several aspects of the utilization of the available possibilities in the decision making process.
Data Envelopment Analysis (DEA) is used to evaluate the utilization of several inputs for the generation of outputs in any type of production or service systems. DEA evaluates the efficiency of decision making units based on the ratio of weighted input and weighted output using linear programing. In the presented case a constant return to scale, input oriented, two- phase DEA model is used for the evaluation of students performance in the decision making process. The results of the model help to evaluate the performance of student groups, and also provides information about the teaching effectiveness of several study areas necessary in the decision making process.

Keywords: performance evaluation, data envelopment analysis, higher education, training

1. INTRODUCTION

The comparison of the performance of several production and/or service units is a general problem which managers frequently have to face. In most cases there is no any single parameter, which can be used for this evaluation. The compared production and/or service systems provide similar outputs (services or products) and they can independently decide on the amount of inputs used. Simply, we call these production and/or service systems as decision-making units (DMU). The comparison of the performance of several branches of a bank, several units of a restaurant chain, or several production lines of the same plant is typical cases of this problem.

Charnes, Cooper and Rhodes (1978) suggested a linear programming model in 1978 which compared DMUs using relative efficiency measures. Based on the suggested model relative efficiency analysis, or *data envelopment analysis* (DEA) became an important research area and a useful tool for practitioners. Several applications of DEA are reported in the literature in the service and in the production sector as well (see for example Panayotis, 1992; Sherman and Ladino, 1995; Markovits-Somogyi, Gecse and Bokor, 2011). A frequently applied area of DEA is higher education. Jones (2006) compared more than 100 higher educational institutions in England using a nested DEA model. Sinuany-Stern, Mehrez and Barboy (1994) analyzed the relative efficiency of several departments within the same university. We also apply DEA in a higher education context, but instead of the performance evaluation of organizations, we focus on the efficiency analysis of student's performance and on teaching efficiency.

In this paper we show, how DEA is applied for the evaluation of the performance of student groups in a production simulation game. This simulation game is part of a course in a master program in the area of management. As a consequence of the complex nature of the simulation game there is not any single measure which can be used for the comparison.

There are two objectives of the application of DEA in this case:

- An evaluation method considering the production and financial results and the efficient utilization of the applied resources is needed for deciding on the ranking of student groups.
- Information about how the methods of production management, financial management and marketing were mastered by the students and used in the simulation game is required.

In the following part of this paper first the basic concepts of DEA and a review of the applied DEA models are provided. Next, the application environment is presented and some important results of the application of DEA are explained. Finally, conclusions are drawn, and the possibilities of the refinement of the presented evaluation and the areas of future research are summarized.

2. BASIC MODELS OF DEA

The objective of DEA is to determine the most efficient decision making units relative to each other, and to assign efficiency measures to each unit. By definition, efficiency is measured as a ratio of weighted output and weighted input. The highest value of efficiency is equal to 1 and the lowest value is equal to 0. In the following, first, a graphical illustration is presented which helps to understand the basic concepts and definitions of relative efficiency analysis. Next, the detailed description of the mathematical models applied in the analysis is provided.

2.1. GRAPHICAL ILLUSTRATION OF EFFICIENCY ANALYSIS

For illustrational purposes let us assume that the efficiency of 8 stores of a supermarket chain must be compared. The stores are the decision making units and denoted by upper case letters from A to H. The management would like to know, which stores apply most efficiently their employees. An acceptable indicator of efficiency in this case can be the average sale generated by one employee. If the total sale and the number of employees in a given period are known, then the required efficiency ratio can easily be calculated. In this case the number of employees working in the store represents the input and the sale value is the output. These data for the eight stores are given in Table 1. For the sake of simplicity of data representation and of graphical illustration input and output values are normalized to get an efficiency score between 0 and 1. Consequently, input values are divided by 10 and output values are divided by 1 million, that is, store A has 20 employees and generates 1 million Euro of sale in a given year. Based on the input and output data the efficiency scores are given in the last line. We can see, that the most efficient store is store B, because on the average 1 employee generates 100 thousand euro of sale. Store F is the least efficient, because only 40 thousand euro is generated by one employee in a year. Figure 1 plots each store in an employee/sale system of coordinates.

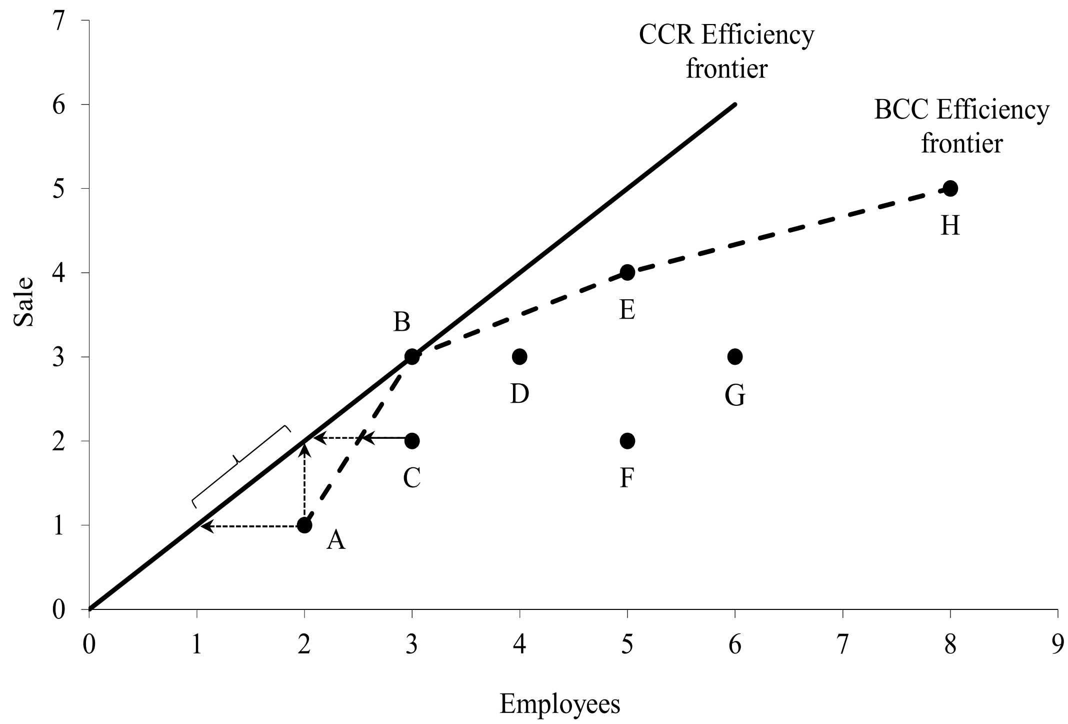
Table 1: Data of the sample problem

DMU	**Store**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Input	Employees	2	3	3	4	5	5	6	8
Output	Sale	1	3	2	3	4	2	3	5
Efficiency	Sale/employee	0.50	1.00	0.66	0.75	0.80	0.40	0.50	0.63

Source: the authors own table based on some data from the book of Cooper et al (2007)

Let us assume first, that there is a linear relationship between the number of employees and sale. In case of an efficient store any added employee generates an additional one million euro of sale. We assume a constant return to scale (CRS) relationship between the input and output values, that is, the size of the input does not influence the marginal change of output. In this case all hypothetically efficient stores can be depicted on a line which gradient is equal to 1. The solid thick line in Figure 1 contains all these efficient units. This line is called the efficiency frontier. This line is also denoted as *CCR efficiency frontier* after the DEA model used for the calculation and developed by Carnes, Cooper and Rhodes (see in the next section). Since all stores except store B are inefficient, their corresponding points are below this line.

Figure 1: Graphical illustration of efficiency analysis in case of one input and one output



Source: the authors own figure based on some data from the book of Cooper et al (2007)

The points below the line belong to inefficient stores. These stores can be made efficient if, as a consequence of management decisions, their inputs are decreased and/or their outputs are increased. Any action which projects the points of an inefficient store to the efficiency frontier represents a proper efficiency improvement policy. There are two main possibilities of this projection as it is indicated in case of store A in Figure 1.

- If point A is projected to the efficiency frontier along the horizontal arrow, then the corresponding sale value (output) does not change, but the number of employees (input) is decreased. The horizontal arrow represents an input oriented policy. If the number of employees can be decreased by 50 per cent and the generated sale will not change, then store A will be efficient.
- If point A is projected to the efficiency frontier along the vertical arrow, then the corresponding sale value (output) is increased, without the change of the number of employees (input). The vertical arrow represents an output oriented policy. If sale can

be increased by 50 per cent without the increase of the number of employees, then store A will be efficient.

Any mixed strategy can also be applied. In these cases the point of store A is projected to one of the point on the efficiency frontier in the interval determined by the vertical and horizontal arrows. This interval is indicated by the brace in Figure 1.

Let assume now, that there is a nonlinear relationship between the number of employees and sale. We assume that in case of few employees the increase of the number of employees has a higher than average effect on the generated sale. This is true up to a critical point. If the number of employees is increased above this critical number, the increase of the number of employees has a lower than average effect on the generated sale. Before the critical number an *increasing return to scale* effect is assumed, while after the critical point a *decreasing return to scale* effect is supposed. In general, since the effect of the change of input is not constant on the generated scale, a *variable return to scale* (VRS) relationship exists.

The dashed thick line in Figure 1 shows the efficiency frontier in case of a variable return to scale situation. This line is also called BCC efficiency frontier after the DEA model used for the calculation and developed by Banker, Carnes and Cooper (1984). We assume in this case, that store A is efficient, because in a store with only 20 employees the generated 1 million euro sale is acceptable, that is, the resulting 400 thousand euro marginal increase of sale is efficient. Increasing now the number of employees in store A the expected marginal increase of sale is higher than 100 thousand euro. The 30 employee of store B is the critical number. If the number of employees is increased above 30, then the expected marginal increase of sale is less than 100 thousand euro.

Applying any efficiency improvement strategy we have to decide whether scaling effect can be assumed or cannot. Let us try to decrease the number of employees in store C without the change of sale. If scaling effect is assumed then store C can be projected with a vertical arrow to the dashed line in Figure 1. If scaling effect is not assumed, then this projection must be done to the solid line in order to make store C efficient. That is, *total* efficiency can be decomposed into *technical* efficiency and *scale* efficiency. The management is responsible for the technical efficiency by using the employees properly. The technology or management practice causing variable return to scale effect is responsible for scale efficiency.

If a variable return to scale approach is used, then stores A, B, E and H are efficient. Store B is the critical store, because it is at the change of the characteristics of scaling effect. The technical and the scale efficiency scores of store B are all equal to 1. Store A has increasing return to scale, while store E and H has decreasing return to scale. Stores C, D, F and G are technical and scale inefficiency as well. If an input oriented approach is used then the number of employees must be decreased in these stores. If the numbers of employees are decreased and these stores are efficient then store D, F and G will have decreasing return to scale.

The employee efficiency analysis of the presented eight stores is simple, because only one input (number of employees) and one output (sale) are considered. If, however, more inputs (for example number of employees, square meter of the stores, etc.) and more outputs (for example sale, profit, customer satisfaction, etc.) are used, the simple analysis presented with the help of Figure 1 gets more complicated. In case of multiple inputs and multiple outputs the presented two dimensional analysis turns into the analysis of multidimensional surfaces and requires the application of linear programming models. The mathematical models used for the analysis of the results of the simulation game are presented in the next section.

2.2. MATHEMATICAL MODELS USED IN THE ANALYSIS

Assume now that we have M inputs and T outputs in case of N DMUs. Notations used in the following parts of the paper are summarized in Table 2.

Table 2: Notation

Indices:
j - indice of decision making units, j=1, …, N,
i - indice of inputs, i=1, … M,
r - indice of outputs, , r=1, …, T.
Parameters:
Y - matrix containing the output values of each DMU,
Y_0 - vector containing the output values of the DMU examined,
Y_j - vector containing the output values of DMU j,
X - matrix containing the input values of each DMU,
X_0 - vector containing the input values of the DMU examined,
X_j - vector containing the input values of DMU j,
e - unit vector,
Variables:
u - vector containing the weights of outputs,
v - vector containing the weights of inputs,
λ - ratio of inputs and ratio of outputs in the optimal composition,
λ_j - ratio of inputs and ratio of outputs of DMU j in an efficient DMU,
θ - relative efficiency score,
θ^* - optimal value of the relative efficiency score,
s^- - vector containing the input surplus values of each DMU,
s^+ - vector containing the output shortage values of each DMU.

Source: the authors own table

Vector Y_j contains the values of outputs of unit j (j=1,…, N), and vector X_j contains the values of inputs of unit j (j=1,…, N). The elements of variable vector u are the weights of the different outputs. The elements of variable vector v are the weights of the different inputs. Our objective is to find those values of the u and the v vectors, which maximize the efficiency of a specific DMU indicated by index 0. The constraints are imposed by the definition of efficiency, that is, at the selected weights the weighted output per weighted input ratio must be less than or equal to 1. The mathematical programming model describing these constraints and goals are the following,

$$\begin{aligned} &\text{Max} \quad \frac{uY_0}{vX_0} \\ &\text{DMU}: \quad \frac{uY}{vX} \leq 1 \\ &u, v \geq 0 \end{aligned} \qquad (1)$$

Model (1) has no unique solution. It is easy to see that multiplying the numerator and the denominator as well with the same number we get different but equally optimal solutions. Fixing, however, the weighted inputs at value 1 and rearranging (1) by eliminating the ratio of variables, we get the primal input model of efficiency. This model is also called multiplier form of the input oriented CCR model after Carnes, Cooper and Rhodes. The multiplier CCR input model is the following,

$$\begin{array}{llllll} \text{Max} & uY_0 & & & & \\ \text{DMU}: & uY & - & vX & \leq & 0 \\ \text{Input}: & & & vX_0 & = & 1 \\ & u,v \geq 0 & & & & \end{array} \tag{2}$$

Linear programming problem (2) consists of N+1 constraints and M+T variables. The optimal solution of model (2) consists of the relative efficiency value of DMU 0, and of the optimal values of the input and output weights (u, v). In case of N DMUs, N number of LP models must be solved, to get the relative efficiency of each DMU. In practice, for mathematical and for management reasons the solution of the dual form of (2) is used. If θ is the dual variable of the input normalization equation and λ_j are the dual variables belonging to the inequality of DMU j, then the dual form of (2) is as follows,

$$\begin{array}{llllll} \text{Min} & & & \theta & & \\ \text{Output}: & \lambda Y & & & \geq & Y_0 \\ \text{Input}: & -\lambda X & + & \theta X_0 & \geq & 0 \\ & \lambda \geq 0; & & & & \\ & \theta \geq 0; \theta \leq 0 & & & & \end{array} \tag{3}$$

Linear programming problem (3) consists of M+T constraints and N+1variables. The optimal solution of (3) consists of the efficiency score (θ^*) of DMU 0, and of the optimal values of the dual variable vector λ. The optimal solution of (3) tells the decision maker how much the input of non-efficient DMUs should be reduced to achieve the efficiency of the best DMUs. It also tells the decision maker the optimal composition of inputs. DMUs with $\lambda_j \geq 0$ create the reference set of DMU 0. If the input of the DMUs in the reference set are combined according to the values of λ_j the highest efficiency can be achieved.

The results of model (2) or (3) provide information about the proportional change of all inputs. It is assumed that all inputs must be decreased by the same proportion (θ^*). Sometimes, however, it is possible to decrease some inputs independently of the other inputs without influencing the outputs. Similarly, sometimes some outputs can be increased independently of the other outputs without requiring more inputs. These possibilities can be explored by the introduction of the input surplus (s^-) and the output shortfall (s^+) vector variables. The model which determines the input surpluses and output shortfalls is called the slack model. The slack model for the dual input oriented CCR model is as follows,

$$\begin{array}{llllllll} \text{Max} & & & es^- & + & es^+ & & \\ \text{Output}: & \lambda Y & & & - & s^+ & = & Y_0 \\ \text{Input}: & -\lambda X & - & s^- & & & = & \theta^* X_0 \\ & \lambda \geq 0; & & & & & & \end{array} \tag{4}$$

First model (3) and next model (4) must be solved. The optimal efficiency score provided by model (3) for DMU 0 is θ^*. The difference between the reduced input of DMU 0 ($\theta^* X_0$) and the optimal composition of inputs (λX) is the input surplus. The difference between the output of DMU 0 (Y_0) and the optimal composition of outputs (λY) is the output shortfall. Model (4) determines the maximal values of the independent reduction for each inputs and the independent increase for each output. Note, that in case of input oriented models first all inputs are decreased according to θ^*, and next inputs are further decreased according to s^-.

Similarly, in case of output oriented models first all outputs are increased according to θ^*, and next outputs are further increased according to s^+.

Several other models can be found in the literature for the calculation of relative efficiency. If in model (1) the weighted output is fixed then an output oriented model is defined. If the scaling effect between input and output is considered, then a variable return to scale (VRS) model is given. If input surplus and output shortage is maximized directly, without determining first the relative efficiency score, then the group of additive models is determined. If efficiency is evaluated in several consecutive periods, the dynamic DEA models can be applied. A good review of the existing models is given by Cooper et al (2007).

In the following, we will show how DEA can be used for the evaluation of the performance of students groups in a production simulation game. The presented analysis is based on the results of models (3) and (4).

3. APPLICATION ENVIRONMENT

The presented production simulation game is developed by Ecosim to support education and training in the production management area. We applied this simulation game in the Decision Making in Production and Service Systems course of the Management and Leadership Master Program for students specialized in Production and Operations Management at the Budapest University of Technology and Economics.

The objective of the game is to simulate production management decision making in a car engine manufacturing factory. The factory produces three different car engines for five different markets. Each market has its own demand characteristics. The car engines are assembled from parts on assembly lines operated by workers. The following decisions must be made by each student group for the next production period (year):

- Production quantities of the three car engines. Forecasts must be prepared about the expected demand based on the known demand of several previous periods. The expected demand, the available production capacity and the final product inventory information are used to determine the production quantities of the next year.
- Prices and paying conditions. Demand can be stimulated by selling price changes and by favorable payment conditions. Decision must be made on the purchase price of the next production period and on the payment delay percentages offered to customers.
- Ordered quantities of parts. Order quantities of the different part groups must be determined based on the planned production quantities, on the bill-of-material of the car engines and on inventory and financial information.
- Number of workers, number of shifts, and quantity of overtime. Production quantity is determined by the machine capacity and by the number of workers. On short term, capacity can be changed by hiring or firing workers and by changing the number of production shifts or by applying overtime. Decision must be made about the workforce level and about the number of shifts and about the quantity of overtime in the next production period.
- Investments in production line and in space. On long term, production capacity can be increased by investments in new production lines and in space available for production and for inventory. Decision must be made in each production period about the number of new production line installations and about the number of square meters of space extensions.
- Launch of efficiency improvement projects. It is possible to launch projects which may improve production conditions. The predefined projects have different effects and different launch and maintenance costs. Decision must be made on which projects to launch in a given production period.

- Application for credits. There are three different credit types available for financing the operation of the factory. Each type of credit has different conditions. Decision must be made about the amount used of each credit type and about the payback of earlier credits.
- After submitting the decisions, the simulation program generates the results of the actual production period. The results are summarized in two reports:
- Production report. The production report summarizes the decisions made by the student groups for the actual production period and the actual state of the production system. It summarizes the quantity of engines produced and sold, the quantity of parts used and the engine and part inventories at the end of the production period. The number of workers, machine capacities, number of production lines, and space, available for the next production period are also listed.
- Financial report. The financial report contains the balance sheet, the revenue report and the cash flow report valid at the end of the actual production period.

Evaluation of the production and financial reports, and decision making for the next production period requires the knowledge of several study areas thought in the master program. The methods of marketing are required to estimate the behaviour of customers when prices and payment conditions changes. Forecasting models are needed to evaluate future demand possibilities. Inventory control and materials requirement planning techniques must be used to determine and control the inflow of raw materials and parts. Capacity planning techniques are needed to determine the workforce level, the number of operating assembly lines and the required amount of space. Cash flow analysis methods are required to evaluate the would-be effect of efficiency improvement projects. Finally, managerial accounting and corporate finance knowledge is needed to the proper understanding of balance statement, cash flow report and revenue report.

Concluding the seventh production period the student groups are evaluated. Evaluation, however, is very difficult even if only the financial situation of the plants is considered. Pure financial analysis can be misleading. Here are some examples to demonstrate the possible traps of narrow minded financial evaluation:

- Short term success may not necessarily lead to long term success. The plant may accumulate high profit in the first seven periods, but if production resources (production lines, production space, improvement projects) do not support production increase for the future, financial performance may later decrease.
- A group may follow a cautious strategy. They may decide on low production quantity, financed by their available own financial sources. In this case small profit, slow but steady growth can characterize the plant.
- Long term strategic thinking may provide unfavorable financial results on the short run. Heavy investments can be made at the beginning using credits in order to secure capacity for future growths. If all this is paired with demand stimulating marketing policy and with efficiency improvement projects, profit will be low at the beginning, but steep growth can be expected in the future.

Evaluation is further complicated by the fact, that the simulation game is used not only for deciding the winner according to a specific financial measure. We also wanted to know how students mastered the different areas of production management. It may occur that students made poor financial decisions, but they made good inventory management and/or capacity management decisions.

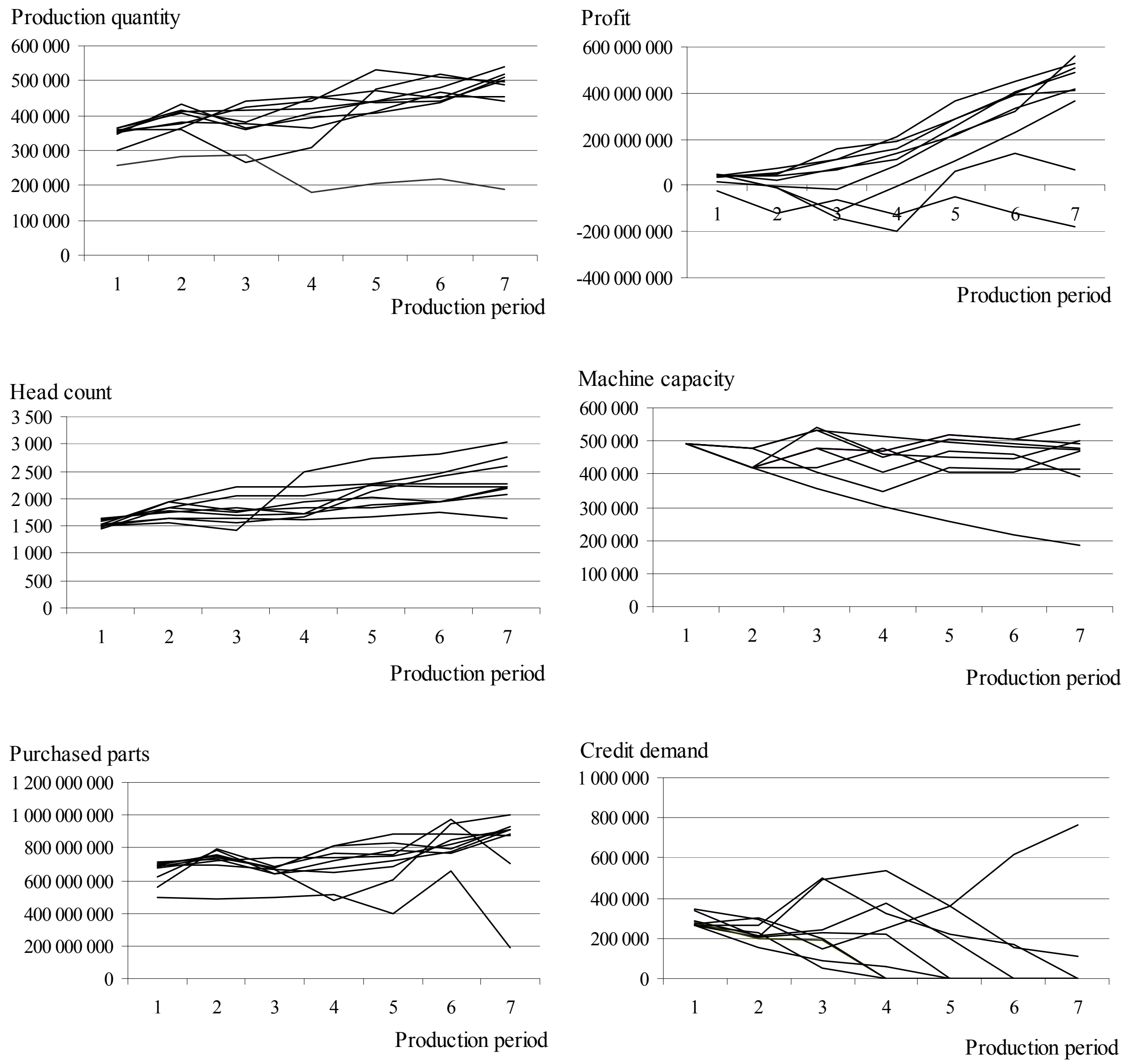
4. ANALYSIS OF THE RESULTS

The huge amount of data generated in the decision making process of the student groups, and by the production simulation model provides a solid basis for performance analysis. First, we show how a traditional approach leads to some general conclusions. Next, we explore the possibilities provided by the application of data envelopment analysis.

4.1. TRADITIONAL ANALYSIS OF THE RESULTS

Figure 2 presents a few charts, which may help to draw some general conclusions, and also highlight the complexity of evaluation.

Figure 2: results of the production simulation game



Source: the authors own figure

The change of production quantity during the seven production periods can be seen in the *Production quantity* chart. It can be seen that, apart from a few exceptions, production is increased from period to period and reached the neighborhood of 500,000 engines per year by the end of the seventh period. One group performed very badly, but the rest of the groups stabilized production around this quantity. Some groups provided a fluctuating curve, while others had smooth curve reflecting consistent production and marketing policy and thoughtful production planning.

The *Profit chart* shows a much higher fluctuation and reflects better the errors made during the decision making process. Since the profit curves are steeper and spread more, the accumulated profit indicates higher differences of performance at the end of the seventh period. One group showed a steadily poor performance, while others presented poor performance at the beginning, and an improved decision making process in later periods.

The amount of human resources applied in each year is illustrated by the *Head count* chart. The number of employees varies between 1500 and 3000 in the final period showing different policy of the groups in hiring. The groups increased the number of employees constantly but differences in growth policy and in capacity planning are reflected in the chart. Some groups implemented new shift, and opened new production lines, while others answered to demand for increased production capacity by increased overtime. These differences led to different head count values and ultimately to different labor cost.

The change of the amount of applied technical resources of the student groups can be observed in the *Machine capacity chart*. Machine capacity, in general, did not increase during the production periods. New production lines were only used by the groups to substitute old machines. It can be seen, that the original 500,000 machine hours is exceeded only by one group at the end of the seventh production period. This result may reflect that the groups did not prepare for future demand increase with the installation of new and expensive production lines.

The different inventory policies of the groups can be seen in the *Purchased part* chart. We can observe that this chart is very similar to the *Production quantity* chart. We can conclude that, apart from a few exceptions, material planning and inventory control was successfully applied by most groups.

The *Credit demand* chart shows the highest differences among student groups. Some groups applied very good financial planning and demanded very little financial sources. Others built up high debts at the beginning, and needed several periods to balance the cash flow. One group found itself in a financial disaster. Note, that credit demand is influenced by efficiency improvement projects. Some groups financed the initial high cost of these projects from credits to pay it back later with the help of improved operation.

Each of the six charts of figure 2 presents only one specific aspect of decision making during the production simulation game. There are, however, several interdependencies among the charts. For example, the lack of machine capacity increase might be the consequence of increased overtime, and high operating cost, which may influence credit demand. A steep profit increase curve in a later period can be the result of demand stimulating pricing and payment conditions at the beginning.

A method is required which can help to evaluate the efficient utilization of employees, machine capacity, parts and materials and financial sources from the point of view of production quantity and profit. Data envelopment analysis may help to provide an aggregate picture, which includes each of the resources influencing the performance of the groups.

4.2. ANALYSIS OF THE RESULTS WITH *DEA*

We used relative efficiency analysis (DEA) for evaluating the performance of student groups at the end of the seventh period of the simulation game. Two outputs and four inputs were considered in the analysis. The two *outputs* are the following:

- Cumulated production quantity. The production quantity reflects the effect of production management decisions related to machine and worker capacity, to material requirement planning and to inventory management.
- Net cumulated profit. The profit integrates the effect of marketing, production and financial decisions.

The four *inputs* represent the resources used in the production process, that is,

- The cumulated number of workers represents the amount of human resources.
- The cumulated number of machine hours represents the amount of technical resources.
- The cumulated sum of money spent on raw materials and on parts represents the amount of material resources.
- The cumulated value of credits represents the amount of financial resources.

The performance of 9 student groups is compared using a two-phase input oriented CCR model. The results are summarized in Table 3, 4 and 5.

Table 3: DEA results with production quantity output

1	2	3	4	5	6	7	8
Team	Output Prod. Quant.	Efficiency θ^*	Workers $s(1)^-$	Machine cap. $s(2)^-$	Material $s(3)^-$	Credit $s(4)^-$	Reference set
Group 1	2 793 305	**1,0000**	0	0	0	0	-
Group 2	2 779 163	0,9454	1 555	140 739	0	1 308 838	7
Group 3	2 899 000	**1,0000**	0	0	0	0	-
Group 4	2 889 423	0,9906	0	237 219	0	79 023	3, 5
Group 5	3 054 527	**1,0000**	0	0	0	0	-
Group 6	2 940 133	0,9838	0	375 767	0	524 956	3, 7
Group 7	3 057 918	**1,0000**	0	0	0	0	-
Group 8	3 130 992	0,9886	0	104 360	0	839 646	3, 7
Group 9	1 621 135	0,8753	2 372	317 291	0	2 030 721	7

Source: the authors own table

Table 3 shows the case when the cumulated production quantity is the *only* output and the previously indicated four inputs are considered. These results help to evaluate the application of production management knowledge in the decision making process. Column 2 shows the total quantity of engines produced during seven production periods. Column 3 shows the relative efficiency scores. We can see that the highest quantity is found at group 8, although, the efficiency score of this group is not the highest. This group should have produced this output using less input. Group 8 would be efficient if all input were smaller by 1.14 percent. Furthermore, excess machine capacity and overly high credit was used, as indicated by column 5 and 7. The last column shows, that if this group wants to increase efficiency, a mixture of the production practices of group 3 and 7 must be implement.

Table 3 also shows that groups 1, 3, 5 and 7 have the maximum efficiency. We can see that the production quantity of group 5 and 7 is among the highest, the production quantity of group 3 is around the average, and the production quantity of group 1 is below the average. These groups have applied different but equally efficient production practices. In case of group 1 and 3 smaller quantities were produced, but the quantity of resources used was smaller as well.

Table 4: DEA results with profit output

1 Team	2 Output Profit	3 Efficiency θ^*	4 Workers $s(1)^-$	5 Machine cap. $s(2)^-$	6 Material $s(3)^-$	7 Credit $s(4)^-$	8 Reference set
Group 1	1 578 563	**1,0000**	0	0	0	0	-
Group 2	0	0,0000	0	0	0	0	-
Group 3	1 759 553	**1,0000**	0	0	0	0	-
Group 4	1 538 303	0,9856	0	521 462	334 359 868	0	1, 3
Group 5	1 410 080	0,9005	0	378 256	383 806 582	0	1, 3
Group 6	1 182 609	0,6588	538	38 959	0	194 838	3
Group 7	1 259 507	0,7683	1 155	0	247 415 155	0	1, 3
Group 8	632 569	0,3466	149	0	0	298 208	1, 3
Group 9	0	0,0000	0	0	0	0	-

Source: the authors own table

Table 4 shows the case when the cumulated net profit is the *only* output and the previously indicated four inputs are considered. These results help to evaluate the joint application of marketing, production management and finance related knowledge in the decision making process. The highest possible efficiency is indicated at group 1 and 3. Note that these groups were among the efficient groups in Table 3 as well. The efficiency of group 7 is, however, among the lowest, although it produced the second highest quantity. The reason for this is that high production quantity was not pared with efficient utilization of resources. An efficient group could have produced this output using 23.17 percent less of all resources. Furthermore, overly high number of workers and too many materials were used, as indicated by column 4 and 6 of Table 3. The last column shows, that if this group wants to increase efficiency, it should implement a mixture of the production practices of group 1 and 3.

Table 5: DEA results with production quantity and profit outputs

1 Team	2 Output Prod. Quant.	3 Output Profit	4 Efficiency θ^*	5 Workers $s(1)^-$	6 Machine cap. $s(2)^-$	7 Material $s(3)^-$	8 Credit $s(4)^-$
Group 1	2 793 305	1 578 563	**1,0000**	0	0	0	0
Group 2	2 779 163	0	0,9454	0	0	0	0
Group 3	2 899 000	1 759 553	**1,0000**	0	0	0	0
Group 4	2 889 423	1 538 303	**1,0000**	0	0	0	0
Group 5	3 054 527	1 410 080	**1,0000**	0	312 424	357 210 274	0
Group 6	2 940 133	1 182 609	0,9838	803	58 175	0	290 940
Group 7	3 057 918	1 259 507	**1,0000**	458	0	20 933 541	196 759
Group 8	3 130 992	632 569	0,9886	0	168 424	0	894 769
Group 9	1 621 135	0	0,8753	1 465	235 195	0	1 267 252

Source: the authors own table

Finally, Table 5 considers together the cumulative production quantity and the cumulative profit as outputs. The differences among the groups are smoothed out in this case. Five groups are considered efficient. Group 4 was not efficient in any of the previous two cases, but their efficiency scores were very near to one (0.99 and 0.98). If we evaluate together production quantity and profit, this group joins the set of efficient groups.

5. SUMMARY AND CONCLUSIONS

In this paper the application of DEA is presented for the performance evaluation of student groups in a production simulation game. Relative efficiency of the groups is evaluated based on two different outputs. Cumulated production quantity is used for the evaluation of production management related decisions. Cumulated net profit is used for the evaluation of the joint effect of production, financial and marketing related decisions. Four major resources (human, machine, material financial) are used as inputs in the analysis. The quantity of these inputs used for production is decided exclusively by the student groups, therefore the student groups can be considered as DMUs.

An input oriented two phase CCR model is used for the analysis. The results correctly reflect the performance of the student groups, however, some further refinement of the analysis is recommended:

- We applied large group sizes (5-6 students) in the simulation game and consequently the number of student groups was relatively small. The small group number smoothed out the differences in performance. The application of smaller group size and higher group number is recommended in future applications.
- The same initial conditions were given for each group at the beginning of the simulation. As a result of different growth strategies, however, scaling effect may appear after some production periods. Consequently, the application of a variable return to scale model might be appropriate.
- There was not any specific rule for student group formation. As a result, very different composition of groups concerning the study results and the interest area of students were formed. The consideration of the composition of student groups as non-discretionary variable may further refine the results.
- Finally, the analysis of the dynamic change of performance of student groups during the simulation may highlight some interesting mechanisms of the learning process of student groups. The dynamic DEA models (see for example Tone and Tsutsui 2010) might be promising tools for studying this learning process. The application of dynamic DEA models for the evaluation of the behaviour of student groups is an important direction of our future research.

The presented application of DEA completed with the proposed extensions might be a useful tool for student evaluations in higher education, but can also be applied for the evaluation of participants in any management training program as well.

REFERENCES

1. Banker, D.R., Charnes, A. and Cooper, W.W., 1984. Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science*, 30(9), pp.1078-1092.
2. Charnes, A., Cooper, W.W. and Rhodes, A., 1978. Measuring the efficiency of decision making units. *European Journal of Operations Research*, 2, pp.429-444.
3. Cooper, W.W., Seiford, L.M. and Tone, K., 2007. *Data envelopment analysis*. Springer.
4. Doyle, J.R. and Green, R.H., 1991. Comparing products using data envelopment analysis. *Omega International Journal of Management Sciences*, 19(6), pp.631-638.
5. Johnes, J., 2006. Data envelopment analysis and its application to the measurement of efficiency in higher education. *Economics of Education Review*, 25(3), pp.273-288.
6. Tone, K. and Tsutsui, M., 2010. Dynamic DEA: A slack-based measure approach. *Omega*, 38, pp.145-156.

7. Markovits-Somogyi. R., Gecse, G. and Bokor, Z., 2011. Basic efficiency measurement of Hungarian logistics centres using data envelopment analysis. *Periodica Polytechnica Social and Management Sciences*, 19(2), pp.97-101.
8. Panayotis, A.M., 1992. Data envelopment analysis applied to electricity distribution districts. *Journal of the Operations Research Society*, 43(5), pp.549-555.
9. Sherman, H.D. and Ladino G., 1995. Managing bank productivity using data envelopment analysis (DEA). *Interfaces*, 25(2), pp.60-73.
10. Sinuany-Stern, Z., Mehrez, A. and Barboy, A., 1994. Academic department's efficiency via DEA. *Computers & Operations Research*, 21(5), pp.543-556.