Evaluation of decision making of teams in business simulation games using DEA

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Abstract

The objective of this paper is to explore the available information provided by the reference sets. Different groups of decision making units (DMUs) can have different reference sets, indicating that several decision policies can be followed by the participating team. The paper shows how these different policies can be identified, and explains the main characteristics of the identified best practices. Several examples are used to illustrate the identification of best practices for the different participating teams. The presented method can further enhance the application possibilities of DEA for the evaluation of business simulation games.

Keywords: Data Envelopment Analysis, Business simulation games, Performance evaluation

Introduction

Several studies show that the use of simulation games in education leads to positive attitude towards the subject in which these games are applied and that they present an effective alternative to traditional teaching methods. Many researchers analyze the impact of business simulation games on the participating student and apply various methods for the evaluation of the development achieved by them. Performance evaluation is, however, very complicated when several conflicting evaluation criteria must be considered at the same time. In this paper, Data Envelopment Analysis (DEA) is applied for performance evaluation of student groups in a production simulation game and best practices with the help of DEA information are identified.

First, the role of simulation games in management education and the existing evaluation methods are overviewed. Next, practical applications of DEA models are explored and DEA as a method for the evaluation of the results of a simulation game applied in the education of operations management master studies is discussed. The objective of the game is to simulate production management decision making in a car engine manufacturing factory, where each student group must make different kind of decisions to increase operational performance of the next periods. Finally, the available information collected during the last three years concerning the reference sets are analyzed, and best practices for the participating teams are identified and deviations from the best practice are highlighted and explained.

The novelty of this paper is the application of DEA for performance evaluation in business simulation games. The presented research focuses on the application of reference set information for identifying deviations from best practices.

Simulation games in management education

The application of business simulation games (BSGs) in higher education has become increasingly popular through the last decades. The use of BSGs for educational purposes originates from the use of war games in the 1600s. (Gredler, 2004) The development of operations research and computer technology resulted in the evolution of several management simulation games, starting with AMA Top Management Decision Simulation in 1956. (Cohen-Rhenman, 1960) Besides many other general management games, several functional area games have been developed at top universities and companies all over the world, and many of them has been used in the field of operations management. (Riis et al., 1998) Production and operations management education employs a wide variety of business simulation games, such as the well-known 'beer game', developed by the Sloan School of Management in the 1960s with the purpose of helping students experience and understand the bullwhip effect in supply chains (Pasin-Giroux, 2010), the 'cuppa manufacturing game' concerning Just-in-Time production system, or the 'red bead experiment' referring to lean management. (Ammar-Wright, 1999)

BSGs have a lot of advantages related to training and education. They can be applied effectively to engage students, motivate them and give them a chance to create a link between theory and real-world problems (Ben-Zvi, 2010). BSGs place students in a dynamic situation, where they can see the effects of various strategies but without a real-life competitor (Lewis-Maylor, 2006). Although, there is no evidence about games being a better tool than traditional teaching methods (Parasuraman, 1980), simulation games are widely adopted by world-class universities as a pedagogical tool. The use of games for management education facilitates students to experiment strategy planning and decision making in a "risk-free environment", while they develop other essential skills, like time management, team building and negotiation techniques. (Tiwari et al., 2014)

Simulation game evaluating methods

Many research studies focus on the evaluation of the effectiveness of business simulation games. Pasin and Giroux (2010), in their study, analyze a new simulation game and its impact on operations management education, by focusing on technical mistakes that were made by students during successive rounds of the game. Rosa and Vianello (2014) analyze a distance learning method which employs a computer simulator as the main learning tool. They measure its effectiveness using pre-post-tests, which means that the students had to fill out surveys before and after the class regarding impressions and opinions about the method. This type of studies showed that business simulation games can be more engaging and motivating than other teaching strategies, and their pedagogical application is recommended.

Other research is based on the evaluation of the performance achieved during the simulation games. Hand and Sims (1975) demonstrate that path analysis is a viable technique for the analysis of gaming performance data. Anderson (2005) applies linear regression method to evaluate simulation performance. Peters and Vissers (2004) consider debriefing as the main method for the evaluation of performance.

Basic DEA concepts and applications

Data Envelopment Analysis (DEA) is a linear programming method used for the comparison of the efficiency of decision making units (DMUs), such as departments, universities, hospitals or any similar example with a relatively homogeneous set of units with multiple inputs and multiple outputs (see for example Charnes et al.,1978; Banker et al., 1984). For each DMU an efficiency score is calculated as the ratio of weighted sum of outputs to weighted sum of inputs. DEA is applied to identify relative efficiencies and inefficiencies among the set of examined units and to provide targets for improvements to the inefficient DMUs, by developing peer groups for each one of them.

Liu et al. (2013) present a wide variety of DEA applications and examine the development paths of the five major application fields, which are banking, health care, agriculture and farm, transportation and education.

- The first study that applied DEA to evaluate bank efficiency was Sherman and Gold (1985), which used classical CCR model to compare bank branch efficiencies. Since then, a lot of researchers have studied the banking sector, take for example Jemric and Vujcic (2002), who analyze bank efficiency in Croatia between 1995 and 2000 using DEA.
- Regarding health care applications, DEA is widely used, for example, in the performance evaluation of hospitals, rehabilitation departments (Dénes et al., 2017) and nursing services (Nunamaker, 1983).
- Considering the agriculture sector, researchers apply DEA to identify the reasons of productive or economic inefficiencies; e.g., Iraizoz et al. (2003) analyze horticultural production performance in Spain.
- In the transportation sector, among others, performance of airlines (Schefczyk, 1993), airports, urban road systems (Fancello et al., 2014) and ground transportation systems, as railway and bus, are evaluated by DEA.
- The fifth big category, education performance evaluation, has a broad application literature, public school education and higher education is also widely evaluated (Ray, 1991 and Avkiran, 2001).

Simulation game evaluation using DEA

To apply DEA for evaluating the results of BSGs is a new and promising area of DEA application. In BSGs, students or student groups are the DMUs, and their relative performance is evaluated. Koltai and Uzonyi (2017a) compared the results of different input oriented DEA models in a production simulation game organized for engineering management master students. The analysis of the results of several basic DEA models, like basic radial efficiency measures and slack-based measure models, shows that the use of assurance regain model is recommended in BSGS applications. Besides, this study proves that the performance of student groups participating in a simulation game can be evaluated using the efficiency scores calculated with DEA.

Koltai et al. (2017) assess the performance of student groups with an output oriented, slack-based DEA model with constant returns to scale and explore the differences between the results of static and dynamic DEA models. While the static model accumulates the outputs and inputs of different periods, the dynamic model evaluates student group efficiency in each production period. The dynamic model separates the results of the latest decision from the aggregated result of the previous periods, therefore, it creates the opportunity to students to easily check if their latest strategy improves the performance or not.

Koltai and Uzonyi (2017b) analyze the differences between two types of performance evaluations. First, financial information given from traditional financial reports, like balance sheet, revenue and cash-flow reports are used for evaluation. Next, the evaluation is based on the results of a slack based DEA model. The results show that the biggest advantage of DEA is that it takes into consideration only those inputs, which can directly be influenced by the decision maker, whereas, evaluation based on financial data includes all costs of operation. As a result, DEA based evaluation highlights better the reasons of inefficiencies and settles exact targets for improvement.

Evaluation of student group performance based on reference sets

Application environment

In line with the research studies listed in the previous point, a new set of the DEA results is exploited for DMU evaluation in BSGs. The production simulation game applied in this paper was developed by EcoSim Ltd. to support production management education. The game is used in *Decision Making in Production and Service Systems* module of the Production and Operations Management Master's degree program 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 in seven periods. Each market has its own demand characteristics. The car engines are assembled from parts on assembly lines operated by workers. Decisions must be made by each student team for the next production period in the following areas: sales and marketing, production, investment and financial decisions. The simulation program generates the results of the actual production period. Students get a production report and a financial report based on which each student group tries to increase operational performance of the next periods.

The study used two input oriented DEA models for the evaluation of performance of groups at the end of the seventh period. In the first case, a constant returns to scale model was applied (model 1). In the second case, a constant returns to scale model with weight restrictions (model 2). Two outputs, such as cumulated production quantity and net profit, and four inputs, cumulated number of workers, cumulated number of machine hours, cumulated sum of money spent on raw materials and cumulated value of credits were considered in the analysis.

Reference set analysis

The reference set of an inefficient DMU contains those DMUs, which are efficient and have a non-zero dual variable when the primal model is solved. The DMUs in the reference set can be considered as the 'peers', whose strategies the related inefficient DMUs should ideally follow, in order to become efficient. In this study, we analyzed reference set data from the last three years (2015, 2016 and 2017), to evaluate student group performance and to find correlation between the decision making procedures of the teams and the final results. We studied data from each year related to the input quantities submitted by the teams and the resulted output values, and examined the differences between the results of the two applied DEA models regarding discrepancies in the number of efficient units.

Table 1 shows the set of peer groups and contains the lambda values for each team in the year of 2015. In the first column of the table, groups are denoted with numbers from 1 to 19, it means that in 2015 19 teams participated in the simulation game. Boldface group numbers in the first row of the table refer to the efficient groups according to the applied model, and the numbers in italics below them represent the frequencies of being part of a reference set. On the left hand side of the table, the results of model 1 can be seen, meanwhile, the right hand side shows the results of model 2 with weight restrictions.

Table 1 – Reference set data and lambda values in 2015

Model 1_2015							
Group	**1**	**6**	**7**	**10**	**13**	**14**	**16**
	2	*7*	*5*	*1*	*9*	*3*	*6*
1	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.8899	0.0000	0.0000	0.0000	0.0000
3	0.0000	0.8914	0.0000	0.0000	0.0352	0.0000	0.0000
4	0.0000	0.0082	0.0795	0.0000	0.0093	0.0000	0.8925
5	0.0000	0.0000	0.0000	0.0000	0.9096	0.0735	0.0000
6	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
8	0.0000	0.0594	0.0000	0.0000	0.4352	0.0000	0.3224
9	0.0000	0.0000	0.0000	0.0000	0.8869	0.0000	0.0000
10	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
11	0.0000	0.0000	0.4952	0.0000	0.0000	0.0000	0.4302
12	0.0000	0.0000	0.0000	0.0000	0.8678	0.0000	0.0000
13	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
14	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
15	0.0000	0.0545	0.0000	0.0000	0.5522	0.4234	0.0000
16	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
17	0.1252	0.3879	0.4219	0.0000	0.0000	0.0000	0.0000
18	0.0000	0.2947	0.0000	0.0000	0.0280	0.0000	0.6857
19	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.6453

Model 2_2015			
Group	**7**	**10**	**13**
	15	*1*	*14*
1	0.8101	0.0000	0.0000
2	0.8486	0.0000	0.0000
3	0.7121	0.0000	0.1752
4	0.6905	0.0000	0.3255
5	0.0664	0.0000	0.8134
6	0.6230	0.0000	0.3888
7	1.0000	0.0000	0.0000
8	0.2196	0.0000	0.5967
9	0.0000	0.0000	0.7757
10	0.0000	1.0000	0.0000
11	0.9378	0.0000	0.0000
12	0.0000	0.0000	0.7434
13	0.0000	0.0000	1.0000
14	0.5726	0.0000	0.1957
15	0.3030	0.0000	0.6131
16	0.8070	0.0000	0.2223
17	0.8124	0.0000	0.0542
18	0.6681	0.0000	0.3533
19	0.5471	0.0000	0.0833

As it can be seen from Table 1, model 1 resulted in a set of 7 efficient units, which contained group 6 and 16 with relatively high frequency values. According to the second model, only 3 student groups resulted to be efficient and the two groups mentioned before (6 and 16) disappeared from the list. Thus, when weight restrictions came into consideration, group 6 and 16 couldn't remain efficient. The reason behind this, is that model 1 didn't assign weights to every input and output, however, model 2 did. Analyzing the background data of these two groups, we found that in the case of group 6, model 1 didn't take into consideration net profit, raw materials and credits in the efficiency analysis (see Table 2). Model 2, however, assigned weights to these inputs and output, and as a result, the efficiency score of group 6 dropped from 1 to 0.9961. The results suggest that group 6 should have managed its inventory level and planned the production quantities better and paid more attention to its financial report.

Considering group 16, the weight values showed almost the same: model 1 considered the group efficient but didn't assign weights to net profit and credits, and the weight of the number of workers was almost zero (0.002). When, however, model 2 was applied, the efficiency score of the group dropped from 1 to 0.9284. The results show that in the case of group 16, human resource planning problems appeared in addition to financial ones.

Table 2 – Weights of groups 6 and 16 in model 1

Group	Production quantity	Number of workers	Machine hours	Raw materials	Credits	Net profit
6	0.326	0.0404	0.1561	0	0	0
16	0.3124	0.002	0.0279	0.1722	0	0

As a result of applying weight restrictions in model 2, groups 7, 10 and 13 remained efficient, from which group 10 stands as peer group for only itself. We found that group 10 employed almost 25% more workers than the other efficient groups, and used the least credit of all groups. Considering the outputs, group 10 reached higher net profit than group 13, still group 13 appeared in the reference set of other inefficient groups. This results suggest that group 10 maintained a different strategy than the rest of the groups in respect to human resource management and financial planning, consequently, group 10 takes place in a remote point of the efficiency frontier from the other groups.

Table 3 – Reference set data and lambda values in 2016

	Model 1_2016									Model 2_2016	
Group	**4**	**6**	**7**	**9**	**10**	**11**	**15**	**19**	Group	**4**	**7**
	3	*1*	*5*	*2*	*4*	*3*	*8*	*1*		*17*	*2*
1	0.0000	0.0000	0.5045	0.0000	0.0000	0.0000	0.5150	0.0000	1	0.9366	0.0000
2	0.2048	0.0000	0.0000	0.0000	0.5565	0.0537	0.0000	0.0000	2	0.7503	0.0000
3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0012	0.0000	3	0.9986	0.0000
4	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	4	1.0000	0.0000
5	0.0000	0.0000	0.4068	0.0000	0.4912	0.0000	0.0000	0.0000	5	0.8562	0.0000
6	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	6	0.0000	0.8114
7	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	7	0.0000	1.0000
8	0.3870	0.0000	0.0000	0.1612	0.0000	0.2264	0.0000	0.0000	8	0.6703	0.0000
9	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	9	1.0192	0.0000
10	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	10	1.0187	0.0000
11	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	11	0.8035	0.0000
12	0.0000	0.0000	0.1385	0.0000	0.0000	0.0000	0.6360	0.0000	12	0.7265	0.0000
13	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.8043	0.0000	13	0.7509	0.0000
14	0.0000	0.0000	0.0000	0.0000	0.8482	0.0000	0.0000	0.0000	14	0.7783	0.0000
15	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	15	1.0557	0.0000
16	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9543	0.0000	16	0.9106	0.0000
17	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.6926	0.0000	17	0.5468	0.0000
18	0.0000	0.0000	0.7464	0.0000	0.0000	0.0000	0.2432	0.0000	18	0.8922	0.0000
19	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	19	1.0683	0.0000

Table 3 shows the set of peer groups and contains the lambda values for each team in the year of 2016, with the same structure as in Table 1. In this year again 19 student groups participated in the simulation game, but the final results are different. From this set of data, we analyzed the relationship between groups 6 and 7. As the table shows, both groups proved to be efficient when applying model 1, but in the case of weight restrictions, only group 7 remained efficient. The efficiency score of group 6 dropped to

0.9909 and group 7 became its peer group. Another important fact, that group 7 showed up as part of the reference set of 5 DMUs when applying model 1. Applying model 2, however, this frequency decreased to 2 and became peer group only for itself and for group 6 with a relatively high lambda, meaning that group 6 should consider group 7 as a good benchmark for improvement.

Comparing the decision making processes of this two groups (6 and 7) some correlation between their decision making policy can be found. First, we checked the weights of each input and output, which is shown in Table 4, then we confronted these data with the decisions made during the game.

Table 4 - Weights of groups 6 and 7 in model 2

Group	Production quantity	Number of workers	Machine hours	Raw materials	Credits	Net profit
6	0.3773	0.0452	0.0452	0.0452	0.4524	0.0943
7	0.3089	0.021	0.2104	0.021	0.0756	0.0772

Table 4 shows that group 6 got a higher weight regarding credits, meanwhile group 7 got a higher weight in the case of machine hours. We compared these two pieces of information with the final input and output results at the end of the game, and we found that group 6 was performing the best related to credits, but group 7 didn’t operate so well in relation with machine hours. Overall, it can be said that group 6 has a similar strategy to group 7 related to input decisions, yet group 7 managed to reach higher output values. Input strategies of the other 16 inefficient groups showed more similarity to the decisions made by group 4 and that is the reason why group 7 remained peer group only for group 6.

Table 5 shows the reference set and the lambdas for each team in the year of 2017. In this year 18 groups participated in the game. The main peculiarity of this set of data is that groups 5, 10, 16 and 18 resulted efficient in both DEA models, but with diverse reference set frequencies and lambda values. After reviewing every information given from the table, we found that group 5 emerged 14 times as a peer group applying model 1, however, when applying model 2, this number decreased to 8, meanwhile group 18 managed to grow its frequency rate from 9 to 12. In the case of 6 groups, group 5 disappeared as a proposed benchmark in the second model, and group 18 took over its place at 3 groups. We analyzed what could be the reason behind this switch and explored the relationship between the decision making processes and model parameters of groups 5 and 18.

Table 6 shows an important change between the two model parameters. Applying model 1 group 5 didn’t get a weight on its net profit, however group 18 did, but later, applying model 2, both groups got a similar weight on their net profit. This result suggests that group 5 should have been more careful about its financial report and should have taken into consideration net profit results when deciding about its strategy. Examining the final input and output results we learned that despite of operating better than group 18 regarding the input quantities – group 5 worked with an overall lower level in the number of workers, machine hours and credits, this group produced 30% less net profit than group 18. The results show that group 5 lost 6 groups as being a benchmark for them, because of its poor financial performance.

Table 5 - Reference set data and lambda values in 2017

	Model 1_2017					Model 2_2017			
Groups	**5**	**10**	**16**	**18**	Groups	**5**	**10**	**16**	**18**
	14	*6*	*2*	*9*		*8*	*9*	*2*	*12*
1	0.5738	0.1329	0.0000	0.0000	1	0.5065	0.1232	0.0000	0.0000
2	0.3508	0.5754	0.0000	0.0000	2	0.0000	0.7416	0.0000	0.1690
3	0.7447	0.1901	0.0000	0.0000	3	0.6466	0.2521	0.0000	0.0000
4	0.3008	0.7288	0.0000	0.0000	4	0.0000	0.8650	0.0000	0.1414
5	1.0000	0.0000	0.0000	0.0000	5	1.0000	0.0000	0.0000	0.0000
6	1.0411	0.0000	0.0000	0.0000	6	0.9811	0.0000	0.0000	0.0000
7	0.4765	0.0000	0.0000	0.5010	7	0.1167	0.1414	0.0000	0.5579
8	0.0000	0.0000	0.0000	0.8402	8	0.0000	0.0000	0.0000	0.5344
9	0.4648	0.0000	0.4158	0.0446	9	0.4056	0.0000	0.3982	0.0596
10	0.0000	1.0000	0.0000	0.0000	10	0.0000	1.0000	0.0000	0.0000
11	0.2929	0.0000	0.0000	0.5339	11	0.0000	0.0512	0.0000	0.4315
12	0.3590	0.6628	0.0000	0.0000	12	0.0000	0.7864	0.0000	0.1490
13	0.5355	0.0000	0.0000	0.0818	13	0.0000	0.1873	0.0000	0.2551
14	0.1978	0.0000	0.0000	0.5972	14	0.0000	0.0000	0.0000	0.5940
15	0.7643	0.0000	0.0000	0.0396	15	0.7001	0.0000	0.0000	0.0796
16	0.0000	0.0000	1.0000	0.0000	16	0.0000	0.0000	1.0000	0.0000
17	0.1976	0.0000	0.0000	0.5750	17	0.1100	0.0000	0.0000	0.5015
18	0.0000	0.0000	0.0000	1.0000	18	0.0000	0.0000	0.0000	1.0000

Table 6 – Weights of groups 5 and 18 in models 1 and 2

Group	Production quantity	Number of workers	Machine hours	Raw materials	Credits	Net profit
5_m1	0.4315	0.086	0	0.0474	0	0
18_m1	0.4234	0.0824	0	0.0644	0	0.0561
5_m2	0.4017	0.0697	0.0593	0.0472	0.007	0.1004
18_m2	0.4035	0.0804	0.008	0.0618	0.008	0.1009

Conclusion

DEA is a well known tool of performance evaluation, and it is widely used in several application settings. In this paper DEA is used for performance evaluation of student groups in business simulation games. This is a novel area for DEA application. In this paper, particularly the reference set information of DEA was analyzed and its application for best practice identification was used.

In the presented research, the application of a production simulation game was studied, where students groups formed the DMUs and made decisions concerning the amount of resources used for production and about the planned production quantities and product mixes. DEA can supply abundant information for evaluation. In this paper the information content of the reference set results were explored and evaluated. We may conclude that reference set information can provide reliable information for identifying best practices; however, the evaluation of these sets requires careful analysis and it is not as straightforward as the comparison of relative efficiency scores. The main benefit is, however, the knowledge we gain concerning the deviation of DMUs from best practice, and about the direct sources of improvement possibilities.

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