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# Evaluation of the efficiency of engineering courses in a Brazilian University: An application of Data Envelopment Analysis

Christiane Lopes dos Santos, Rafael de Azevedo Palhares, Natália Veloso Caldas de Vasconcelos

Engineering Department, Universidade Federal Rural do Semi-Árido, Brazil

***Abstract*— *Assessing the efficiency of similar undergraduate courses based on the analysis of reliable and complete information, allows opportunities for improving courses to be identified to support the institution's management, which are assigned the decision-making role. In this way, this research aims to evaluate the efficiency of Engineering courses at a Brazilian university from the Data Envelopment Analysis (DEA). For this, the BCC model was used with orientation to the output. As inputs the variables Number of Entries ($x^1$) and Faculty Size ($x^2$) were used, and as outputs the Number of Graduates ($y^1$) and the Course Concept ($y^2$). Thus, 13 Engineering courses, such as Civil, Electrical, Chemical, Industrial, Environmental and Sanitary Engineering and Computer Engineering were evaluated. The inefficiency of 2 courses was found and aspects of improvement were indicated to be put into practice to achieve this efficiency.*

***Keywords*— University education. Engineering. Efficiency. Data Envelopment Analysis.**

## I. INTRODUCTION

Engineering was born out of the need to create armaments and secure fortifications in Europe in the 16th and 17th centuries [1]. Until the 1950s, in Brazil, there were only 16 institutions teaching about 62 engineering undergraduate courses [2]. In 2018, 6.106 undergraduate engineering courses were accounted for, in 60 different areas, distributed throughout the country [3]. Despite the growing increase in the offer of engineering courses, there is a high number of dropouts from students in these courses [4].

An important issue, in addition to increasing the offer of courses, is to analyze their efficiency. Evaluating the efficiency of undergraduate courses allows defining opportunities for improving courses [5] [6]. Relating the academic activities and the efficiency of each of them is essential to support the institution's management, which are assigned the decision-making role, based on the analysis of reliable and complete information [7].

To evaluate this efficiency, Data Envelopment Analysis (DEA), developed by Charnes, Cooper and Rhodes in 1978, can be used. In this context, this research aims to analyze the comparison between Engineering courses at a university Brazilian. With this, we intend to present management metrics for the respective coordinations of the courses, based on efficiency indexes, goals and benchmarks.

The work is divided into 5 sections. The first comprises the introduction about the theme, together with the objective of the work. The second section covers the theoretical foundation, with a brief explanation of the Data Envelopment Analysis in conjunction with the Two-dimensional Representation. Then, the third section will demonstrate the methodology applied in the work, with the steps for conducting the research. The fourth section presents the results achieved. And the last section, the conclusion, concerns the understanding of the entire study.

## II. THEORETICAL FOUNDATION

### a. Data Envelopment Analysis

Efficiency is the comparison between what was produced with the available inputs and what could have been produced with those same inputs [8]. To calculate efficiency there are three techniques that can be used: the Stochastic Frontier, the Malmquist Index and the Data Envelopment Analysis [9]. This work has a scope the application of the last technique, motivated by the fact of

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being a tool that since its emergence has been applied to the educational scenario.

Data Envelopment Analysis (DEA) is a tool based on mathematical programming models with the objective of measuring the efficiency of Decision Making Units (DMU's), considering multiple input variables and multiple output variables [10]. The application of DEA comprises some steps described below [8]:

- Definition and selection of DMU's: They can be defined as organizations that transform a set of inputs into a set of products or services. These DMU's must be homogeneous, so they perform the same tasks and have similar goals.
- Selection of inputs and outputs variables: Input variables, known as inputs and output variable, known as outputs. These variables must be the same for each DMU analyzed, varying only in terms of intensity. With the selected inputs and outputs, the productivity of the DMU's can be calculated, which is the ratio between the number of outputs and the number of inputs, indicating the performance of the DMU.

The last stage comprises the identification and application of the model. For this there are two classic DEA models: the CCR model that considers constant returns to scale, which considers an increase in the number of inputs, consequently, causes an increase proportional to the number of outputs; the BCC model considers variable returns to scale [10]. Figure 1 depicts the borders corresponding to the two models.

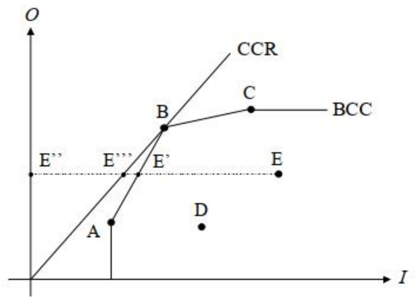

*Fig.1: BCC and CCR models efficiency frontier*

Efficient DMU's have an efficiency score of 1 and serve as a reference for inefficient DMU's, which have an efficiency score of less than 1, to become efficient [11]. In Figure 1, it is possible to see that DMU's A, B, and C are efficient ad DMU's D and E are inefficient. DEA models have two orientations: input and output. Input-oriented models aim to minimize inputs with constant outputs. The output-oriented models seek to maximize the outputs with constant inputs [12]. Chart 1 shows the model that will be used in this work.

| | **Orientation: Input** |
|---|---|
| **Configuration: Primal** | $Max \sum_{i=1}^{m} u_i y_{io} + u$<br>$s.t. \sum_{i=1}^{m} u_i y_{ik} + u - \sum_{j=1}^{n} v_j x_{jk} \leq 0, k = 1,2, \dots, z$<br>$\sum_{j=1}^{n} v_j x_{jo} = 1$<br>$u_i, v_j \geq 0;\ i = 1, \dots, m; j = 1, \dots, n$ |
| **Configuration: Dual** | $Min\ \theta$<br>$s.t. \sum_{k=1}^{z} y_{ik} . \lambda_k \geq y_{io}$<br>$\sum_{j=1}^{n} x_{jk} . \lambda_k - \theta . x_{jo} \leq 0$<br>$\lambda_k\ e\ \theta \geq 0;\ i = 1, \dots, m; j = 1, \dots, n;$<br>$k = 1, \dots, z$ |
| | **Orientation: Output** |
| **Configuration: Primal** | $Min \sum_{j=1}^{n} v_j x_{jo} + v$<br>$s.t. \sum_{i=1}^{m} u_i y_{ik} - v - \sum_{j=1}^{n} v_j x_{jk} \leq 0, k = 1,2, \dots, z$<br>$\sum_{j=1}^{n} u_i y_{io} = 1$<br>$u_i, v_j \geq 0;\ i = 1, \dots, m; j = 1, \dots, n$ |
| **Configuration: Dual** | $Max\ \eta$<br>$s.t. \sum_{k=1}^{z} x_{jk} . \lambda_k \leq x_{jo}$<br>$\sum_{j=1}^{n} y_{ik} . \lambda_k - \eta . y_{io} \geq 0$<br>$\lambda_k\ e\ \eta \geq 0;\ i = 1, \dots, m; j = 1, \dots, n; k = 1, \dots, z$ |

*Chart 1 – BCC model*

The primal configuration calculates the utilities of the DMU, while the dual configuration calculates the goals for an inefficient DMU to become efficient and to identify the

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efficient DMU's that will serve as a reference for the others [12].

### b. Two-dimensional representation

Graphical representation has been used since the seminal work of Charnes, Cooper and Rhodes (1978), aiming to demonstrate the position of each DMU in relation to the established efficiency frontier. However, this representation was limited to situations of three variables, be they two inputs and one output, or one input and two outputs. This representation is a powerful tool for decision making, for visualizing DMU's that are outside the efficiency frontier and how to make it become efficient [13].

In a study proposed by Costa, Mello and Meza (2016), two-dimensional graphical representation would encompass multiple inputs and outputs, being possible for both CCR and BCC models. For the BCC model with output orientation, the application is made as follows, as described in Chart 2.

Step 1: $$Min \frac{\sum_i v_i x_{io} + v_*}{\sum_r u_r y_{ro}}$$

$$\text{s.t. } \frac{\sum_i v_i x_{ij} + v_*}{\sum_r u_r y_{rj}} \geq 1, \forall_j$$

$$u_r \geq 0, v_i \geq 0, \forall_r, i, v_* \in R$$

Step 2: $$S_j = \sum u_{ij}$$

Step 3: $$v'_{*j} = \frac{v_{*j}}{S_j}$$

Step 4: $$I'_j = \sum_i v'_{ij} x_{ij} + v'_{*j}$$

$$O'_j = \sum_i u'_{rj} y_{rj} + u'_{*j}$$

*Chart 2 – Calculation of two-dimensional representation*

In step 1 the problem to be solved is described. Step 2 comprises the sum of all the weights of outputs, since the problem used is output oriented. Step 3 concerns the normalization of the outputs. Finally, in step 4, the calculation of virtual inputs and outputs is performed and, later, the graph is plotted.

## III. METHODOLOGHY

The current research was carried out in some stages, as shown in Figure 2.

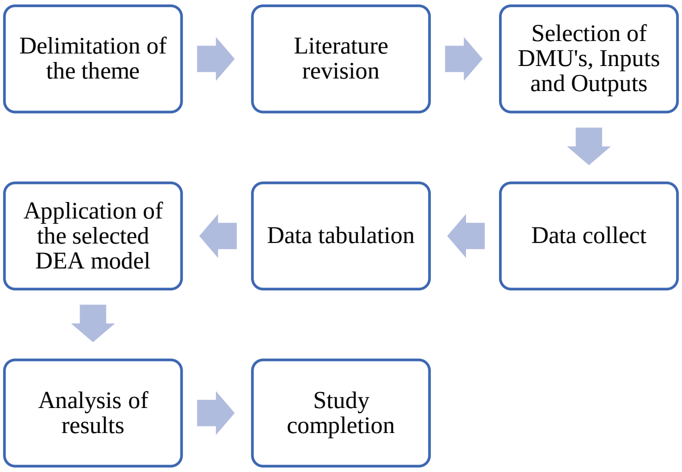


*Fig.2: Research steps*

The selected DMU's (engineering courses), as well as the inputs (number of entries and size of the faculty) and outputs (number of graduates and course concept) are demonstrated in the transformation model proposed in Figure 3.

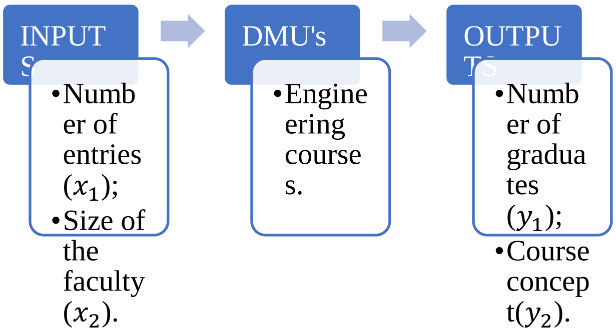


*Fig.3: Transformation model*

An application of the DEA technique was made, with the DMU's referring to the undergraduate courses in Engineering. All DMU's have the same inputs and outputs. Chart 3 shows the DMU's that will be used.

| Acronym DMU | Course | Campus |
|---|---|---|
| DMU 2.1 | Civil Engineering | C1 |
| DMU 2.2 | Civil Engineering | C2 |
| DMU 2.3 | Civil Engineering | C3 |
| DMU 2.4 | Civil Engineering | C4 |
| DMU 2.5 | Electrical Engineering | C1 |
| DMU 2.6 | Electrical Engineering | C3 |
| DMU 2.7 | Mechanical Engineering | C1 |

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| | | |
|---|---|---|
| DMU 2.8 | Mechanical Engineering | C3 |
| DMU 2.9 | Chemical Engineering | C1 |
| DMU 2.10 | Production Engineering | C1 |
| DMU 2.11 | Production Engineering | C2 |
| DMU 2.12 | Environmental and Sanitary Engineering | C4 |
| DMU 2.13 | Computer Engineering | C4 |

*Chart 3 – DMU's for undergraduate engineering courses*

Later, after deciding which DMU's, inputs and outputs would be available, it was possible to collect data. This collection was made on the institutional website of the University, where it was collected from the existing undergraduate courses on the institution's campuses, the numbers of entries and graduates (from the years 2009 to 2019) and the size of the faculty, and, finally, the concept of the course was collected on the e-MEC website. Table 1 shows the data obtained.

*Table 1 – Input and output variables*

| Acronym DMU | INPUTS | | OUTPUTS | |
|---|---|---|---|---|
| | Number of entries ($X_1$) | Size of the faculty ($X_2$) | Number of graduates ($Y_1$) | Course concept ($Y_2$) |
| DMU 2.1 | 392 | 13 | 359 | 4 |
| DMU 2.2 | 222 | 11 | 191 | 4 |
| DMU 2.3 | 164 | 14 | 144 | 3 |
| DMU 2.4 | 143 | 14 | 121 | 4 |
| DMU 2.5 | 61 | 16 | 25 | 4 |
| DMU 2.6 | 65 | 10 | 39 | 4 |
| DMU 2.7 | 338 | 13 | 282 | 4 |
| DMU 2.8 | 81 | 11 | 59 | 4 |
| DMU 2.9 | 286 | 21 | 237 | 4 |
| DMU 2.10 | 290 | 15 | 233 | 4 |
| DMU 2.11 | 60 | 12 | 37 | 3 |
| DMU 2.12 | 23 | 14 | 21 | 4 |
| DMU 2.13 | 20 | 20 | 9 | 4 |

The tabulation of data was performed in the EXCEL software, in the form of tables for the best visualization of the collected data and subsequent interpretation. That done, it is possible to apply this information in the chosen model of the DEA. Therefore, for this purpose, the output-oriented DEA BCC model was selected. This choice was made based on the articles selected for reading in the literature review, in which most of the authors used these characteristics, using as a justification the fact that the undergraduate courses observed were of different sizes. With the application of the data in the DEA model, it will be finally possible to carry out the analysis of the results obtained and finalize the study with the conclusion about it.

## IV. RESULTS

The central campus, here called C1, has 21 undergraduate courses in total, of which we can highlight the courses that are the focus of the study, Civil Engineering, Electrical Engineering, Mechanical Engineering, Chemical Engineering and Production Engineering. Campus C2 has 6 training courses, highlight Civil Engineering and Production Engineering. On campus C3, among the 7 undergraduate courses, Civil Engineering, Electrical Engineering and Mechanical Engineering stand out. Finally, campus C4 holds 7 courses, with emphasis on Civil Engineering, Environmental and Sanitary Engineering and Computer Engineering.

In this stage, 13 DMU's referring to the engineering courses of the 4 campuses of the institution will be analyzed. Performing the application in the DEA model, the efficiencies of each DMU, its clearances and the benchmarks are obtained. In table 2, it will be possible to observe these data.

*Table 2 – DMU's efficiency and benchmarks*

| | **Efficiency** | **Benchmark** |
|---|---|---|
| **DMU 2.1** | 1 | 2.1 |
| **DMU 2.2** | 1 | 2.2 |
| **DMU 2.3** | 0,9590 | 2.12 |
| **DMU 2.4** | 1 | 2.6 |
| **DMU 2.5** | 1 | 2.8 |
| **DMU 2.6** | 1 | 2.6 |
| **DMU 2.7** | 1 | 2.1 |
| **DMU 2.8** | 1 | 2.8 |
| **DMU 2.9** | 1 | 2.1 |
| **DMU 2.10** | 1 | 2.1 |

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| | | |
|---|---|---|
| **DMU 2.11** | 0,8231 | 2.12 |
| **DMU 2.12** | 1 | 2.12 |
| **DMU 2.13** | 1 | 2.13 |

According to the data obtained, it is possible to realize at the outset that DMU's 2.1, 2.2, 2.4, 2.5, 5.6, 2.7, 2.8, 2.9, 2.10, 2.12 and 2.13 are efficient. Some DMU's may have indicators that point them as efficient, but if they have clearances equal to 0, they are called as highly efficient, the opposite occurs when the clearances are different from 0, being negative or positive, these are called weakly efficient [14]. Table 3 shows the improvements that must be made to achieve efficiency.

*Table 3 – Improvements to engineering courses*

| | **Number of entries ($x_1$)** | **Size of the faculty ($x_2$)** | **Number of graduates ($y_1$)** | **Course concept ($y_2$)** |
|---|---|---|---|---|
| **2.1** | 0% | 0% | 0% | 0% |
| **2.2** | 0% | 0% | 0% | 0% |
| **2.3** | 0% | -3% | 4% | 33% |
| **2.4** | 0% | -16% | 0% | 0% |
| **2.5** | 0% | -13% | 70% | 0% |
| **2.6** | 0% | 0% | 0% | 0% |
| **2.7** | -8% | 0% | 0% | 0% |
| **2.8** | 0% | 0% | 0% | 0% |
| **2.9** | 0% | -52% | 9% | 0% |
| **2.10** | 0% | -1% | 13% | 0% |
| **2.11** | 0% | 0% | 21% | 33% |
| **2.12** | 0% | 0% | 0% | 0% |
| **2.13** | 0% | 0% | 0% | 0% |

Thus, it is possible to affirm that the DMU's that are highly efficient are 2.1, 2.2, 2.6, 2.8, 2.12 and 2.13, which correspond to the courses, respectively, of Civil Engineering at campus C1, Civil Engineering at campus C2, Electrical Engineering at campus C3, Mechanical Engineering on campus C3, Environmental and Sanitary Engineering on campus C4 and Computer Engineering on campus C4.

The units considered weakly efficient are DMU's 2.4, 2.5, 2.7, 2.9 and 2.10, which indicate, respectively, the Civil Engineering courses on campus C4, Electrical Engineering on campus C1, Mechanical Engineering on campus C1, Chemical Engineering on campus C1 and Production Engineering at campus C1.

According to the clearances presented after the application of the model, it is possible to perceive the variables that need improvement. In the Civil Engineering course at campus C4 (DMU 2.4) there was a need to reduce the size of the faculty by 16%. While the Electrical Engineering course on campus C1 (DMU 2.5) requires a 13% reduction in the size of the faculty and an increase of 70% in the number of graduates.

Mechanical Engineering on campus C1 requires an 8% reduction in the number of incoming students. The Chemical Engineering course ate campus C1 requires a 52% reduction in the size of the faculty and an increase of 9% in the number of graduates. Finally, the Production Engineering course at campus C1 needs a 1% reduction in the size of the faculty and a 13% increase in the number of graduates.

The units considered inefficient were DMU's 2.3 and 2.11, corresponding, respectively, to the Civil Engineering courses on campus C3 and Production Engineering on campus C2. To become efficient, the Civil Engineering course must reduce 3% of the faculty size, increase the number of graduates by 4% and extend the concept of the course by 33%. The Production Engineering course should expand 21% of the number of graduates and 33% of the course concept.

In view of these improvements presented, Table 4 shows the goals that the units must achieve. These goals are in line with the reduction or expansion improvements shown in the previous table.

*Table 4 – Goals of engineering courses*

| | **Number of entries ($x_1$)** | **Size of the faculty ($x_2$)** | **Number of graduates ($y_1$)** | **Course concept ($y_2$)** |
|---|---|---|---|---|
| **2.1** | 392 | 13 | 359 | 4 |
| **2.2** | 222 | 11 | 191 | 4 |
| **2.3** | 164 | 13,6 | 150,2 | 4 |
| **2.4** | 143 | 11,8 | 121 | 4 |
| **2.5** | 61 | 13,95 | 42,6 | 4 |
| **2.6** | 65 | 10 | 39 | 4 |
| **2.7** | 312,3 | 13 | 282 | 4 |
| **2.8** | 81 | 10,97 | 59 | 4 |
| **2.9** | 286 | 14,99 | 259,3 | 4 |

| | | | | |
|---|---|---|---|---|
| **2.10** | 290 | 14,9 | 263,03 | 4 |
| **2.11** | 60 | 12 | 44,9 | 4 |
| **2.12** | 23 | 14 | 21 | 4 |
| **2.13** | 20 | 20 | 9 | 4 |

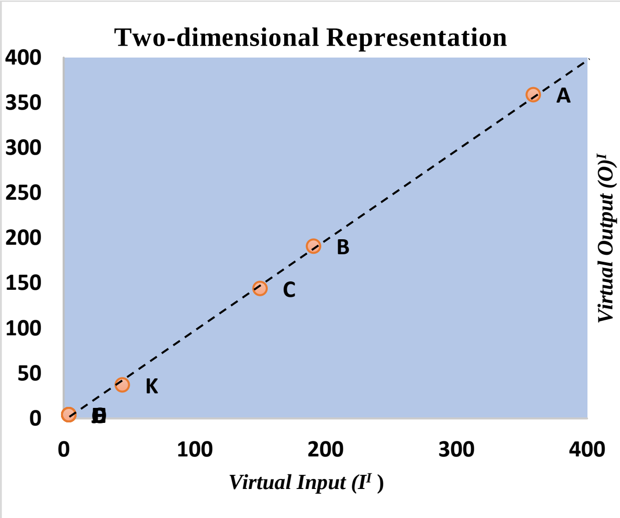
It is well known that DMU's 2.1, 2.2, 2.6, 2.8, 2.12 and 2.13 are highly efficient, as previously stated, and, for this reason, do not have goals to be achieved. However, DMU's that have shown themselves to be weak have goals. The Civil Engineering course on campus C4 (DMU 2.4) needs to decrease the faculty size from 14 to 12. The Electrical Engineering course on campus C1 (DMU 2.5) needs to reduce the faculty size from 16 to 14 and increase the number of graduates from 25 to 43. The Mechanical Engineering course on campus C1 (DMU 2.7) needs to reduce the number of incoming students from 338 to 312.

The Chemical Engineering course on campus C1 (DMU 2.9) should reduce the number of teachers from 31 to 15 and increase the number of trainees from 237 to 259. While the Production Engineering course on campus C1 (DMU 2.10), from according to the improvements, it needs to reduce the size of the faculty by 1%. However, as the percentage is very low, the reduction in numerical terms is significantly low, and the number of teachers should remain. In this same course, it is necessary to increase the number of graduates from 233 to 263.

The inefficient units previously seen are Civil Engineering on campus C3 and Production Engineering on campus C2. The first needs to reduce the size of the teaching staff by 3%, again it is a vary low percentage to interfere in numerical terms, keeping 14 teachers. The number of graduates should also be increased from 144 to 150 and the concept of the course should be increase the number of graduates from 37 to 45 and increase the concept of the course from 3 to 4.

Units that have presented goals to reduce the number of incoming students (2.7) and increase the number of graduates students (2.3, 2.5, 2.9, 2.10 and 2.11) must implement incentive policies for the increase of these graduates, thus, it will not be necessary to reduce the number of incoming students. As well as the units that need to increase the Course Concept, they must carry out incentive policies to increase the concept.

The two-dimensional representation of engineering courses is shown in Graph 1, shown below.




*Graph 1 – Two-dimensional representation of engineering courses*

In this graph it is possible to see that DMU's C and K, which correspond to DMU's 2.3 and 2.11, respectively, despite being close to the efficiency frontier, are not on top of it and, therefore, it is not considered efficient. The rest of the DMU's are on the frontier of efficiency, reaffirming what was said early and, with that, are considered efficient.

## V. CONCLUSION

The evaluation of productive efficiency is an important factor in any enterprise, as it is possible to define the opportunities for improvement of an inefficient DMU in relation to an efficient one. A technique that allows the evaluation of efficiency is the Data Envelopment Analysis, created by Charnes, Cooper and Rhodes, in 1978, and its first use has already been directed to the educational field.

This work made use of this tool, evaluating the efficiency of Engineering courses at a Brazilian university. Four variables were used, two inputs and two outputs. In the analysis, 13 engineering courses were evaluated, highlighting 11 as efficient, of these 6 are highly efficient and 5 are weakly efficient, and 2 DMU's are inefficient.

It is worth emphasizing the importance of analyzing efficiency so that managers are aware of the improvements that can be implemented so that a weakly efficient and inefficient unit reaches efficiency. It is suggested, for future work, the application of other existing techniques to carry out a comparative analysis with the current one, in addition to this application of methodology in other educational institutions and future update of the data to analyze the evolution of the courses.

## REFERENCES

[1] ALMEIDA, Mariana R.; MARIANO, Enzo B.; REBELATTO, Daisy A. N. Ferramenta para calcular a eficiência: Um procedimento para engenheiros deprodução. **COBENGE**: Ensino de Engenharia: Empreender e preservar, Passo Fundo, 2006.

[2] OLIVEIRA, Vanderlí Fava **et al**. Um estudo sobre a expansão da formação em engenharia no Brasil. *Revista de Ensino de Engenharia*, [**s. l.**], v. 32, 2013.

[3] MINISTÉRIO DA EDUCAÇÃO. **Diretrizes Curriculares Nacionais do Curso de Graduação em Engenharia, 23/01/2019**. Distrito Federal, 23 abr. 2019.

[4] LOBO, Roberto Leal; FILHO, Silva. **Demanda pela engenharia precisa ser acompanhada pelo número de formandos**. [*S. l.*], 29 maio 2017. Disponível em: https://jornal.usp.br/artigos/demanda-pela-engenharia-precisa-ser-acompanhadapelo-numero-de-formados/. Acesso em: 6 mar. 2020.

[5] BOTELLO; A. J.; SALINAS, E. M. C.; PÉREZ, D. E. R. (2015). Estudio de la satisfacción de los estudiantes con los servicios educativos brindados por instituciones de iducación superior del Valle de Toluca. ***Revista Iberoamericana sobre Calidad, Eficacia y Cambio em Educación***, v. 13, n. 2, p. 5-26

[6] LAVOR, J. F.; ANDRIOLA, W. B.; LIMA, A. S. (2016). Avaliando o impacto da qualidade da gestão acadêmica no desempenho dos cursos de graduação. Um estudo em Universidade pública Brasileira. ***Revista Iberoamericana de Evaluación Educativa***, v. 8, n. 2.

[7] CAVALCANTE, Sueli Ma.; ANDRIOLA, Wagner. Avaliação da eficiência dos cursos de graduação da Universidade Federal do Ceará (UFC) através da Análise Envoltória de Dados (DEA). ***Revista Iberoamericana de Evaluación Educativa***, [s. l.], v. 5, n. 3, 2012.

[8] MELLO, João Carlos Correia Baptista Soares **et al**. Curso de Análise de Envoltória de Dados. *Simpósio Brasileiro de Pesquisa Operacional* , Gramado, 2005.

[9] ALMEIDA, Mariana R.; MARIANO, Enzo B.; REBELATTO, Daisy A. N. Ferramenta para calcular a eficiência: Um procedimento para engenheiros de produção. **COBENGE**: Ensino de Engenharia: Empreender e preservar, Passo Fundo, 2006.

[10] CHARNES, A., COOPER, W. W. & RHODES, E. (1978). Measuring the efficiency of decision making units. European Journal of Operational Research, 2, 429-444.

[11] TAVARES, Rafael Santos; MEZA, Lidia Angulo. Uso da análise envoltória de dados para a avaliação da eficiência em cursos de graduação: Um estudo de caso em uma Instituição de Ensino Superior brasileira. **Revista Espacios**, [*s. l.*], v. 38, n.20, 2017.

[12] GIACOMELLO, Cintia Paese; OLIVEIRA, Ronald Lopes de. Análise Envoltória de Dados (DEA): Uma proposta para avaliação de desempenho de unidades acadêmicas de uma universidade. **Revista Gestão Universitária na América Latina**, Florianópolis, v. 7, n. 2, p. 130-151, 2014.

[13] COSTA, Carlos A. Bana e; MELLO, João Carlos C. B. Soares de; MEZA, Lidia Angulo. A new approach to the bi-dimensional representation of the DEA efficient frontier with multiple inputs and outputs. **Elsevier**, [*s. l.*], 13 maio 2016.

[14] FARE, R.; LOVELL, C. A. K. Measuring the technical efficiency of production. **Journal of Economic theory**, v. 19, n. 1, p. 150-162, 1978.