Evaluation of Educational Quality Under a Six Sigma Approach to Engineering Degrees in Colombia

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Abstract. In this research, a methodology is developed to measure the quality of the Colombian educational system by analyzing universities and their academic programs. For the above, a Six Sigma approach is used as a tool for educational management in order to classify, evaluate and analyze the educational system having two approaches: universities and academic programs. Consequently, this article is divided into 5 sections: In the first section, a review of research carried out on quality and HEIs is carried out. The second section presents the research methodology, describes the study population and variables. The third section shows the results derived from the application of the Six Sigma methodology. The fourth section presents the discussion and recommendations. Finally, the fifth section presents the conclusions. Now, within the most significant findings, it is found that the sigma level of the Colombian educational system is found at $Z = 2.17$ and $Y = 75\%$ and is considered, according to what is established in the methodology of this work, as an acceptable level.

Keywords: Six Sigma · Higher education · Learning analytics · Continuous improvement · Quality

1 Introduction

The increase in competitive pressure in the goods and services industries constantly forces the search for new ways to improve their performance, be competitive, and thus, sustain in the long term [1–4]. This unleashes several requirements and challenges for all organizations, for example, to have in their work team a skilled staff that manages to help the company grow. Consequently, Higher Education Institutions (HEIs) are not exempt from these requirements, since they are the ones that provide professionals with the competencies and skills required by companies [2, 5, 6].

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According to the above, the objective of HEIs should be framed in the training of competent professionals who are capable of adapting to the volatility of the environment; in this way, these professionals will help industry and society in their development [7, 8]. Amador and Martínez [9] affirm that the supplier-client relationship between HEIs and organizations is of vital importance, due to the creation of a collaborative work culture called "win-win". Consequently, one of the main concerns of HEIs is to comply with the minimum standards associated with factors such as infrastructure, projection, relevance, and resources, which respond to institutional accreditations, which are granted by independent agencies [10]. But first, HEIs must prepare themselves to be evaluated, for this, they must have tools that are useful for educational management and to be able to meet the objectives set.

Therefore, in this research, a Six Sigma approach is used as a tool for educational management to classify, evaluate and analyze the educational system with two approaches: universities and academic programs. It should be noted that this research takes into account only the academic results of the national standardized assessments in Colombia (SABER PRO). Accordingly, this article is divided into 5 sections: In the first section, the review of research conducted around quality and HEIs are carried out. The second section presents the research methodology and describes the population and variables of the study. In the third section, the results derived from the application of the Six Sigma methodology are shown. In the fourth section, the discussion and recommendations are presented. Finally, the fifth section presents the conclusions.

2 Literature Review

2.1 Assessing Quality in the Service Industry

Throughout these last years, new concepts and approaches to service quality have been added to the literature, in addition to the vast existence of comments on the interpretation, contributions, and variants of quality in services, and how important it is nowadays in competitive scenarios. On the other hand, services for [11] are a means to deliver value and benefits to customers at a specific time and place producing the desired change in favor of the service. Services must have a tactical approach and function in managing the nature of the service, as well as having a clear scope of service quality, customer expectations, and quality particularities. However, when evaluating service quality, customer perception is the ideal and most commonly used perspective. The Service Quality (SERVQUAL) model proposed more than two decades ago is still in force and is still an important reference for the evaluation of quality in various services [12].

Service quality in organizations is the measure of the degree to which the service provided meets customer expectations [13]. The success of business activity will depend on the perceived quality of service delivery. Therefore, the ability of a company or organization to estimate the quality of service is a prerequisite for achieving a high level of quality in that service provision [14, 15].

2.2 Application of Six Sigma in the Service Industry

Six Sigma applies the Define, Measure, Analyze, Improve, and Control (DMAIC) methodology, which is a perfect fit for effective process improvement. Likewise, to

permeate quality in products must be done from the design phase, a preventive approach to design for Six Sigma (DFSS) De-sign for Six Sigma [16] is needed. The main objective of Six Sigma is to increase the sigma level by reducing defects per million opportunities (DPMO) [17]. This quality tool aims to achieve as close to perfection as possible, is used in many organizations, and is based on evidence, analytics of inputs, and procedures [18]. Likewise, throughout the implementation of Six Sigma, statistical tools are used for the characterization and study of the processes (hence the name of the tool), since sigma is the standard deviation that gives a clue of how the variability is in the process and the main objective is to reduce it so that the process is in the limits established by the customer requirements [19].

Now, implementing Six Sigma allows the elimination of all activities that do not add value to the process. Six Sigma makes significant contributions in the main areas of the organizations that influence the long and medium-term performance periods, such as process design, process approach and improvement, broad participation in problem-solving, knowledge sharing, goal setting, supplier selection, and data-driven decision making [20].

Six Sigma is a powerful methodology that ultimately helps to reduce costs due to defect prevention and improvement of products and processes, leading to increased profitability, where customer satisfaction and competitiveness are at the center of focus for any quality improvement practice and performance measurement. Likewise, the relationship between Six Sigma and service in some research is named as Six Sigma Transactional Service because it provides organizations with a disciplined approach to improve service efficiency and effectiveness [21–23].

2.3 Application of Six Sigma in Higher Education

When talking about quality and the terms of Six Sigma in education, it is established that the IES is completely different from what usually the quality of services and the Six Sigma tool face. In that same order of ideas, the experience to be evaluated is divided into two areas: the evaluation of the quality in the teaching and learning process, and the evaluation of the quality taking into account the student's experience. The latter involves the development of specific instruments and mechanisms for service quality assessment for the environment of higher education institutions. Education is an important organization to give a change to the economy through knowledge. The market of higher education institutions has led to their students being highly regarded as customers/consumers. Additionally, in the education sector where even though there is no product involved, the service provided will impact the competitive demarcation between institutions in terms of their superiority. The evaluation of service quality in HEIs can provide an important contribution and inputs which will be of excellent help for the administrative side to make decisions to further improve the quality of their education [13].

Although most of the concepts of the Six Sigma tool are built for manufacturing industries, they are related to the educational service. The scope given to Six Sigma in education is commonly used in very specific cases of improvement or in conjunction with the Baldrige Criteria for Performance Excellence to facilitate application to educational structures [24].

However, there are divided opinions regarding the implementation of six sigma in the field of education, for example, waste and rework in the educational environment differs in terms of tangibility to how it is in manufacturing industries, wherein the latter has a physically noticeable impact [25].

3 Methodology

The present research is evaluative and consists of five stages (see Fig. 1). The first stage is contextualization; here we seek to establish the units of the study and determine the dimensions of quality. The second stage seeks to apply the evaluation metrics to universities and academic programs. The third stage seeks to analyze the universities and academic programs in terms of the results of the metrics. And finally, the fourth stage consists of performing an analysis of the compliant and non-compliant units of the study.

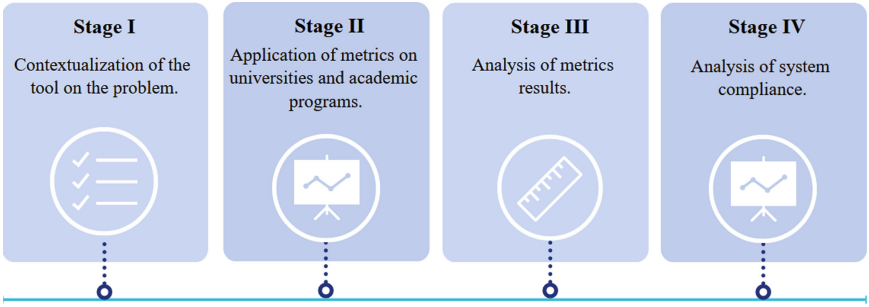

Fig. 1. Research methodology

3.1 Population

The database used contains 12,411 observations, each one representing one student. These observations come from 135 universities and 8 academic programs (Industrial, Civil, Mechanical, Chemical, Chemical, Electronic, Electrical, Aeronautical, and Control Engineering). In this research the database is summarized combining universities and academic programs, leaving a total of 265 observations to analyze (academic programs taking into account the university). It should be noted that the analysis of the research has two approaches, the first is an analysis by universities (135 observations) and the second is by academic programs (265 observations).

3.2 Academic Competencies

The SABER PRO tests are designed by the Colombian Institute for the Evaluation of Education (ICFES) and seek to measure the quality of public and private universities, whether they are accredited or not. The tests are applied to students who complete their

Table 1. Information on the study variables.

Variable	Name	Mean
QR	Quantitative reasoning	77,42
CR	Critical reading	62,20
CS	Citizenship skills	59,19
ENG	English	67,50
WC	Written communication	53,70

Source. Information taken from Dataset of academic performance evolution for engineering students [26].

professional training and consist of two parts: the first evaluates the generic competencies of all professionals, the second evaluates the specific competencies of the academic program to which a student belongs; consequently, for the development of this research, the generic competencies module was selected, which correspond to those presented in Table 1.

3.3 Quality Dimensions

To perform the analysis by universities and academic programs, it was established that the quality dimensions for the educational service correspond to each competency evaluated in the SABER PRO test: Quantitative Reasoning (QR), Critical Reading (CR), Citizenship Competencies (CS), Written Communication (WC) and English (ENG). On the other hand, Table 2 shows the conforming and non-conforming levels associated with the academic competencies. It should be noted that the information contained in the orientation guide for the SABER PRO tests offered by ICFES (2020) was used to establish the levels of conformity and non-conformity. These levels correspond to the achievement reached by the student in each competency, with the lowest level being those students with the lowest scores in the evaluation results, while the highest level corresponds to the students with the highest scores in the evaluation results. On the other hand, an additional interpretation of the levels corresponds to the measurement of the development of academic competencies for problem-solving.

Table 2. Information on the configuration of skill levels.

Competencies	Number of levels	Non-conforming levels	Conforming levels
QR	3	I, II	III
ENG	5	I, II, III	IV, V
CR	3	I, II	III
CS	5	I, II, III	IV, V
WC	8	I, II, III, IV, V	VI, VII, VII

Now, taking into account Table 2, the proportion of compliant and non-compliant observations of the universities in the study is presented at the global level as shown in Table 3.

Table 3. Proportion of compliant and non-compliant results in the universities of the study example at the global level.

Universities	Proportion of compliant	
	Compliant	Non-compliant
Universidad de Los Andes	88,79%	11,21%
Universidad de La Sabana	78,31%	21,69%
Universidad Nacional Sede Medellín	82,67%	17,33%
Universidad del Norte	82,96%	17,04%
Corporación Universitaria Comfacauca	41,20%	58,80%
Universidad Autónoma de Manizales	55,87%	44,13%
Fundación Universitaria Los Libertadores	41,72%	58,28%
Universidad de La Guajira	34,80%	65,20%

4 Results

In this chapter it is important to align the concepts of the Six Sigma methodology to the objective of this research, that is why it is necessary to relate each metric of the model with the study group and educational context, as shown in Table 5.

Table 4. Description of performance in relation to Sigma Level and Yield for the dimensions to be evaluated.

Performance	Sigma level	Yield
Deficient	$Z < 2$	$Y < 69{,}1\%$
Acceptable	$2 \leq Z \leq 3$	$69{,}1\% \leq Y \leq 93{,}3\%$
Good	$3 \leq Z \leq 4$	$93{,}3\% \leq Y \leq 99{,}4\%$
Excellent	$Z > 4$	$Y \geq 99{,}4\%$

Source. Adapted from Evaluation of service quality through Six Sigma in a university document service center [27].

On the other hand, the relationship between the Six Sigma metrics and the educational context in Table 5 is done as follows [28, 29]: The parameter U is the study population, for this research it is the universities. Parameter O corresponds to the opportunities for error

found in the competencies evaluated in the SABER PRO test and means the number of times that an observation (student) can fail (see Table 4). Parameter n, on the other hand, is the non-compliant observations. The parameter Y is the performance of the university that varies between 0 and 1, taking into account the reference values established in Table 5. Finally, Defects Per Million Opportunities (DPMO) is the number of observed defects extrapolated to every million opportunities for defects.

Table 5. Quantitative relation of the different concepts of the Six Sigma in the variables of the study.

Metrics	Study definition
U	Total number of universities evaluated (Tests evaluated)
O	Chance of error
n	Total unsatisfactory results (for each competency)
Y	Yield of evaluated universities
DPMO	Defects per million opportunities metric

4.1 Six Sigma Results Analysis

Now, in the same sense, for the representation and application of the Six Sigma metrics in this study, 8 universities were taken as examples, under the criteria that 4 are the universities with the best performances in the SABER PRO tests and the other 4 are universities with average performances in these tests.

Table 6 shows that the Quality Dimension evaluated with the best performance on average is the English proficiency where the highest Yield is 99.79% obtained by the Universidad de Los Andes. On the other hand, the Quality Dimension with the lowest average performance is Critical Reading, where the lowest Yield is 60.20%, which corresponds to the Universidad de La Guajira.

Table 6. Six Sigma Metrics for the Universities taken as an example for this study.

University	Metrics	Quality dimensions evaluated				
		QR	CR	CS	ENG	WC
Universidad de Los Andes	DPMO	31828,47	368018,87	192639,4	14860,3	316693,19
	YIELD	99,46%	93,86%	95,9%	99,79%	94,71%

(*continued*)

Table 7 shows the proportion of conformity of the results of the academic programs of the universities in the study. The quality dimension with the highest proportion of conformity is English in all academic programs, and the program with the highest proportion

Table 6. (*continued*)

University	Metrics	Quality dimensions evaluated				
		QR	CR	CS	ENG	WC
	Z	4,43	3,06	3,46	4,48	3,11
Universidad de La Sabana	DPMO	223328,7	223328,7	172313,7	23046,3	77197,8
	YIELD	88,82%	88,82%	91,38%	98,84%	96,13%
	Z	2,73	2,73	2,85	3,81	3,27
Universidad de Nacional Sede Medellin	DPMO	15625	477087,73	339160,51	93370,42	486857,47
	YIELD	99,68%	90,44%	93,21%	97,90%	90,25%
	Z	4,73	2,85	3	3,54	2,80
Universidad del Norte	DPMO	195631,11	379779,95	333763,64	44227,22	321505,44
	YIELD	96,08%	90,02%	93,31%	99,11%	93,56%
	Z	3,26	2,79	2,40	4,87	3,08
Corporación Universitaria Comfacauca	DPMO	235294,12	1663348	196078,43	176470,59	164705,88
	YIELD	76,47%	66,73%	80,39%	82,35%	83,52%
	Z	2,22	1,93	2,35	2,42	2,47
Universidad Autónoma de Manizales	DPMO	138235,2	814705,88	629411,76	145098,03	377647,05
	YIELD	95,3%	72,8%	79,01%	95,16%	87,00%
	Z	3,66	2,10	2,31	3,63	2,65
Fundación Universitaria Los Libertadores	DPMO	868007,1	663348	1094315	670994,8	741295,2
	YIELD	78,29%	66,73%	78,11	86,58%	78,11
	Z	2,29	1,93	2,27	2,62	2,27
Universidad de La Guajira	DPMO	893752	1518120	751164,6	751054,6	407095
	YIELD	70,20%	60,28%	81,22%	74,96%	78,82%
	Z	2,03	1,80	2,40	2,18	2,78

Table 7. Proportion of compliance with results by academic program.

Academic program	Percentage of compliance of academic competencies assessed				
	QR	CR	CS	ENG	WC
Industrial engineering	84,73%	67,72%	73,76%	87,91%	69,47%
Civil engineering	90,58%	76,47%	78,52%	86,17%	62,94%
Mechanical engineering	89,76%	73,22%	72,04%	88,58%	62,2%
Chemical engineering	92,55%	79,78%	82,26%	97,87%	71,98%
Electronic engineering	90,54%	81,08%	78,37%	95,94%	55,4%
Electrical engineering	91,66%	81,66%	83,33%	96,66%	76,66%
Control engineering	72,09%	44,18%	44,18%	69,76%	32,55%
Aeronautical engineering	100%	63,63%	72,72%	90,9%	45,45%

of conforming results for this dimension is Chemical Engineering. On the other hand, the quality dimension with the lowest proportion of compliant results in the academic programs is Written Communication, being Chemical Engineering the program with the highest proportion of compliant results for this dimension and Control Engineering the one with the lowest proportion for this dimension (Table 8).

In terms of Six Sigma, the dimension evaluated with the highest performance is the English competency, on average for all academic programs, being Chemical Engineering and Electrical Engineering the programs with the highest performance in this dimension and competency, with Yield = 99.17% and Yield = 99.27% respectively. On the other hand, the Quality Dimension evaluated with the lowest performance on average for all academic programs is Critical Reading. However, the program with the highest performance in this dimension is Electrical Engineering with a Yield = 92.75% and the program with the lowest performance for this dimension is Aeronautical Engineering with a Yield = 72.09%.

4.2 Conformity Analysis

This section analyzes the system according to the level of conformity. Consequently, Fig. 2 shows each competency associated with its percentage of compliant units per level.

Figure 3 shows the percentage of compliant units taking into account the accreditation of the HEI.

On the other hand, Table 9 shows the average results of the competencies by the accredited and non-accredited universities. Note that the competencies with the highest average correspond to ENG and QR for both accredited and non-accredited universities; on the other hand, the competencies with the lowest average are WC and CS for accredited universities and CR and CS for non-accredited universities.

Similarly, as Table 9 is developed, an analysis is performed for the average of compliant and non-compliant units (see Table 10). As can be seen, the competencies with

Table 8. Six Sigma metrics for the academic programs of the Universities used in the study at a global level.

Academic program	Metrics	Quality dimensions assessed				
		QR	CR	CS	ENG	WC
Industrial engineering	DPMO	1122120,01	1869111,87	3384732,63	789371,82	721147,4
	YIELD	85,95%	76,38%	85,81%	90,01%	90,98%
	Z	2,93	1,78	2,31	3,13	2,88
Civil engineering	DPMO	264873,18	483218,27	265633,21	229794,36	290451,56
	YIELD	93,37%	84,94%	93,27%	94,25%	92,73%
	Z	3,69	2,66	3,03	3,40	2,96
Mechanical engineering	DPMO	659191,17	1310864,36	956860,22	540641,80	672267,10
	YIELD	89,01%	78,15%	94,12%	99,17%	94,08%
	Z	3,47	2,82	3,06	3,96	3,06
Chemical engineering	DPMO	100951,81	291231,46	176226,80	24722,03	77383,50
	YIELD	96,63%	90,28%	94,12%	99,17%	96,08%
	Z	3,47	2,82	3,06	3,96	3,06
Electronic engineering	DPMO	260683,75	697115,38	437179,36	111111,11	486495,71
	YIELD	93,48%	82,57%	87,81%	97,22%	87,83%
	Z	3,88	2,56	2,75	4,43	2,78
Electrical engineering	DPMO	54347,82	144409,93	72463,76	14492,75	100621,11
	YIELD	97,28%	92,75%	96,37%	99,27%	94,96%
	Z	4,05	3,01	3,97	4,34	3,14
Control engineering	DPMO	0	181818,18	90909,09	30303,03	109090,90
	YIELD	100%	81,81%	90,90%	96,96%	89,09%
	Z	5	2,40	2,83	3,37	2,73
Aeronautical engineering	DPMO	139534,88	279069,76	186046,51	100775,19	134883,7
	YIELD	86,04%	72,09%	81,39%	89,92%	86,51%
	Z	2,58	2,08	2,39	2,77	2,60

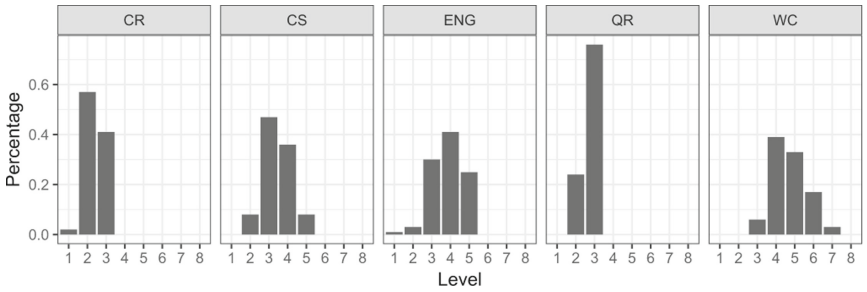

Fig. 2. Distribution of the study population.

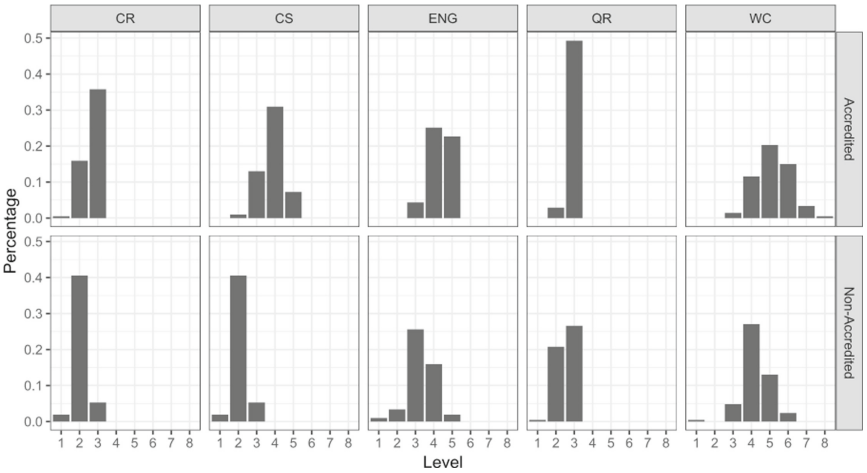

Fig. 3. Proportion of accreditation of the universities in the study.

Table 9. Average of competencies by accreditation.

Competencies	Accredited	Non-accredited
QR	81,83	65,26
CR	67,02	48,98
ENG	72,40	53,16
WC	61,42	49,39
CS	63,54	47,58

the highest averages are CR and CR for both the group of compliant and non-compliant units. On the other hand, the competencies with the lowest averages are WC and CS for the conforming group and ENG and CS for the non-conforming group.

Table 10. Average of competencies per compliance.

Competencies	Compliant	Non-compliant
QR	79,43	57,41
CR	74,65	49,55
ENG	72,68	48,46
WC	69,83	49,25
CS	69,66	46,15

Now, with the support of Fig. 3, Table 11 is constructed, showing the averages of the competencies according to the conformity and accreditation of the unit. It is observed that the highest averages of the competencies for the accredited and compliant universities correspond to CR and CR; the lowest averages correspond to the competencies WC and CS. For the non-accredited and compliant universities, the highest averages are for CR and CR; in contrast, the competencies with the lowest averages are WC and CS. On the other hand, for the accredited and non-compliant universities, the highest averages are for the competencies QR and CR, in contrast, the competencies with the lowest averages are ENG and CS. Finally, the competencies with the highest averages of the non-accredited and non-compliant universities are ENG and QR, in contrast, the competencies with the lowest averages are WC and CS.

Finally, an analysis is presented in the Pareto diagram (see Fig. 4), in the diagram it can be observed that 76.81% of the non-compliant results are concentrated in the first

Table 11. Average of competencies by compliance and accreditation.

Competencies	State	Accredited	Non-accredited
QR	Compliant	83,95	74,90
	Non-compliant	61,11	57,09
CR	Compliant	75,08	72,03
	Non-compliant	56,84	47,84
ENG	Compliant	74,87	68,73
	Non-compliant	53,61	48,06
WC	Compliant	70,54	68,23
	Non-compliant	54,86	47,43
CS	Compliant	70,54	67,27
	Non-compliant	51,72	44,96

three competencies which are Written Communication (WC), Critical Reading (CR), and Citizenship Competencies (CS). Therefore, this indicates that the performance of the study population can be improved if they focus on these three competencies, and consequently the quality level of the HEIs will increase.

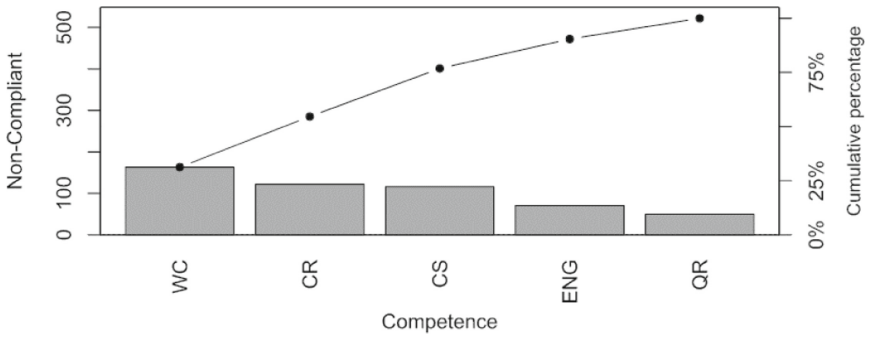

Fig. 4. Cause analysis using the Pareto diagram.

5 Discussion

As is well known, the success of the application of the Six Sigma methodology depends mainly on the identification and selection of the factors that influence the quality of the system being evaluated [30]. In this regard, our research takes as a premise that professional performance and success depends on the development of students' core competencies [31, 32], therefore, the analysis resources for this research are students' professional core competencies: Quantitative Reasoning, Critical Reading, English, Written Communication, and Citizenship Competencies.

Reviewing the applications of Six Sigma in the literature to evaluate educational quality we found that: Paramasivam and Muthusamy [33] develop research that aims to identify the critical factors that are necessary in the working world, and because of this, engineers must have them in their curriculum, through the DMAIC approach of Six Sigma, they manage to identify that the critical factors are: Washington Accord, Outcome Based Education (OBE), Problem Based Learning (PBL), Theory for Inventive Problem Solving (TRIZ), Project-Based Learning, Case-Based Learning (CBL), internships and Continuous Quality Improvement (CQI). Mehrabi [30] in his work identifies that the success of Six Sigma implementation in the educational sector depends on the selection of factors, therefore, the author proposes to consider in the implementation of Six Sigma factors such as management participation, organizational commitment, project management, skills management, cultural change, and continuous training. In contrast to the works presented, Adina-Petruta and Roxana [34] in their work present how the Six Sigma methodology integrated with the ISO 9000 quality model helps the development, continuous improvement, and success of HEIs. On the other hand, Ameen Abdulla et al. [35] in their research seek to ensure quality according to the criteria proposed by the

National Board of Accreditation India (NBA), to achieve their objective the authors used various Six Sigma techniques under the DMAIC methodology, within their results they identified that the versatility of the program curriculum, laboratories, workshops and credibility among universities are important factors for quality assurance, in addition, they add that with the Six Sigma tool it is possible to mitigate the defects found. Finally, we can highlight the research of MacIel-Monteon et al. [36], these authors propose the design and validation of an instrument to evaluate the implementation of the critical success factors during the execution of the Six Sigma methodology for the improvement of HEIs. Of eleven factors studied in their work, the authors determined as truly critical the participation, managerial commitment, linkage of Six Sigma with the institutional strategy, linkage of Six Sigma with suppliers, communication, and selection of team members.

From the works presented above, it can be pointed out that specific factors are selected that are mostly applied to a particular area of knowledge; on the other hand, in MacIel-Monteon's research, a significant contribution is generated by proposing a methodology to validate the implementation of Six Sigma according to the selected factors. Considering the above, it can be highlighted that the present research makes use of the basic competencies as inputs of the Six Sigma methodology to generate a greater opportunity for improvement on the system. In addition, our methodology can be applied to any area of knowledge because these basic competencies are transversal for all professionals.

6 Conclusions

The significant contribution of this research is the evaluation of the educational quality of universities in Colombia and their respective programs with the Six Sigma tool. The tool is usually applied to the manufacturing sector and gradually has been implemented in other sectors such as education. In this research, the evaluation process of the educational quality is highlighted using as inputs of our system the results obtained in the standardized tests SABER PRO in the Colombian universities of the engineering programs.

In the same way, the results of this research show the pertinence that exists to combine and structure concepts of educational quality with the metrics of Six Sigma, allowing to design a standard of the performance of the universities for the improvement of the quality of the educational system employing the contextualization of Six Sigma. This is important because it allows improving the education sector in Colombia, allowing to continue forming and building the professionals of the country that will contribute from their different knowledge for the development of the society.

Following this same order of ideas, the following conclusions can be drawn: first, the quality of the education sector presents an acceptable performance, taking into account its sigma level and Yield (2.17 and 75%). Surely, the methodology applied for this study allowed a quantitative analysis, through the use of the dimensions of quality proposed for this study (academic competencies) and the relationship with the metrics of the Six Sigma tool, which made it possible to perform a holistic evaluation and analysis of the educational service. However, this research is left as a basis for future works related to the evaluation of the educational quality in universities and its contribution to the quality of the Colombian educational sector.

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