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Management of calibration intervals for temperature and static pressure transmitters applied to the natural gas industry

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A B S T R A C T

The commercialization of natural gas in Brazil is carried out on a volumetric basis. To guarantee reliability of this quantity, it is of paramount importance to have metrological control of static pressure and temperature among other items. With a view to meeting this demand, the Brazilian Regulations defines the fixed interval for calibration, but it may be extended using historical data, without however specifying the statistical tool to be used in the study. Four statistical techniques widely published in literature have been selected to establish the interval of calibration for the temperature and static pressure transmitters in natural gas networks with ultrasonic meters. This article uses a modified SWOT (Strengths-Weaknesses-Opportunities-Threats) analysis, with weightings for each indicator, to define the statistical tool with the greatest potential, extracting from it the new calibration interval for the cases studied. The results show that, in truth, the calibration intervals could at least be extended from 90 days to 180 days in custody transfer measurements, according to the revision of the Brazilian Regulations.

1. Introduction

The oil shocks in the 1970s, followed by the increases in international interest rates, imposed a revision of the Brazilian energy policies. Among the measures taken to effect this substitution was the increase of Brazilian production of oil and also the use of natural gas. Within this scenario, the policy adopted by the Brazilian Federal Government had the firm intention of raising the participation of natural gas (NG) in the national energy matrix by the year 2030, from the then 12 %–15.5 % (Vasconcelos et al., 2013).

In the middle of 2013, in Brazil, the National Agency for Oil, Natural Gas and Biofuels (ANP) and the National Institute of Metrology, Quality and Technology (INMETRO) published the revision of Joint Resolution No. 1. This Resolution regulates the measurement of oil and natural gas, bringing great benefits to the sector, but also great challenges for the regulated agents in this area (Brazilian National Agency of Petroleum, 2013).

All of the measurement instruments must meet the metrology technical regulations in force, including the calibrations and dimensional inspections required in these regulations, executed at the expense and risk of the regulated agent.

The measurement of natural gas has presently become highly relevant, because it is through this process that a great effort is made by the regulated agent to make its measurement systems appropriate for the new rules and calibration intervals established as from the revision of the Joint Resolution.

According to Joint Resolution No. 1, it was determined that the new calibration intervals of temperature and pressure transmitters, changed from 90 days to 180 days, for custody transfer measurement without any study being divulged.

One point of special interest is that the Resolution establishes that the calibration intervals may be altered at the request of the regulated agent. In this process, the regulated agent must present to ANP a series of technical documents, which justify the alteration in frequency of calibration, aiming at assuring the reliability of the results of future measurements. Notwithstanding, the Resolution does not indicate the statistical techniques and analytical methods to be used by the regulated agent for the purposes of authorization by the ANP for the alteration of calibration frequency required.

The objective of this study is to identify and analyze the applicability of tools (statistical and support strategies for the decision making) for the study into re-evaluating the calibration intervals of

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the instruments for temperature and static pressure utilized in natural gas networks in Brazil. This is justified because the regulatory agent does not establish the statistical technique to be used, and the diversity of techniques could lead to different intervals of calibration.

The principal motivations for studying the importance in re-evaluating the frequency of calibration are the direct impacts that it could have on costs and the preservation of metrological reliability of the equipment (Oliveira et al., 2015).

The costs arising from the calibration process must be measured constantly, considering that, on increasing the frequency of calibration, if subject to the risk of uncertainty being increased, this could compromise the metrological reliability of the measurement equipment, operational costs and quality through adequate adjustment of intervals between calibrations.

2. Methodology

Based on the precepts established by International Organization of Legal Metrology (OIML) D10 (2007), the process to determine the intervals of calibration is a complex mathematical and statistical one that needs highly reliable data during the calibration procedure. The principal factors that impact the interval of calibration are (OIML D10, 2007):

- Uncertainty of measurement required or declared by the laboratory;
- Risk of a measurement instrument exceeding the admissible maximum error limits when in use;
- Cost of correction measures necessary when it is verified that the instrument has not been appropriate over a long period of time;
- Type of instrument and tendency to wear and to drift;
- Recommendation of the manufacturer and extension and severity of the utilization;
- Environmental conditions (climatic, vibration, ionic radiation, etc …);
- Data of tendency obtained from records of previous calibrations;
- Recorded history of maintenance and repairs;
- Frequency of crossing data with other standards of reference or measuring devices;
- Frequency and quality of calibrations and qualified labor.

The gamut of measuring instruments, associated with the non-existence of a specific methodology in literature, for adjustment of the intervals between calibrations, permits that, in the event of the laboratory responsible for the calibration developing (which is optional) a method, this may be used, given that it is duly validated and documented. Such results must be collected as historical data, with the intention of basing future decisions on the determination of the interval of calibration.

Independent of the frequency of calibrating the instruments, it is worth underlining that the laboratory needs to be structured in a way that provides an adequate system of calibration, thus guaranteeing: the quality of its calibrations, the efficacy of the quality system, and the traceability of the results of its standards. That is to say that it must guarantee the good operation and condition of the calibration of standards and the instruments of calibration.

Starting from the diversity of existing approaches to estimate the interval of calibrations, this study proposes a tool to support decision making (Guarnone et al., 2012), a modified SWOT (Strengths-Weaknesses-Opportunities-Threats) analysis, with a view to helping the user in the choice of the approach with the greatest potential.

2.1. *Methods for revising calibration intervals — statistical tools*

Due to the variety of methods available for revising calibration intervals, this work approaches instruments that are treated individually or as groups (for example, model from the manufacturer or by type).

Within this scope, four different approaches are presented, which may be utilized to evaluate calibration intervals.

The three initial approaches are considered by sampling, while the last one is considered by population: adjustment of the interval by drift; adjustment based on the three previous calibrations — on a weighted basis; Schumacher method and Poisson method.

The sampling approach uses a subset (sample) of the population data. This evaluation is carried out individually by instruments, although the frequency is the same, being associated to the shortest interval defined by the method chosen among the instruments installed. The population approach determines a calibration interval based on the performance of similar instruments used in a similar way.

2.1.1. *Adjustment of the interval for drift*

Based on International vocabulary of metrology — Basic and general concepts and associated terms, VIM (2012), instrumental drift is "continuous or incremental change over time in indication, due to changes in metrological properties of a measuring instrument".

Instrumental drift is not related either to a change in a quantity being measured or to a change of any recognized influence quantity (VIM, 2012).

This approach calculates the drift of the history over a determined period, D_{period}, Equation (1):

$$D_{period} = \frac{\frac{Drift_1}{period_1} + \frac{Drift_2}{period_2} + \frac{Drift_3}{period_3} + \cdots + \frac{Drift_n}{period_n}}{n} \qquad (1)$$

Then, the estimated period of validity is given by Equation (2):

$$Calibration\ interval = \frac{Criterion\ of\ acceptance}{D_{period}} \qquad (2)$$

Where:

- $Drift_n$ is the variation of the indication throughout time;
- $period_n$ is the time in days, months, etc.;
- n is the number of instruments;
- *Criterion of acceptance* is the maximum or minimum value acceptable.

2.1.2. *Adjustment based on the last three calibrations (on a weighted basis) (NCLSI, 2010)*

In this approach, the new calibration interval is calculated from the weighting between the period and the status of the calibration, Equation (3).

$$NI = CI(W_1X + W_2Y + W_3Z) \qquad (3)$$

In this expression:

- NI = new interval calculated; CI = current interval of calibration;
- W_1 = Weighting of most recent calibration = 0.8; W_2 = Weighting of penultimate calibration = 0.2;
- W_3 = Weighting of the antepenultimate calibration = 0.1;
- X = Multiplier referring to the most recent calibration;
- Y = Multiplier referring to the penultimate calibration;

- Z = Multiplier referring to the antepenultimate calibration.

X, Y and Z assume the following numerical values (A, B, C, D or E) depending on the status of the last calibrations:

- A = Result of the last calibration within the criterion of acceptance = 1;
- B = Result of the last calibration outside the criterion of acceptance, up to one time = 0.8;
- C = Result of the last calibration outside the criterion of acceptance, up to twice = 0.6;
- D = Result of the last calibration outside the criterion of acceptance, up to four times = 0.4;
- E = Result of the last calibration outside the criterion of acceptance, more than four times = 0.3.

2.1.3. *Schumacher Method (NCSLI, 2010)*

In this approach, the instruments are classified according to the conditions in which they are found, based on the historical records where the conditions of revalidation are registered. In these records the following notations are used:

- A (Damage): designates the problem that could prejudice one or more parameters of the instrument;
- C (Conformity): designates conformity proven during the revalidation;
- F (Outside the Tolerance): the instrument works well, but outside the specified tolerance (does not conform).

In the event of altered tolerances, they could lead to classifications A or F.

Taking the information obtained through the historical records as a base, it may be deduced in respect of the instruments.

For example, an instrument that "conforms" is not going to improve its status from "conform" only by the fact of being revalidated; it could occur that the instrument becomes damaged as a result of unnecessary revalidations.

The sequence of C (Conformity) in the historical records indicates that the instrument has always been "conform" and the conclusion is immediate. In this case the calibration becomes unnecessary, thereby making it possible to lengthen the cycle of calibration.

Similarly, a sequence of A (Damage) indicates the existence of problems, making a reduction in the cycle of calibrations obvious and necessary, together with research into the cause of the problem.

There could arise intermediate cases, such as results varying among A (Damage), C (Conform) and F (Out of Tolerance). This being the case, the information registered in the records is going to enable the taking of a decision in respect of the length of the cycles.

Based on the condition the equipment was received in, and the two or three calibrations before, the decision to be taken may be determined through Table 1.

These decisions may be expressed by the letters as follows:

- D = Indicates that the period should diminish; E = Indicates that the period should be extended;
- P = Indicates doubt and the period should not be altered;
- M = Indicates that the reduction in the period should be the maximum possible.

Based on the decision made using Table 1, and the present period of calibration, the new period of calibration is defined through Table 2.

Table 1
Decision to be made.

Condition			
In previous periods	On receipt		
	A	F	C
CCC	P	D	E
FCC	P	D	P
ACC	P	D	E
CF	M	M	P
CA	M	M	P
FC	P	M	P
FF	M	M	P
FA	M	M	P
AC	P	D	P
AF	M	M	P
AA	M	M	P

Table 2
New calibration intervals.

Present period	New calibration intervals (weeks)			
	D	E	P	M
5	4	7	5	[a]
6	5	8	6	5
8	7	10	8	5
10	9	13	10	6
12	11	15	12	7
14	13	17	14	8
16	14	19	16	10
18	16	21	18	12
20	18	24	20	13
24	22	28	24	15
28	25	32	28	19
32	29	37	32	21
36	32	41	36	24
52	47	52	52	27

[a] Separate this equipment. It is not constructive to reduce the period to less than 4 (four) weeks.

2.1.4. *Poisson Method or approach based on Bayesian predictive distribution (Huang, 2010)*

In this approach, the relationship between the total set of instruments calibrated and those outside the criterion for acceptance due to time, have an exponential character.

The interval of calibration is calculated to meet a determined level of confidence and furnish exactitude for the estimate.

The calculation of the new interval of calibration is based on Equations (4)–(6):

$$\lambda = \frac{\sum C}{T} \tag{4}$$

$$T = \sum_{j=1}^{m} n_j t_j \tag{5}$$

$$I = \frac{-\ln(R)}{\lambda} \tag{6}$$

Where:

- C is the total number of instruments rejected;
- λ is the rate that indicates the values outside the tolerance;
- n_j is the number of instruments calibrated;
- t_j is the present interval of calibration;
- R is the level of confidence, 0.95 (95%);

- m is the number of events (instruments versus intervals) involved in the calibrations;
- I is the new interval of calibration.

2.1.5. Comparing the statistical methods

In order to help readers to compare these statistical methods, some advantages and shortcomings that do not depend on the application are available in Table 3. These complete parameters applied to calculate the best calibration interval of temperature and static pressure transmitters applied to the natural gas industry are available in item 4.1.

2.2. Support tool for decision making

The SWOT analysis is frequently used to verify, evaluate and support decision making in internal and external environments of an organization. Due to being easily understood and applied, it may be adapted or combined with other tools to strengthen its application. The SWOT analysis is divided into the following groups: strengths, weaknesses, opportunities and threats. The purpose of using SWOT is to identify the key elements, which aligned with the objectives (present and future), provide support for strategic decision making (Görener et al., 2012), Fig. 1 and Table 3.

To analyze the strong points, weak points, opportunities or threats in a company or statistical techniques as set out in this article, becomes an important support instrument in the making of decisions. This is because through a detailed analysis and the processing of certain data, it is possible to generate information that subsequently enables and assists the making of those decisions that need to be made, having the results obtained through analysis and the crossing of pre-established criteria as a basis. According to Daychoum (2013), starting from the result of the SWOT, a more detailed analysis is possible that will help in the choices for strategic decisions in the present and future.

Accordingly, starting from the results of these analyses, the choice of a technique as proposed in this article becomes more consistent.

After the definition of the indicators (or criteria) which will comprise the strong points, weak points, opportunities and threats, the specialists in the area – calibration of temperature and static pressure transmitters applied to the natural gas industry – will evaluate the weighting for the criteria, which characterizes a modified and innovative approach. This approach does not form part of the traditional SWOT matrix, it gets closer to an Analytic Hierarchy Method (AHP) (Wu et al., 2014). The next step is to attribute grades to these criteria with a view to evaluating the degree of influence between the statistical technique and the criterion, using Equation (7).

$$\text{Point of each cell} = w_1 \times w_2 \times g \tag{7}$$

where:

- w_1 is the weighting referring to the criterion that comprises a strong or weak point;

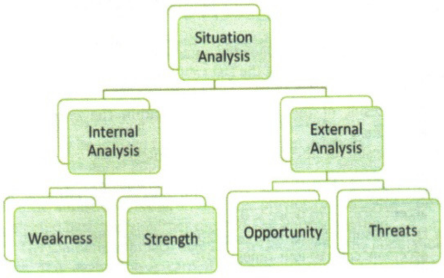


Fig. 1. Flowchart of SWOT matrix.

- w_2 is the weighting referring to the criterion that comprises an opportunity or threat;
- g is the grade applied to the crossing of the criteria referring to w_1 and w_2.

After the processing of the data inserted above, the calculation of the quadrants is begun. Table 4 has the purpose of showing which technique obtained the highest score, utilizing the Equations (8)–(11).

$$QD(I) = \text{Sum of the points from quadrant I} \tag{8}$$

$$QD(II) = \text{Sum of the points from quadrant II} \tag{9}$$

$$QD(III) = \text{Sum of the points from quadrant III} \tag{10}$$

$$QD(IV) = \text{Sum of the points from quadrant IV} \tag{11}$$

$QD(I)–QD(III)$ represents offensive capacity while $QD(II)–QD(IV)$ represents defensive capacity.

After finding the value of each quadrant, the total value of the global strategic planning of each statistical technique is computed by Equation (12):

$$Total = QD(I) - QD(III) + QD(II) - QD(IV) \tag{12}$$

3. Experimental analysis

96 transmitters approached in this article are from the suppliers: ROSEMOUNT, SMAR, YOKOGAWA and SIEMENS, which are utilized in ultrasonic measurement systems in natural gas networks in Brazil, for custody transfer applications. These sensors are located in the States of Espírito Santo, Rio de Janeiro, Minas Gerais, São Paulo and North, Northern Northeast, Southern Northeast of Brazil, and the experimental data were collected during 2011 and 2012.

The acceptance criteria utilized for the evaluation of the acceptance criteria between successive calibrations are the following: (Oliveira, 2006)

Table 3
Advantages and shortcomings of each statistical approach.

	Advantages	Shortcomings
Drift Method	Statistical support and time of sample collection	Lack of representation of the sample and robustness
Schumacher Method	Facility of application and credibility	Robustness and statistical support
Weighted Method	Time of sample collection and statistical support	Lack of representation of the sample
Poisson Method	Time of sample collection, statistical support and credibility	Difficulty of application

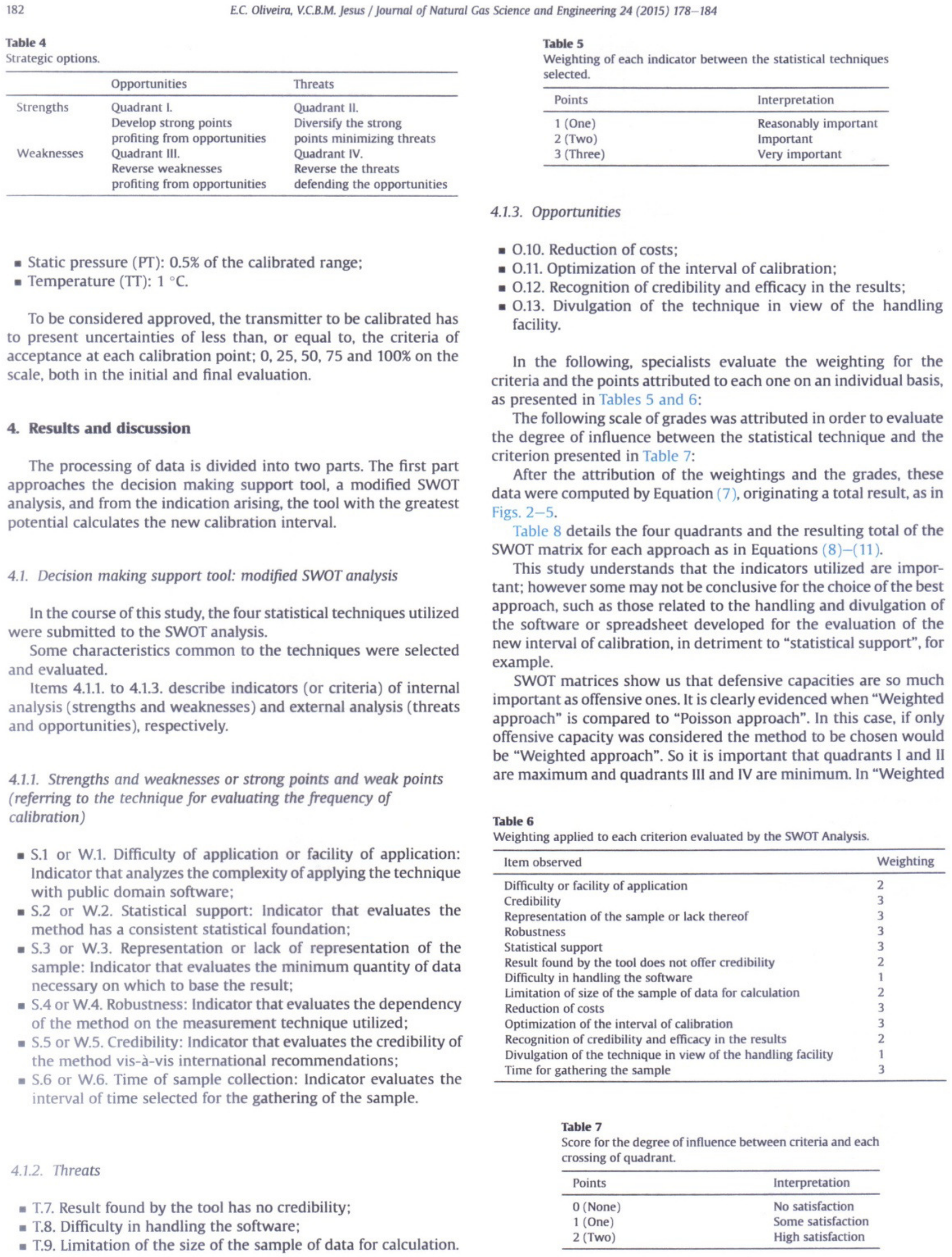


Table 4
Strategic options.

	Opportunities	Threats
Strengths	Quadrant I. Develop strong points profiting from opportunities	Quadrant II. Diversify the strong points minimizing threats
Weaknesses	Quadrant III. Reverse weaknesses profiting from opportunities	Quadrant IV. Reverse the threats defending the opportunities

- Static pressure (PT): 0.5% of the calibrated range;
- Temperature (TT): 1 °C.

To be considered approved, the transmitter to be calibrated has to present uncertainties of less than, or equal to, the criteria of acceptance at each calibration point; 0, 25, 50, 75 and 100% on the scale, both in the initial and final evaluation.

4. Results and discussion

The processing of data is divided into two parts. The first part approaches the decision making support tool, a modified SWOT analysis, and from the indication arising, the tool with the greatest potential calculates the new calibration interval.

4.1. *Decision making support tool: modified SWOT analysis*

In the course of this study, the four statistical techniques utilized were submitted to the SWOT analysis.

Some characteristics common to the techniques were selected and evaluated.

Items 4.1.1. to 4.1.3. describe indicators (or criteria) of internal analysis (strengths and weaknesses) and external analysis (threats and opportunities), respectively.

4.1.1. *Strengths and weaknesses or strong points and weak points (referring to the technique for evaluating the frequency of calibration)*

- S.1 or W.1. Difficulty of application or facility of application: Indicator that analyzes the complexity of applying the technique with public domain software;
- S.2 or W.2. Statistical support: Indicator that evaluates the method has a consistent statistical foundation;
- S.3 or W.3. Representation or lack of representation of the sample: Indicator that evaluates the minimum quantity of data necessary on which to base the result;
- S.4 or W.4. Robustness: Indicator that evaluates the dependency of the method on the measurement technique utilized;
- S.5 or W.5. Credibility: Indicator that evaluates the credibility of the method vis-à-vis international recommendations;
- S.6 or W.6. Time of sample collection: Indicator evaluates the interval of time selected for the gathering of the sample.

4.1.2. *Threats*

- T.7. Result found by the tool has no credibility;
- T.8. Difficulty in handling the software;
- T.9. Limitation of the size of the sample of data for calculation.

Table 5
Weighting of each indicator between the statistical techniques selected.

Points	Interpretation
1 (One)	Reasonably important
2 (Two)	Important
3 (Three)	Very important

4.1.3. *Opportunities*

- O.10. Reduction of costs;
- O.11. Optimization of the interval of calibration;
- O.12. Recognition of credibility and efficacy in the results;
- O.13. Divulgation of the technique in view of the handling facility.

In the following, specialists evaluate the weighting for the criteria and the points attributed to each one on an individual basis, as presented in Tables 5 and 6:

The following scale of grades was attributed in order to evaluate the degree of influence between the statistical technique and the criterion presented in Table 7:

After the attribution of the weightings and the grades, these data were computed by Equation (7), originating a total result, as in Figs. 2–5.

Table 8 details the four quadrants and the resulting total of the SWOT matrix for each approach as in Equations (8)–(11).

This study understands that the indicators utilized are important; however some may not be conclusive for the choice of the best approach, such as those related to the handling and divulgation of the software or spreadsheet developed for the evaluation of the new interval of calibration, in detriment to "statistical support", for example.

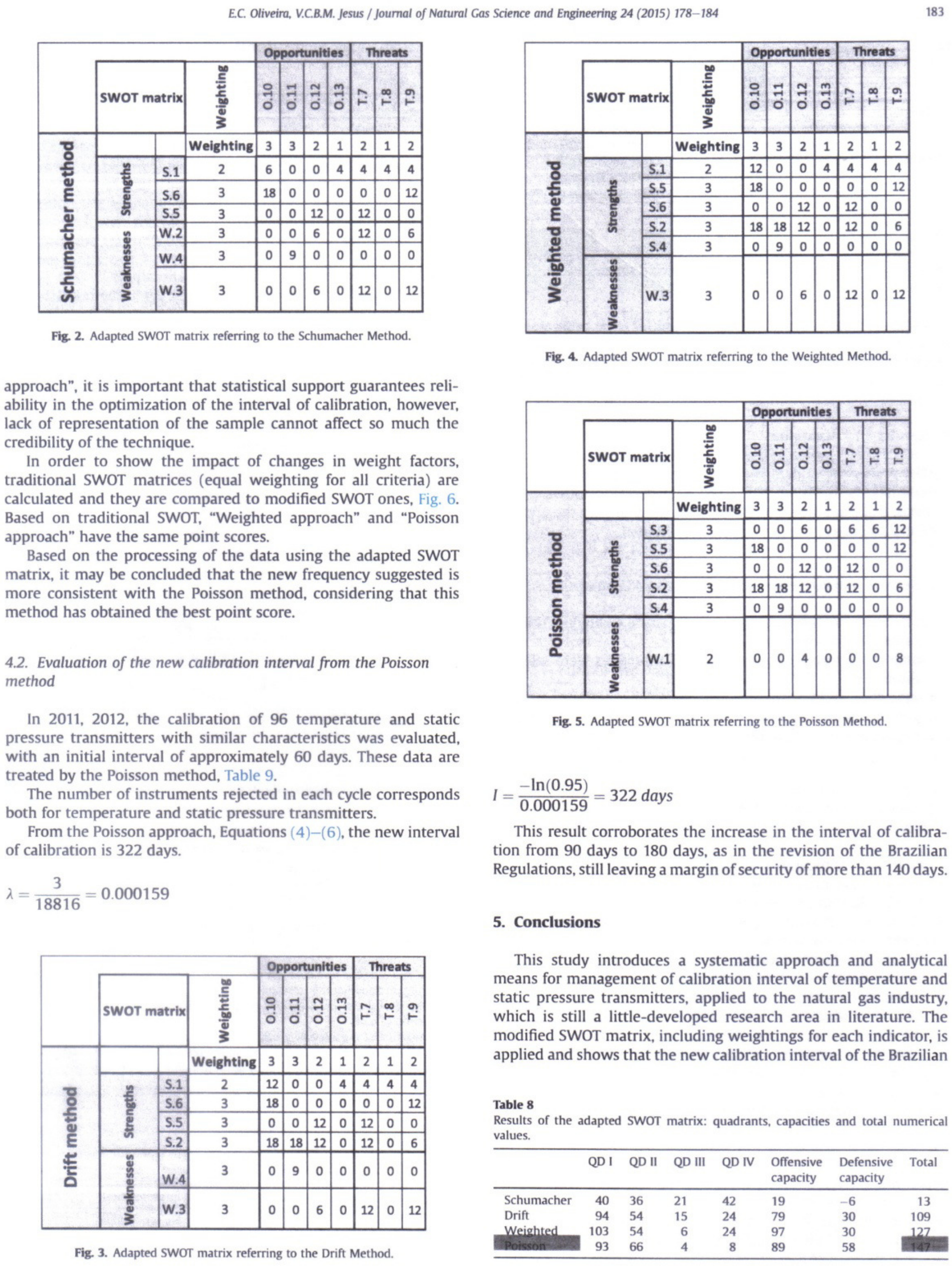
SWOT matrices show us that defensive capacities are so much important as offensive ones. It is clearly evidenced when "Weighted approach" is compared to "Poisson approach". In this case, if only offensive capacity was considered the method to be chosen would be "Weighted approach". So it is important that quadrants I and II are maximum and quadrants III and IV are minimum. In "Weighted

Table 6
Weighting applied to each criterion evaluated by the SWOT Analysis.

Item observed	Weighting
Difficulty or facility of application	2
Credibility	3
Representation of the sample or lack thereof	3
Robustness	3
Statistical support	3
Result found by the tool does not offer credibility	2
Difficulty in handling the software	1
Limitation of size of the sample of data for calculation	2
Reduction of costs	3
Optimization of the interval of calibration	3
Recognition of credibility and efficacy in the results	2
Divulgation of the technique in view of the handling facility	1
Time for gathering the sample	3

Table 7
Score for the degree of influence between criteria and each crossing of quadrant.

Points	Interpretation
0 (None)	No satisfaction
1 (One)	Some satisfaction
2 (Two)	High satisfaction



		SWOT matrix	Weighting	Opportunities				Threats		
				O.10	O.11	O.12	O.13	T.7	T.8	T.9
Schumacher method			Weighting	3	3	2	1	2	1	2
	Strengths	S.1	2	6	0	0	4	4	4	4
		S.6	3	18	0	0	0	0	0	12
		S.5	3	0	0	12	0	12	0	0
	Weaknesses	W.2	3	0	0	6	0	12	0	6
		W.4	3	0	9	0	0	0	0	0
		W.3	3	0	0	6	0	12	0	12

Fig. 2. Adapted SWOT matrix referring to the Schumacher Method.

approach", it is important that statistical support guarantees reliability in the optimization of the interval of calibration, however, lack of representation of the sample cannot affect so much the credibility of the technique.

In order to show the impact of changes in weight factors, traditional SWOT matrices (equal weighting for all criteria) are calculated and they are compared to modified SWOT ones, Fig. 6. Based on traditional SWOT, "Weighted approach" and "Poisson approach" have the same point scores.

Based on the processing of the data using the adapted SWOT matrix, it may be concluded that the new frequency suggested is more consistent with the Poisson method, considering that this method has obtained the best point score.

4.2. Evaluation of the new calibration interval from the Poisson method

In 2011, 2012, the calibration of 96 temperature and static pressure transmitters with similar characteristics was evaluated, with an initial interval of approximately 60 days. These data are treated by the Poisson method, Table 9.

The number of instruments rejected in each cycle corresponds both for temperature and static pressure transmitters.

From the Poisson approach, Equations (4)–(6), the new interval of calibration is 322 days.

$$\lambda = \frac{3}{18816} = 0.000159$$

		SWOT matrix	Weighting	Opportunities				Threats		
				O.10	O.11	O.12	O.13	T.7	T.8	T.9
Drift method			Weighting	3	3	2	1	2	1	2
	Strengths	S.1	2	12	0	0	4	4	4	4
		S.6	3	18	0	0	0	0	0	12
		S.5	3	0	0	12	0	12	0	0
		S.2	3	18	18	12	0	12	0	6
	Weaknesses	W.4	3	0	9	0	0	0	0	0
		W.3	3	0	0	6	0	12	0	12

Fig. 3. Adapted SWOT matrix referring to the Drift Method.

		SWOT matrix	Weighting	Opportunities				Threats		
				O.10	O.11	O.12	O.13	T.7	T.8	T.9
Weighted method			Weighting	3	3	2	1	2	1	2
	Strengths	S.1	2	12	0	0	4	4	4	4
		S.5	3	18	0	0	0	0	0	12
		S.6	3	0	0	12	0	12	0	0
		S.2	3	18	18	12	0	12	0	6
		S.4	3	0	9	0	0	0	0	0
	Weaknesses	W.3	3	0	0	6	0	12	0	12

Fig. 4. Adapted SWOT matrix referring to the Weighted Method.

		SWOT matrix	Weighting	Opportunities				Threats		
				O.10	O.11	O.12	O.13	T.7	T.8	T.9
Poisson method			Weighting	3	3	2	1	2	1	2
	Strengths	S.3	3	0	0	6	0	6	6	12
		S.5	3	18	0	0	0	0	0	12
		S.6	3	0	0	12	0	12	0	0
		S.2	3	18	18	12	0	12	0	6
		S.4	3	0	9	0	0	0	0	0
	Weaknesses	W.1	2	0	0	4	0	0	0	8

Fig. 5. Adapted SWOT matrix referring to the Poisson Method.

$$I = \frac{-\ln(0.95)}{0.000159} = 322\ days$$

This result corroborates the increase in the interval of calibration from 90 days to 180 days, as in the revision of the Brazilian Regulations, still leaving a margin of security of more than 140 days.

5. Conclusions

This study introduces a systematic approach and analytical means for management of calibration interval of temperature and static pressure transmitters, applied to the natural gas industry, which is still a little-developed research area in literature. The modified SWOT matrix, including weightings for each indicator, is applied and shows that the new calibration interval of the Brazilian

Table 8
Results of the adapted SWOT matrix: quadrants, capacities and total numerical values.

	QD I	QD II	QD III	QD IV	Offensive capacity	Defensive capacity	Total
Schumacher	40	36	21	42	19	−6	13
Drift	94	54	15	24	79	30	109
Weighted	103	54	6	24	97	30	127
Poisson	93	66	4	8	89	58	147

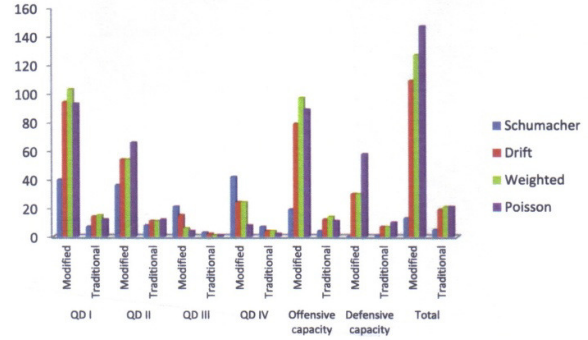


Fig. 6. Comparison of all quadrants of each (modified and traditional) SWOT matrix.

Table 9
Results of the adapted SWOT matrix: quadrants and total.

Interval in days (t_j)	Instruments calibrated (n_j)	Instruments rejected (C)	$n_j t_j$
56	16	3	896
112	16	0	1792
168	16	0	2688
224	16	0	3584
280	16	0	4480
336	16	0	5376
Sum	96	3	18,816 (T)

Regulation revision is suitable. This innovation highlights that not all indicators are equally important and that different conclusions can be reached when using the traditional SWOT matrix and the modified one. The outcome was the grading of interval of calibration approaches, helping the user to choose a statistical tool within the several that could reach different conclusions. The Poisson approach is the utmost relevance in the interval of calibration process.

This study is important because the calibration interval proposed here, 322 days, is well above of the last revision of the Brazilian Regulation, 180 days. Firstly, it has a margin of safety; on the other hand, costs can be optimized if a larger interval of calibration can be reached without endangering the management of the calibration process of temperature and static pressure transmitters as applied to the natural gas industry.

As future work, this research group intends to apply this methodology to evaluate the calibration interval of ultrasonic meters, which is not yet consolidated in the natural gas industry.

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