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A Mathematical Model to Estimate the Cost of The Absence of Ergonomics and The Financial Impact of Non-Compliance in Organizations: An Economic-Focused Approach to Ergonomics Management

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Abstract

The absence of ergonomics in organizations can lead to significant economic costs and legal penalties. This study presents a mathematical model to estimate the Economic Cost of the Absence of Ergonomics (CAE) and the financial impact of regulatory non-compliance, based on Brazilian Regulatory Standards NR 17 and NR 28. The model incorporates the severity of nonconformities (G_i), company size (E), and an interpolation between the minimum and maximum penalty values defined by law. Applied to real ergonomic assessment reports, the model enables calculation of the Nonconformity Index (ID) and the Total Estimated Penalty (PT), providing objective parameters on organizational exposure due to lack of ergonomic compliance. The results indicate that proactive ergonomics management helps reduce financial impacts and promotes organizational maturity. The proposed tool supports managerial decision-making based on normative and quantitative criteria.

***Keywords**: Cost of absence of ergonomics, Occupational risk management, Ergonomics.*

1. Introduction

Ergonomics has been globally established as a fundamental element for safety, health, and efficiency within organizational environments. The proper implementation of ergonomic practices contributes to reducing occupational diseases, enhancing worker well-being, and enabling productivity gains within organizations. Conversely, the absence or insufficiency of these practices in the productive environment can yield significant negative impacts from both human and economic perspectives.

In Brazilian organizations, compliance with Regulatory Standards (Normas Regulamentadoras) is an essential legal requirement. This includes, in particular, NR 17 (which addresses Ergonomics) and NR 28 (which regulates penalties for non-compliance). However, this observance does not preclude adherence to other standards set forth by the Ministry of Labor and Employment (MTE). Furthermore, one such standard, NR 01, mandates the implementation of a Risk Management Program (PGR). The PGR is a fundamental instrument for identifying, assessing, and controlling occupational hazards, including those often mischaracterized as "Ergonomic Risks.[1]"

Integrating the PGR with other standards is essential for ensuring effective risk management and promoting regulatory compliance, thereby mitigating adverse economic and operational impacts. However, the quantification of economic costs associated with the absence of ergonomics still lacks robust mathematical models. Specifically, there is a need for models that integrate regulatory and financial aspects in a practical, applicable manner. This gap is particularly evident for methods and methodologies grounded in macro ergonomic

[1] *Ergonomics is understood as a scientific discipline dedicated to the prevention, identification, and correction of mismatches between work and the worker. Therefore, in this study, Ergonomics is not treated as a risk in itself, but rather as a field of study and professional practice aimed at minimizing risks of other natures (physical, cognitive, or organizational). Consequently, the risks discussed herein are defined as those arising from the absence or inadequate application of Ergonomics.*

analyses and supported by the Regulatory Standards of the Brazilian Ministry of Labor and Employment (MTE).

Within the Brazilian context, this study introduces an innovative mathematical model to estimate the Economic Cost of the Absence of Ergonomics (CAE) and the financial impact of regulatory non-compliance in organizations. The model considers the severity of ergonomic non-conformities—based on NR 17—and company size, utilizing interpolation between the minimum and maximum penalties legally stipulated in NR 28. The application of the model to several real-world reports allows for the quantification of the non-conformity index (ID) and the estimated total penalty (PT), providing a quantitative tool that supports ergonomic and financial management within organizations.

The significance of this study lies in providing a technical basis for managers to make informed decisions based on the proposed model's results. This enables them to prioritize investments and actions that enhance ergonomic conditions in work environments, reducing financial and human risks, while simultaneously advancing the organization's ergonomic maturity.

2. Literature Review

Ergonomics, as noted, is a multidisciplinary scientific field aimed at the adequate optimization of the interaction between humans and elements of productive systems, promoting safe, healthy, and efficient working conditions (Dul et al., 2012). In the contemporary organizational context, Ergonomics management is increasingly recognized as a strategic vector affecting not only occupational health but also financial results and business competitiveness (Wilson, 2000; Carayon et al., 2014).

Over the last few decades, the literature has demonstrated significant advances in applied computational mathematical modeling; the field of Ergonomics is no exception. Various models have been proposed, though for specific purposes, including, among others, those cited below.

- Ergonomic risk assessment: Quantitative models have been used to measure exposure to risk factors, such as awkward postures, repetitive movements, and force exertion, allowing for the identification of critical tasks and supporting prioritization (e.g., OCRA, REBA, etc.) (Rocha, 2016).
- Work system optimization: Mathematical techniques have been applied to the design and redesign of workstations, tools, and operational sequences, aiming to minimize the physical and cognitive load on workers (Chapanis, 1996; Konz & Johnson, 2008).
- Human performance analysis: Predictive models, based on equations or computational algorithms, have been used to estimate performance under conditions of fatigue, mental load, and reaction time, contributing to the definition of safe work limits (Mehta & Parasuraman, 2002; Salvendy, 2012).
- Cost-benefit analysis: Recent literature has sought to integrate economic aspects into ergonomic models, estimating the costs associated with the absence of interventions (e.g., leave of absence, accidents, absenteeism) compared to the benefits derived from their implementation (Vink & Imbeau, 2020; Goggins et al., 2008).

Scenario simulation: Mathematical and computational models, including techniques such as discrete-event simulation, augmented reality, system dynamics, and neural networks, have been employed to virtually test ergonomic interventions before execution, reducing risks and optimizing decisions (Rocha & Cassano, 2020).

The diversity and complexity of these models vary widely, ranging from simplified approaches for index calculation to robust structures employing mathematical optimization, artificial intelligence, and integration with cyber-physical systems in industrial environments. However, these are tools for specific applications that address highly particular aspects. That is, for broad-spectrum (diverse situations) and large-scale (high number of evaluation foci) scenarios, this approach is less applicable given the multifaceted context. Thus, these approaches fulfill a very specific and delimited measurement and application role.

In the Brazilian scenario, Ergonomics is regulated by Regulatory Standard 17 (NR 17), which defines parameters for adapting work conditions to the psychophysiological characteristics of workers. Complementarily, NR 28 establishes the penalties applicable to non-compliance with regulatory standards, while NR 01 mandates the Risk Management Program (PGR). The PGR explicitly includes the necessity of mapping and addressing risks arising from the absence of Ergonomics (e.g., psychosocial) as objects of identification, evaluation, and control (Brasil, 2024).

Despite international advances, a gap is observed in the national literature regarding the integration of mathematical models applicable to the Preliminary Ergonomic Assessment (AEP) and current legal provisions. Few studies address the quantification of the financial impact of non-compliance with NR 17 using the penalties defined by NR 28 as a measurable economic variable. This proposed work seeks to fill this gap by proposing a mathematical model that promotes transparency in how fines are applied, in addition to calculating the Cost of the Absence of

Ergonomics (CAE). The model considers the severity of non-conformities, company size, and an interpolation between the minimum and maximum penalty values stipulated in the labor legislation. In doing so, this work contributes to the advancement of applied Ergonomics with a normative-financial approach capable of supporting Ergonomic Management based on quantitative evidence.

3. Methodology

This study introduces a mathematical model to estimate the Economic Cost of the Absence of Ergonomics (CAE) within organizations, integrating technical, regulatory, and financial aspects derived from the Brazilian legal framework. The model is specifically grounded in Regulatory Standards (NR) 17, which defines ergonomic parameters, and NR 28, which stipulates the applicable penalties for non-compliance.

The model was constructed to provide a quantitative tool applicable to real-world organizational scenarios. It is designed to transform qualitative data on ergonomic non-conformities into financial and risk indicators. It allows for the standardized calculation of the Total Penalty (PT)—the estimated financial impact—and the Non-conformity Index (ID). The ID is a dimensionless metric of ergonomic exposure, enabling interpretations comparable to standard risk indices.

3.1. General Structure of the Model

The model considers three groups of variables:

1. The severity of the non-conformities, as classified by NR 28 (Levels I to IV).
2. The company size, determined by the number of employees (ranging from 1 to over 1000).
3. The interpolation between the minimum and maximum penalty values applicable to each severity level and company size, based on the official matrix in NR 28 (2024) (Annex I-A).

3.2. Calculation of the Non-conformity Index (ID)

The Non-conformity Index (ID) is a dimensionless metric that reflects an organization's risk load from the Absence of Ergonomics. It is calculated using the following model proposed herein:

$$ID = \frac{\sum_{i=1}^{D}(G_i \,.\, w_i)}{\sum w_i}$$

Where

ID: The Non-conformity Index, a dimensionless metric.
D: total number of non-conformities found.
G_i: severity of non-conformity i, with integer values provided by NR 28:

Minor = 1
Medium = 2
Serious = 3
Critical = 4

w_i: weight of the non-conformity, representing its impact.

Low impact = 1.0
Moderate impact = 1.5
High impact = 2.0
$\sum_{i=1}^{D}(G_i . w_i)$: is the summation of all products (Severity w_i) for each non-conformity found.
$\sum w$: is the summation of all assigned weights.

Table 1: Interpretive scale for the Non-conformity Index (ID)

Risk Level	ID Range	Interpretation
Very Low	1.00 – 1.60	Average severity close to 'Minor'
Low	1.61 – 2.20	Average severity approaching 'Medium'
Moderate	2.21 – 2.80	Average severity between 'Medium' and 'Serious'
High	2.81 – 3.40	Average severity close to 'Serious'
Critical	3.41 – 4.00	Average severity trending towards 'Critical'

3.3. Calculation of the Total Penalty (PT)

The Total Penalty (PT) is estimated based on the monetary values stipulated by NR 28 (2024). It utilizes an interpolation between the minimum and maximum value for each severity level and company size, derived from the regulatory classification of the issue in question. In this regard, the following equation is proposed:

$$PT = \sum_{i=1}^{D}[V_{min}(G_i\,, E) + r_i.\,(V_{max}\,(G_i\,, E) - \,V_{min}\,(G_i\,, E))]$$

Where

- D: total number of non-conformities found;
- G_i : severity of non-conformity i (1 to 4 → Minor to Critical);
- E: company size bracket (based on number of employees, 1 to over 1000);

- $V_{min}\ (G_i\ , E)$: minimum fine value from the NR 28 table for severity G_i and size bracket E.;
- $V_{max}\ (G_i\ , E)$: maximum fine value from the NR 28 table for severity G_i and size bracket E.;
- r_i: interpolation factor for non-conformity i, with values from 0 to 1.

This calculation allows for the simulation of both conservative scenarios (r_i= 0) and critical scenarios (with r_i= 1), as well as more realistic intermediate situations.

The r_i factor enables the representation of intermediate severity levels, adjusting the penalty to reflect the reality of the observed situation within legal limits. It can be interpreted according to the following proposition.

Table 2: Interpolation factor (r_i) scale

Scenario	r_i *Value*	**Technical Justification**
Conservative	0.25	Controllable situation, isolated non-conformity
Moderate	0.50	Recurrent situation, medium impact
Severe	0.75	Critical situation, with actual risks
Maximum	1.00	Extreme or recurring situation

Reference Table (NR 28 - Annex I)

NR 28 defines fines based on two criteria arising from the non-conformities found: (a) the severity of the infraction and (b) the number of company employees. To find the fine value, $\mathrm{E} = (\mathrm{e}_{\mathrm{lc}})_{8 \times 16}$ is used. In this matrix, the row l indicates the number of employees in the organization, while the column c indicates the severity of the infraction, which may vary according to the risk classification between the fields of Occupational Safety and Occupational Medicine.

Table 3: Matrix E – Number of Employees vs. Infraction Severity in Reais (R$)

		OCCUPATIONAL SAFETY FINES (R$)							
		C1		C2		C3		C4	
		MINOR		MEDIUM		SERIOUS		CRITICAL	
		I1		I2		I3		I4	
	Employees	Min	Max	Min	Max	Min	Max	Min	Max
l1	01-10	R$ 2.993,00	R$ 3.463,33	R$ 5.363,65	R$ 6.617,86	R$ 8.033,60	R$ 9.933,92	R$ 10.698,80	R$ 13.264,23
l2	11-25	R$ 3.468,08	R$ 3.943,16	R$ 6.622,62	R$ 7.905,33	R$ 9.938,67	R$ 11.853,25	R$ 13.268,98	R$ 15.839,17
l3	26-50	R$ 3.947,91	R$ 4.446,75	R$ 7.910,08	R$ 9.192,80	R$ 11.858,00	R$ 13.767,82	R$ 15.843,92	R$ 18.414,10
l4	51-100	R$ 4.579,77	R$ 5.244,88	R$ 9.197,55	R$ 10.451,76	R$ 13.772,57	R$ 15.687,14	R$ 18.418,85	R$ 20.989,03
l5	101-250	R$ 5.249,63	R$ 5.895,74	R$ 10.456,51	R$ 11.739,23	R$ 15.691,89	R$ 17.663,47	R$ 20.993,79	R$ 23.506,96
l6	`251-500	R$ 5.900,49	R$ 6.527,60	R$ 11.743,98	R$ 13.055,20	R$ 17.668,23	R$ 19.578,05	R$ 23.511,71	R$ 26.081,89
l7	501-1000	R$ 6.532,35	R$ 7.159,46	R$ 13.059,95	R$ 14.347,42	R$ 19.582,80	R$ 21.497,37	R$ 26.086,64	R$ 28.661,58
l8	+1000	R$ 7.164,21	R$ 7.819,82	R$ 14.352,17	R$ 15.601,63	R$ 21.502,12	R$ 23.416,69	R$ 28.666,33	R$ 29.949,04

		OCCUPATIONAL MEDICINE FINES (R$)							
		C1		C2		C3		C4	
		MINOR		MEDIUM		SERIOUS		CRITICAL	
		I1		I2		I3		I4	
	Employees	Min	Max	Min	Max	Min	Max	Min	Max
l1	01-10	R$ 1.795,80	R$ 2.033,34	R$ 3.211,54	R$ 3.985,92	R$ 4.822,06	R$ 5.957,50	R$ 6.413,58	R$ 7.981,34
l2	11-25	R$ 2.038,09	R$ 2.365,90	R$ 3.990,67	R$ 4.760,30	R$ 5.962,25	R$ 7.126,20	R$ 7.986,09	R$ 9.492,10
l3	26-50	R$ 2.370,65	R$ 2.755,46	R$ 4.765,05	R$ 5.539,43	R$ 7.130,95	R$ 8.294,90	R$ 9.496,85	R$ 11.021,86
l4	51-100	R$ 2.760,21	R$ 3.145,03	R$ 5.544,18	R$ 6.290,06	R$ 8.299,65	R$ 9.435,09	R$ 11.026,61	R$ 12.580,12
l5	101-250	R$ 3.149,78	R$ 3.534,60	R$ 6.294,81	R$ 7.040,69	R$ 9.439,84	R$ 10.570,53	R$ 12.584,87	R$ 14.138,38
l6	`251-500	R$ 3.539,35	R$ 3.924,16	R$ 7.045,44	R$ 7.819,82	R$ 10.575,28	R$ 11.739,23	R$ 14.143,13	R$ 15.663,39
l7	501-1000	R$ 3.928,91	R$ 4.304,22	R$ 7.824,57	R$ 8.598,95	R$ 11.743,98	R$ 12.907,92	R$ 15.668,14	R$ 17.188,39
l8	+1000	R$ 4.308,98	R$ 4.703,29	R$ 8.603,70	R$ 9.373,33	R$ 12.912,67	R$ 14.048,12	R$ 17.193,15	R$ 17.967,53

Source: Adapted from NR 28 (Fine gradation in reais) by Rocha & Azevedo (2025).

3.4. Application

To validate the proposal, the model was applied to several real-world technical reports from Ergonomic Analyses, extracted from the Computerized System for Support of Ergonomic Action (SISAE). The non-conformities were extracted, classified according to NR 17 criteria, and associated with NR 28 parameters.

The monetary penalty values were calculated by converting the official fine gradation table (Annex I), using the value of the Fiscal Reference Unit of the State of Rio de Janeiro (UFIR), which was R$ 4.7508. This calculation aligns with the values presented in Table 2: Matrix E – Number of Employees vs. Infraction Severity in Reais (R$), and is in accordance with Resolution SEFAZ/RJ Nº. 746 (December 27, 2024).

UFIR values vary among the Federation Units, as each state has the autonomy to set its own value. For the examples in this study, the UFIR from the State of Rio de Janeiro was used, as this is where the study was conducted.

This application allowed for testing the model's functionality in real-world scenarios within large-scale organizations. It demonstrated the model's capability to translate qualitative data into quantitative metrics directly associated with risk and compliance.

3.4.1. Mathematical Model Application Example (Simulated Scenario)

In a large-scale organization (over 1000 employees), a Preliminary Ergonomic Assessment (AEP) was conducted in an administrative department characterized by a high digital workload. During the assessment, five non-conformities associated with risks arising from the absence of Ergonomics were identified, as listed below.

Table 4: Mathematical Model Application Example

#	Non-conformity Description	NR 17 Item	Severity (NR 28)	r_i Factor	Rationale
1	Inadequate posture due to lack of chair adjustment	17.3.2	IV (Critical)	0.7	Prolonged exposure, postural risk
2	Monitor positioned below eye level	17.4.3.1	III (Serious)	0.5	Poor visibility, cervical strain
3	Deficient illumination and glare	17.5.3	III (Serious)	0.6	Frequent complaints of visual discomfort
4	Lack of regular breaks during continuous work	17.5.1	IV (Critical)	0.8	Reported fatigue and absence of a protocol
5	Insufficient space under the work surface	17.6.3	II (Medium)	0.4	Limited movement of lower limbs

3.4.2. Total Penalty (PT) Calculation – (Simulated Scenario)

- Utilizing the NR 28 reference values (for the +1000 employees size bracket)

Table 5: Reference Values – NR 28 (Occupational Safety, +1000 Employees Bracket)

Severity (Level)	Description	Minimum Value (R$)	Maximum Value (R$)
II	Medium	14,352.17	15,601.63
III	Serious	21,502.12	23,416.69
IV	Critical	28,663.33	29,949.04

3.4.3. Interpolation Calculation

$$V_i(V_{min} + r_i \,.\, (V_{max} - V_{min}))$$

3.4.4. Application of the formula

Table 6: Simulated scenario results (R$)

#	Calculation	Estimated Penalty V_i (R$)
1	28,666.33 + 0.7 × (29,949.04 – 28,666.33) =➔	29,564.23
2	21,502.12 + 0.5 × (23,416.69 – 21,502.12) =➔	22,459.41
3	21,502.12 + 0.6 × (23,416.69 – 21,502.12)=➔	22,560.86
4	28,666.33 + 0.8 × (29,949.04 – 28,666.33)=➔	29,692.50
5	14,352.17 + 0.4 × (15,604.63 – 14,352.17) =➔	14,853.15

3.4.5. Total Penalty (PT)

PT = 29,564.23 + 22,459.41 + 22,650.86 + 29,692.50 + 14,853.15 = R$ 119,220.15

Table 7: Non-conformity Index (ID) Calculation - (Simulated Scenario)

Item (from Table 4)	Severity (G)	Weight (w)	Product (G · w)
1 Chair)	4	2.0	8.0
2 (Monitor)	3	1.5	4.5
3 (Illumination)	3	1.5	4.5
4 (Breaks)	4	2.0	8.0

5 (Space)	2	1.5	3.0
Totals		8.5	28.0

3.4.6. Non-Conformity Index (ID) Calculation

The ID is calculated using the weighted average of the severity (G_i) for the 5 non-conformities identified in the scenario (Table 4), using the weights (w_i) defined by the model.

$$ID = \frac{\sum_{i=1}^{D}(G_i \, . w_i)}{\sum w_i}$$

Applying the formula:

(Item1: $G = 4, w = 2$)+(Item2: $G = 3, w = 1.5$)+(Item3: $G = 3, w = 1.5$)+(Item4: $G = 4, w = 2.0$)+(Item5: $G = 2, w = 1.5$)

$$ID = \frac{(4\ x\ 2.0) + (3\ x 1.5) + (3\ x\ 1.5) + (4\ x\ 2.0) + (2\ x\ 1.5)}{2.0\ +\ 1.5\ +\ 1.5 + 2.0 + 1.5}$$

ID Result:

$$ID = \frac{28.0}{8{,}5} \approx 3.29$$

The analyzed scenario, when evaluated by the weighted average formula, now reveals a High risk index (ID≈3.29), falling within the 2.81 – 3.40 range (Table 1). This result is consistent with the associated financial penalty, which is considerably high (R$ 119,220.15).

The model thus demonstrates its robustness and consistency: the presence of multiple severity III (Serious) and IV (Critical) non-conformities synergistically impacts both the risk index and the financial penalty. This dual quantitative finding reinforces the criticality of the scenario and justifies the urgent prioritization of corrective action plans.

4. Results

The proposed model was applied using a synthesis of data extracted from real-world technical reports from the Computerized System for Support of Ergonomic Action (SISAE[2]). The study population comprised large-scale organizations with complex structures and varied activities. For confidentiality reasons, the organizations' names were anonymized.

Synthesis of Results per Report – Real-world Application

The data from the reports, following the application of the mathematical model, are presented below.

Table 8: Synthesis of Results per Report – SISAE

Nº	Report	No. of Non-conformities	Predominant Severity	*r*	ID	Risk Level	Estimated PT (R$)
1	Report 001	10	Serious (III)	0.60	3.41	Critical	253,585.83
2	Report 002	4	Serious (III)	0.69	3.14	High	98,121.84
3	Report 003	9	Serious (III)	0.56	3.41	Critical	230,485.08
4	Report 005	6	Critical (IV)	0.58	4.00	Critical	176,487.47
5	Report 006	4	Critical (IV)	0.75	3.73	Critical	111,823.14
6	Report 007	5	Critical (IV)	0.65	3.61	Critical	133,961.87
7	Report 008	6	Serious (III) / Critical (IV)	0.38	3.27	High	147,333.00
8	Report 009	5	Serious (III)	0.65	3.22	High	120,423.28
09	Report 010	4	Serious (III) / Critical (IV)	0.50	3.67	Critical	103,218.24

[2] *SISAE: A system developed by the author (Raphael Pacheco) during his doctoral research for the surveillance of work environments.*

10	Report 011	3	Critical (IV)	0.67	4.00	Critical	88,564.41
11	Report 012	3	Critical (IV)	0.50	4.00	Critical	87,923.06
12	Report 013	6	Serious (III) / Critical (IV)	0.50	3.56	Critical	155,143.32
13	Report 014	15	Critical (IV)	0.47	3.74	Critical	417,841.82
14	Report 015	32	Critical (IV)	0.44	3.41	Critical	859,907.76
15	Report 016	1	Medium (II)	0.25	2.00	Low	14,664.54
16	Report 017	84	Critical (IV)	0.46	3.59	Critical	2,385,465.89
17	Report 018	20	Critical (IV)	0.48	3.34	High	522,841.39
TOTALS		217	17	0.54	3.48	17	5,907,791.94

4.1. Interpretation of Indicators

The Non-conformity Index (ID) proved effective in translating the cumulative severity of non-conformities, reflecting the level of attention required for each scenario.

The Total Penalty (PT) ranged widely, from R$ 14,664.54 (Report 016) to R$ 2,385,465.89 (Report 017), even among organizations with similar structures. This highlights the critical influence of the number and severity of non-conformities.

The interpolation between NR 28 penalty values avoided unrealistic extremes (i.e., the systematic application of minimum or maximum values), thereby providing a more realistic representation of the potential financial impact.

4.2. Managerial Applicability

The empirical application of the model demonstrated that its results can be used as:

- A tool to support the prioritization of Ergonomic Actions
- A basis for budgetary projections for occupational risks
- An instrument for preventive internal audits focused on Ergonomic Maturity
- A rationale for justifying investments and corrective actions to senior management
- A means to enhance the participation of the Internal Commission for Accident Prevention

5. Discussion

The results obtained from the application of the developed mathematical model demonstrate its utility as a management support tool for Ergonomics and organizational risk. The quantification of the financial impact of the Absence of Ergonomics, grounded in the legal parameters established by NR 28, allows organizations to address the issue not merely from the lens of regulatory compliance, but also as a matter of strategic economic management.

By translating qualitative information—such as the severity of non-conformities, frequency, and exposure—into monetary values and risk indices, the model enables an effective integration of Ergonomics with Health, Safety, and Financial Management. This capability aligns with trends in recent literature, which recognize the importance of quantitative tools in strengthening the role of Ergonomics in corporate decisions (Vink & Imbeau, 2020; Dul et al., 2012).

Unlike other models focused exclusively on biomechanical analysis, human performance simulation, or cognitive ergonomics, the proposed model focuses on the regulatory-financial dimension. It explicitly incorporates the Brazilian legal frameworks (NR 17 and NR 28) and the requirements of the Risk Management Program (PGR), established by NR 01. This approach directly addresses the need for instruments that support compliance monitoring and intervention planning based on objective data.

Furthermore, the interpolation between the minimum and maximum values from the NR 28 table proved to be a robust solution for estimating penalties realistically, avoiding distortions arising from the automatic application of extreme values. The *r* interpolation factor, in turn, demonstrated versatility, as it allows the model to be adjusted according to the specific context of each organization or workstation evaluated.

Despite these contributions, limitations must be acknowledged. The assignment of the *r* factor still relies on specialized technical judgment, which may introduce variability among different assessors. Furthermore, the model assumes a linear relationship between severity, penalty, and risk. This may not adequately capture situations with exponential effects on health or organizational performance, thus necessitating a more indepth Ergonomic Analysis. To address this, studying the implementation of Fuzzy Logic is recommended to provide the mathematical model with a better understanding of variations in the severity scale.

By implementing the mathematical model into SISAE and exploring machine learning techniques, it is expected to assist ergonomics practitioners in characterizing impacts and, in the future, addressing other aspects required by the SISAE system.

6. Conclusion

This study presented the development and application of a mathematical model designed to quantify the Economic Cost of the Absence of Ergonomics (CAE) in organizations, integrating regulatory, technical, and financial principles. Grounded in Regulatory Standards NR 01, NR 17, and NR 28, the model objectively estimates the potential penalty associated with ergonomic non-conformities and measures the degree of organizational risk via the Non-conformity Index (ID).

The empirical application to technical reports demonstrated that the model is sensitive to variations in the number, severity, and criticality of non-conformities, providing results consistent with the operational reality of the analyzed companies. The use of interpolation between the NR 28 minimum and maximum values proved suitable for capturing severity nuances not addressed by dichotomous approaches. The r_i interpolation factor, in turn, proved to be flexible and adjustable to different organizational contexts, allowing for the refinement of the financial impact analysis.

As a theoretical contribution, the model broadens the scope of quantitative Ergonomics assessment, establishing connections between the risk of the absence of ergonomics, regulatory compliance, and economic consequence. From a practical standpoint, it represents a strategic tool for managerial decision-making, supporting corrective actions, budgetary planning, internal auditing, and the monitoring of ergonomic maturity.

Thus, the continuation of this research line is recommended, including: the integration of the model into computational decision support systems; the validation of the r factor using statistical methods (such as Fuzzy Logic or artificial intelligence); and the expansion of its application to diverse sectors, including small and medium-sized organizations.

Author Contributions

Raphael Pacheco da Rocha - Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Validation, Writing – review & editing.

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