

Article

Patterns of Occupational Safety Violations and Enforcement Strategies: Insight from a Multi-Year Analysis in Abruzzo, Italy

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Abstract

Occupational injuries and work-related diseases remain a major concern in Italy, particularly in high-risk sectors such as construction, agriculture, manufacturing and healthcare. This study retrospectively analyzed a series of breaches of occupational safety regulations and the determining factors that caused them over a seven-year period in a mixed industrial-rural area of Abruzzo, Italy. Inspections were classified by period (pre-pandemic, post-pandemic), economic sector, type of intervention, type of violation, multiple non-compliances, responsible party, age of the responsible party, and restored compliance. Two hundred and seventy-four inspections led to penalties, mainly in the construction sector (65%). Procedural violations were the most frequent, followed by structural, documental, and combined violations. Violations and the violation/inspection ratio decreased after the pandemic. The type of violation was significantly associated with the economic sector, the type of intervention, and the responsible party; moreover, the pandemic period was associated with changes in sectoral inspections, violation patterns, multiple non-compliances, and restoration of compliance. The results highlight sector-specific and context-dependent compliance dynamics, with construction and agriculture presenting complex chains of responsibility. Strengthening an integrated inspection–training supervisory body may improve long-term compliance and safety governance. This study proposes a pilot model for standardized data collection enabling comparative analyses across sectors and institutional contexts.

Keywords: safety; violation; inspection; occupational regulation



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1. Introduction

Despite advances in science and in regulations, occupational injuries and work-related diseases continue to be a major concern in Italian society. According to data from the National Institute for Insurance against Occupational Injuries, over 350,000 occupational injuries and approximately 70,000 work-related diseases were reported in 2023 [1]. The highest incidence rates are observed in sectors such as manufacturing, construction, healthcare, and agriculture, both in Italy and in other countries [2,3]. Most countries have enacted specific occupational health and safety legislation and set up government agencies to ensure compliance with national regulations. In Italy, for instance, Legislative Decree No.

81/2008 establishes the primary regulatory framework [4]. Health and Safety at Work Services (HSWSs) within Local Health Authorities perform surveillance and control activities throughout the country. Their primary focus is on preventing unsafe behaviors and promoting health and safety in the workplace rather than on punitive enforcement [5].

The preventive approach implemented by local health authorities has been associated with a reduction in workplace accident rates, as demonstrated by Ruggiero et al. [6]. In their study conducted in the Lombardy region, Italy, it was found that accident rates decreased significantly in companies that were inspected compared to those that were not. Although safety inspections can have a positive impact on accident and compliance rates in the short term [7], this effect tends to diminish in the medium and long term. The nature of the inspection and the imposition of citations or penalties have also been linked to lower injury rates and improved regulatory compliance. Furthermore, a recent study found that safety violations are negatively correlated when related to the same clause, but positively correlated when involving different clauses [8]. The authors also noted that enforcing safety regulations is associated with voluntary occupational health and safety certifications and stricter penalties.

Different production sectors have different criticalities regarding occupational hazards and safety rules violations. In the agricultural setting, workers face biological, chemical, and mechanical hazards, also due to a lack of risk assessment and inadequate safety regulations [9]. Both in the construction industry and in industry in general [10,11], a lack of knowledge and compliance with the rules plays a role in high injury rates and safety violations. Inadequate workers' behavior and safety training also appear to be relevant issues. Factors such as inspections, economic sectors, and type of violations may be studied with the scope to identify weaknesses in regulation compliance or the prevalence of occupational injuries and diseases in a specific territory. In recent years, the COVID pandemic profoundly affected nearly all productive sectors. Global production markedly decreased and, according to estimates [12], economic growth contracted by approximately 3.2% in 2020. Consequently, during 2020–2021, a significant reduction in notified injuries and work-related diseases was observed [1,13].

Compliance with safety regulations may have a positive impact on the number and the gravity of occupational injuries and diseases. New information about the gaps in regulatory adherence is essential to improve health and safety conditions in the workplace. Building on this context, the present study draws on data collected through the inspection activities conducted by the HSWSs of the Local Health Authority 1 Abruzzo. The main purpose of this work is to explore potential associations between a subset of safety violations that occurred during HSWS inspections and additional factors such as the economic sector, the type of HSWS intervention, and characteristics of the responsible party, including age. A further objective is to assess the impact of the pandemic on the occurrence of safety violations and on related variables. Identifying weaknesses in the enforcement of safety regulations within the examined area is essential for improving future prevention strategies and guiding the operational activities of the HSWSs.

2. Materials and Methods

The data that were reported derive from HSWSs' mandatory inspection activities in the Peligno-Sangrino area (Abruzzo, Italy). This area, according to public national information [14], encompasses five municipalities (Sulmona, Scanno, Pratola Peligna, Castelvecchio Subequo, and Castel di Sangro), covering approximately 320 km² with about 38,000 inhabitants. Based on the data available to the HSWSs in its role as a supervisory authority, the studied zone hosts about 6500 companies. The most represented are commerce (21.7%), the food industry (11.95%), and agriculture (10.33%). We analyzed and included in the study

the data regarding the 274 inspections that led to regulatory breaches. For the purpose of this research, a regulatory breach is defined as a situation in which an entity fails to comply with a law, regulation, technical rule, or formal requirement established by a regulatory authority [4]. Information from inspected enterprises was organized into a dataset comprising the following variables:

- Safety Violations: This is categorized as procedural, structural, or documental; combinations of different types were coded accordingly (e.g., procedural + structural). A procedural violation refers to a lack of respect for the correct workflow or workers' or supervisors' behavior, and it constitutes a deviation from the established proper practice. A structural violation refers to the absence of relevant characteristics or to a deficiency of the work environment or equipment. A documental violation refers to the absence or deficiency of a mandatory document required by occupational safety regulations. Some examples for each type of violation include a lack of personal protective equipment quality or availability (procedural); a lack of supervision or coordination (procedural); a lack of risk assessment or risk management (procedural); a lack of fences, parapets, and protections in general (structural); non-compliant equipment or workplaces (structural); and insufficient or absent documentation (documental). All kinds of recorded safety violations are fully reported and explicitly described in Table S1 (Supplementary Material).
- Period: This includes inspections conducted between 2017 and 2023, which were divided into pre-pandemic (2017–2019) and post-pandemic (2020–2023) categories.
- Economic Sector: Here, enterprises were classified into ten categories that are fully described in the Supplementary Materials (Table S1) (construction, food, public administration/schools, manufacturing, craftsmanship/logistics, services, agriculture/forestry, commerce, waste, and healthcare).
- Type of Intervention: The inspections were coded as scheduled or emergency. An inspection is defined as scheduled when it is carried out in accordance with the inspection activity schedule and does not constitute an emergency. This means that it was not acquired as a result of an event causing harm or injury to workers, but rather was scheduled during the planning phase. An emergency inspection, on the other hand, occurs outside routine activities and becomes necessary following unforeseen events that have posed, or had the potential to pose, a risk to workers' health and safety.
- Multiple Non-compliance: This is a dichotomous variable indicating whether more than one article of the law has been violated.
- Responsible Party: The perpetrator is held accountable under Italian safety law (client, safety coordinator, supervisor, employer, worker).
- Age of the Responsible Party: This is grouped into five ranges (<30; 31–40; 41–50; 51–60; >61).
- Restored Compliance: This indicates whether there is compliance with the law, regulation, technical rule, or formal requirement after an identified breach. It is presented as a dichotomous variable.

Given the limited sample size, this study should be regarded as preliminary and introduces a pilot framework for standardized data collection to support comparative analyses.

The relationships between the total number of inspections, the number of violations, and the HSWS staff in the pre- and post-pandemic periods were examined using Spearman's correlation, with the significance level set at $p < 0.05$. Descriptive frequency distributions were then calculated, and associations among categorical variables (specifically safety violations and period) were tested using the Chi-square test for independence ($\alpha = 0.05$). Effect size was measured with Cramer's V, interpreted as weak (>0.1), moderate (>0.3), or

strong (>0.5) [15]. Statistically significant associations were further examined through post hoc adjusted residuals analysis ($z > 2$ considered significant).

Inferential analyses were conducted to assess the impact of the pandemic period (the secondary outcome of the present study) on other variables. For this purpose, a binomial logistic model was conducted. Regarding the main outcome of the study, a multivariable logistic regression model was not conducted because the distribution of observations across categories resulted in fewer than 10 events per variable. This characteristic affected the dependent variable “Safety violations”. This violates recommended sample size criteria for logistic regression and may produce biased coefficients and model overfitting.

All analyses were performed using Jamovi (version 2.6).

3. Results

Out of a total of 598 inspections in the period considered, 274 resulted in regulatory breaches. As shown in Table 1, the total number of violations and the violations-to-inspections ratio both decreased between the pre- and post-pandemic periods. Additionally, the total number of inspections and HSWS inspection personnel fell between 2017 and 2020 and 2021 and 2023. Spearman’s rank correlation (Table 1) revealed a significant association between staff reduction and decreased inspections in 2021–2023, as well as a strong positive correlation between the number of violations and their relative ratio.

Table 1. Descriptive data related to the number of inspections, the number of violations, the inspections/violation ratio, and the number of HSWS inspection personnel. Spearman’s rank correlation between the variables is performed.

Year	Total Inspections	Number of Violations	Ratio % (Violations /Inspections)	HSWS Inspection Personnel
2017	100	67	67.00	5
2018	106	54	50.94	5
2019	109	75	68.81	5
2020	120	16	13.33	5
2021	28	17	60.71	3
2022	66	20	30.30	3
2023	69	25	36.23	3
Correlation matrix				
		Total inspections	Number of violations	HSWS inspection personnel
Number of violations	Spearman’s Rho	0.214	-	
	<i>p</i> -value	0.662	-	
HSWS personnel	Spearman’s Rho	0.866	0.433	-
	<i>p</i> -value	0.012	0.332	-
Ratio % (violations/inspections)	Spearman’s Rho	−0.036	0.786	0.289
	<i>p</i> -value	0.662	0.048	0.530

Between 2017 and 2023, 274 inspections resulted in legislative infractions. Limited to these, the dataset includes information on safety violations, inspection period (pre- and post-pandemic), economic sector, multiple non-compliances, compliance restoration, responsible party, age group, and type of intervention. Breaches occurred in 28% of penalized cases. Compliance was restored in almost all instances (96.4%). The employer constituted the most frequently accounted responsible party (76.6%), followed by the safety coordinator (12.5%) and the client (5.5%). The predominant age groups were 41–50, 51–60, and >61 years (each about 26%). As shown in Table 2, the construction sector accounted for the majority

of cases (65%), followed by agriculture/forestry (11.3%) and manufacturing (6.9%). Among companies, 79 reported two types of violations, 19 reported three, and four reported four. Procedural violations were the most frequent (37.2%), followed by structural violations (25.2%) and documental violations (15.3%). Post-pandemic inspections represented 28.5% of the total, and 72% of all inspections were scheduled activities. A detailed description of the studied variables is provided in the Supplementary Materials (Table S1).

The Chi-square test for independence revealed significant associations between safety violations and economic sector, responsible party, and type of intervention (Table 3), with corresponding Cramer's V values of 0.255, 0.258, and 0.312, indicating weak to moderate relationships. No significant associations emerged with multiple non-compliances, compliance restoration, or age of the party responsible. As shown in Table 4, the pandemic period is significantly linked to the type of safety violations, the occurrence of multiple non-compliances, and compliance restoration, albeit with a weak effect size. A stronger relationship (Cramer's V = 0.435) was observed between the pandemic period and the economic sectors subject to inspection. No significant associations were found with intervention type, responsible party, or age group.

Table 2. Descriptive information: total frequencies observed in relationship with the studied variables. Occupational safety violations, Abruzzo, Italy (N = 274).

Economic sector	Frequency	Total %
Food industry	8	2.9%
Construction industry	180	65.7%
Commerce	7	2.6%
Manufacturing	19	6.9%
Healthcare	4	1.5%
Agriculture/forestry	31	11.3%
Services	3	1.1%
Waste industry	6	2.2%
Craftmanship/Logistics	7	2.5%
Public administration/school	9	3.3%
Safety violation	Frequency	Total %
Documental	42	15.3%
Procedural	102	37.2%
Structural	69	25.2%
Structural + procedural	23	8.4%
Documental + structural	19	6.9%
Procedural + documental	16	5.8%
Structural + procedural + documental	3	1.1%
Period	Frequency	Total %
Post-pandemic (2020–2023)	78	28.5%
Pre-pandemic (2017–2019)	196	71.5%
Intervention	Frequency	Total %
Scheduled	197	71.9%
Emergency	77	28.1%

Table 2. *Cont.*

Multiple non-compliance	Frequency	Total %
No	195	71.2%
Yes	79	28.8%
Restored compliance	Frequency	Total %
No	10	3.6%
Yes	264	96.4%
Responsible party	Frequency	Total %
Employer	209	76.6%
Client	15	5.5%
Safety coordinator	34	12.5%
Supervisor	4	1.5%
Worker	11	4.0%
Age of the responsible party	Frequency	Total %
<30	15	5.5%
Between 31 and 40	40	14.7%
Between 41 and 50	72	26.4%
Between 51 and 60	73	26.7%
>61	73	26.7%

A post hoc adjusted residuals analysis was applied for all significant associations (Tables 5 and 6). Structural violations were positively associated with the agriculture/forestry sector, while procedural violations showed negative associations with the food and agriculture/forestry sectors, and structural violations with public administration/schools. Combined violations (structural + procedural; documental + structural) were negatively associated with agriculture/forestry; the latter combination was also positively linked to emergency interventions and negatively to scheduled ones. Among responsible parties, clients and safety coordinators were positively associated with procedural violations, whereas workers were linked to structural violations. Procedural violations were negatively associated with employers, and documental and structural ones with clients, and structural violations also with safety coordinators, who were not involved in combined structural + procedural or structural + documental violations (Table 5). Table 5 only reports the row with at least one significant association (in bold); the full adjusted residuals analysis is provided in Supplementary Material, Table S2.

As shown in Table 6, documental violations significantly decreased in the post-pandemic period compared to expectations. Manufacturing, healthcare, and services were negatively associated with the pre-pandemic phase, while compliance restoration showed a negative association in the post-pandemic period. Table 6 only reports the row with at least one significant association (in bold); the full adjusted residuals analysis is provided in Supplementary Material, Table S3.

A binomial regression analysis (Table 7) highlighted statistically significant decreases in some predictors. In the post-pandemic period, with respect to the pre-pandemic period, “Documental” violations strongly decreased with respect to “Procedural”, “Structural”, “Structural + Procedural” and “Documental + Structural”. We also observed a positive association (OR = 2.21) of multiple non-compliance with the post-pandemic period. No further statistically significant associations were detected.

Table 3. Analysis of the association between safety violations and the following variables: economic sector, type of intervention, and responsible party. Occupational safety violations, Abruzzo, Italy (N = 274).

Safety Violation								
Economic Sector	Documental	Procedural	Structural	Structural + Procedural	Documental + Structural	Procedural + Documental	Structural + Procedural + Documental	Total
Food industry	2	0	4	0	0	2	0	8
Construction industry	24	77	40	16	14	7	2	180
Commerce	1	5	0	0	0	1	0	7
Manufacturing	2	3	8	4	2	0	0	19
Healthcare	0	3	0	0	0	1	0	4
Agriculture/forestry	5	5	17	0	0	4	0	31
Services	0	1	0	1	1	0	0	3
Waste industry	3	2	0	0	1	0	0	6
Craftmanship/logistics	2	2	0	0	1	1	1	7
Public administra- tion/school	3	4	0	2	0	0	0	9
Total	42	102	69	23	19	16	3	274
χ^2 Test								
	Value	df	p					
χ^2	98.5	54	<0.001					
N	274							
Cramer's V	0.245							
Safety violation								
Intervention	Documental	Procedural	Structural	Structural + procedural	Documental + structural	Procedural + documental	Structural + procedural + documental	Total
Scheduled	32	75	52	16	6	14	2	197
Emergency	10	27	17	7	13	2	1	77
Total	42	102	69	23	19	16	3	274
χ^2 Test								
	Value	df	p					
χ^2	18.2	6	0.006					
N	274							
Cramer's V	0.258							
Safety violation								
Responsible party	Documental	Procedural	Structural	Structural + procedural	Documental + structural	Procedural + documental	Structural + procedural + documental	Total
Employer	39	51	59	23	19	15	3	209
Client	0	15	0	0	0	0	0	15
Safety coordinator	3	30	0	0	0	1	0	34
Supervisor	0	4	0	0	0	0	0	4
Worker	0	2	9	0	0	0	0	11
Total	42	102	68	23	19	16	3	273
χ^2 Test								
	Value	Df	p					
χ^2	106	24	<0.001					
N	273							
Cramer's V	0.312							

Table 4. Analysis of the association between the pre- and post-pandemic periods and the economic sectors, safety violations, multiple non-compliance and restored compliance. Occupational safety violations, Abruzzo, Italy (N = 274).

Economic Sector											
Period	Food	Constru- ction Industry	Commerce	Manufac- turing	Health- care	Agricul- ture/ Forestry	Services	Waste	Craftmanship /Logistics	Public Administra- tion /School	Total
Post- pandemic	3	38	5	14	4	6	3	2	2	1	78
Pre- pandemic	5	142	2	5	0	25	0	4	5	8	196
Total	8	180	7	19	4	31	3	6	7	9	274
X ² test											
	Value	Df	<i>p</i>								
X ²	50.8	9	<0.001								
N	274										
Cramer's v	0.430										
Safety violations											
Period	Documental	Procedural	Structural	Structural + procedural		Documental + structural		Procedural + documental		Structural + procedural + documental	Total
Post-pandemic	4	34	19	9		8		4		0	78
Pre-pandemic	38	68	50	14		11		12		3	196
Total	42	102	69	23		19		16		3	274
X ² test											
	Value	Df	<i>p</i>								
X ²	12.9	6	0.044								
N	274										
Cramer's v	0.217										
Multiple non-compliance											
Period	No			Yes						Total	
Post-pandemic	46			32						78	
Pre-pandemic	149			47						196	
Total	195			79						274	
X ² test											
	Value	Df	<i>p</i>								
X ²	7.9	1	0.005								
N	274										
Cramer's v	0.170										
Restored compliance											
Period	No			Yes						Total	
Post-pandemic	0			78						78	
Pre-pandemic	10			186						196	
Total	10			264						274	
X ² test											
	Value	Df	<i>p</i>								
X ²	4.13	1	0.042								
N	274										
Cramer's v	0.123										

Table 5. Post hoc adjusted residuals analysis to assess the dependence between safety violations and economic sector, type of intervention and responsible party. Bold values represent statistical significance. Occupational safety violations, Abruzzo, Italy (N = 274).

Safety Violations					
Economic sector	Documental	Procedural	Structural	Structural + procedural	Documental + structural
Food industry	0.6397	− 2.441	1.231	−1.159	−1.053
Agriculture/forestry	0.1129	− 2.172	2.841	− 2.281	− 2.073
Public administration/school	1.1917	0.344	− 2.129	1.185	−1.117
Intervention	Documental	Procedural	Structural	Structural + procedural	Documental + structural
Scheduled	0.325	0.194	0.337	−0.133	− 2.33
Emergency	−0.539	−0.314	−0.555	0.208	2.80
Responsible party	Documental	Procedural	Structural	Structural + procedural	Documental + structural
Employer	1.17	− 3.27	0.942	1.227	1.115
Client	− 2.15	3.28	− 2.734	−1.590	−1.445
Safety coordinator	−1.06	4.12	− 4.116	− 2.394	− 2.175
Worker	−1.84	−1.16	2.981	−1.361	−1.237

Table 6. Post hoc adjusted residuals analysis to assess the dependence between period and safety violation, economic sector and restored compliance. Bold values represent statistical significance. Occupational safety violations, Abruzzo, Italy (N = 274).

Period		
Safety violation	Post-pandemic	Pre-pandemic
Documental	− 2.674	1.3937
Economic sector	Post-pandemic	Pre-pandemic
Manufacturing	3.074	− 2.680
Healthcare	2.081	− 2.392
Services	1.802	− 2.072
Restored compliance	Post-pandemic	Pre-pandemic
No	− 2.39	1.003

For a better reading, the key findings are summarized in the following (Table 8).

Table 7. Binomial logistic model with pandemic period as dependent variable. The probability of safety violations was estimated with regard to economic sector, type of intervention, type of safety violation, multiple non-compliances, responsible party, age of the responsible party, and restored compliance. The reference period is the post-pandemic, compared to the pre-pandemic. Occupational safety violations, Abruzzo, Italy (N = 274).

Independent Variable	p-Value	OR	95% Confidence Interval
Economic sector:			
Commerce–food_industry	0.199	0.240	0.0272–2.12
Manufacturing–food_industry	0.086	0.214	0.0369–1.24
Healthcare–food_industry	0.989	3.83×10^{-8}	0.0000–inf
Agriculture/forestry–food_industry	0.287	2.500	0.4631–13.49
Services–food_industry	0.990	3.83×10^{-8}	0.0000–inf
Craftmanship/logistics–food_industry	0.715	1.500	0.1701–13.23
Construction_industry_–food_industry	0.283	2.242	0.5127–9.80
Waste_industry–food_industry	0.872	1.200	0.1303–11.05
Public_administration/school–food_industry	0.223	4.800	0.3847–59.89
Intervention:			
Emergency–scheduled	0.225	0.703	0.398–1.241
Safety violation:			
Procedural–documental	0.006	0.211	0.0694–0.638
Structural–documental	0.030	0.277	0.0870–0.882
Structural + procedural–documental	0.008	0.164	0.0434–0.618
Documental + structural–documental	0.006	0.145	0.0366–0.572
Procedural + documental–documental	0.140	0.316	0.0684–1.459
Structural + procedural + documental–documental	0.987	606,085.564	0.0000–inf
Multiple non-compliances:			
No-yes	0.005	2.21	1.263–3.85
Responsible party			
Client–employer	0.806	1.160	0.3556–3.78
Safety coordinator–employer	0.976	1.012	0.4570–2.24
Supervisor–employer	0.393	0.422	0.0581–3.06
Worker–employer	0.983	6.60×10^6	0.0000–inf
Age of the responsible party:			
Between 51 and 60–less than 30	0.147	0.314	0.0656–1.50
Between 31 and 40–less than 30	0.454	0.530	0.1004–2.80
Between 41 and 50–less than 30	0.103	0.272	0.0569–1.30
More than 61–less than 30	0.401	0.507	0.1039–2.47
Restored compliance:			
No-yes	0.983	6.56×10^6	0.00–inf

Table 8. Summary of key findings.

Key Finding	Description
Decreases in violations and inspections	Post-pandemic (2020–2023) data show fewer violations and inspections, with strong inspector–inspection correlations underscoring the role of workforce availability.
Sector-specific vulnerabilities	Construction showed the highest violation frequency (65.7%), followed by agriculture (11.3%) and manufacturing (6.9%). In the post-pandemic period, a statistically significant decrease in “Documental” violations was observed, compared to “Procedural” and “Structural” ones.
Violation types	Procedural violations dominated (37.2%), followed by structural (25.2%) and documental (15.3%), indicating overlapping/complex compliance patterns.
Associations with intervention type	Emergency inspections revealed more structural and documental violations than scheduled ones, highlighting that reactive checks tend to expose more serious or previously overlooked hazards.
Responsibility attribution	Employers accounted for most violations (76.6%), followed by safety coordinators (12.5%), and clients (5.5%). Procedural breaches, more common among coordinators and clients, point to managerial and organizational shortcomings.

4. Discussion

Despite advances in regulation and prevention, workplace injuries remain a major concern in Italy. This study investigated the relationship between safety violations and contextual factors—including economic sector, intervention type, responsible party, and pandemic period—using data from the HSWSs of Local Health Authority No. 1 (Abruzzo, Italy). Under Italian Legislative Decree 81/2008, local health authorities monitor compliance with workplace safety regulations, focusing primarily on prevention but with the power to impose corrective actions or apply penalties when necessary. McLeod et al. [16] demonstrated that safety inspections can reduce accident rates, although the effects may diminish over time. In the context assessed in our analysis, HSWS inspections have a dichotomous nature. They may be scheduled or triggered by emergencies such as serious or fatal accidents. The present study also assessed how the COVID-19 pandemic influenced these inspection dynamics.

The discussion, addresses temporal dynamics influenced by the pandemic, workforce fluctuations, and inspection activity. Sectoral differences and violation types were examined to identify compliance challenges, while inspection complexity was analyzed in relation to enforcement outcomes. Finally, an integration of these findings into broader policy implications, emphasizing lessons from the pandemic for future preparedness, has been addressed. Overall, the results highlight how enforcement dynamics and sector-specific factors jointly shape compliance with occupational safety standards.

The construction sector accounted for the highest violation frequency (65.7%), followed by agriculture/forestry (11.3%) and manufacturing (6.9%), confirming established sector-specific risk patterns [17,18]. Construction’s predominance reflects inherent hazards—working at heights, machinery use, and complex subcontracting chains—leading to a high prevalence of procedural violations linked to coordination and supervision failures, according to the recent scientific literature [19,20]. In contrast, agriculture and forestry mainly showed structural violations associated with mechanical risks, obsolete equipment, and insufficient risk assessment. These sectors, which often lack systematic safety management systems, are also characterized by limited training, poor regulatory awareness, and workforce vulnerability, particularly among migrant and low-skilled workers [21–24]. The significant association between the type of violation and the economic sector highlights the sector-dependent nature of compliance dynamics [9]. To address these disparities,

tailored preventive strategies are needed that combine technical modernization with personalized training and education, particularly in high-risk sectors such as construction and agriculture. The sector's complexity—where workers face concurrent biological, chemical, physical, and mechanical hazards—combined with limited safety culture and a high proportion of foreign or temporarily integrated workers, further hampers compliance. Optimizing sector-specific approaches is necessary by tailoring prevention activities and training programs that should focus on technical, procedural, and behavioral dimensions in high-risk sectors such as agriculture and construction.

Analysis of inspection types revealed distinct detection patterns: inspections due to occupational injuries/incidents more often identified complex violations (structural + documental), supporting the hypothesis that reactive inspections reveal systemic deficiencies in safety management rather than isolated procedural problems [7]. Post hoc results confirmed significant associations of procedural and structural violations with both economic sector and responsible party. In contrast, scheduled inspections mainly detected procedural and documental non-compliances, which are generally easier to identify and correct. This pattern reflects the broader distinction between deterrence- and compliance-based enforcement models, the former emphasizing sanctions and the latter education [25,26]. Procedural violations indicate organizational shortcomings, structural violations reflect physical risks in the workplace, while documental violations reveal administrative weaknesses. The high rate of compliance restoration (96.4%) demonstrates the corrective capacity of regulatory oversight, while emphasizing the need for sustained preventive action to ensure long-term adherence as a tool for continuous improvement.

According to the temporal dynamics and pandemic effects analysis, the post-pandemic decrease in safety violations can be interpreted through both operational and behavioral perspectives. The temporary slowdown of industrial and construction activities during lockdowns likely reduced exposure to occupational risks, while companies resuming operations may have strengthened safety management systems due to increased health awareness and the adoption of biohazard risk assessment tools. The pandemic also shifted inspection priorities: the rise in healthcare and industrial inspections indicates a focus on infection-prone and essential sectors to assure production continuity [27], consistent with global trends that prioritize biohazard control in health emergency preparedness, rather than the control of other traditional risks [28]. Our data related to the overall decline in violations and the violation-to-inspection ratio mirrors international evidence of reduced work activity and injury reporting during and immediately after COVID-19 [29]. Notably, inspection numbers remained comparable in 2020 to pre-pandemic levels, reflecting the combined effects of operational restrictions and targeted oversight in critical sectors.

Employers emerged as the primary accountable party, consistent with Italian Legislative Decree 81/2008, which assigns them main responsibility for workplace safety. Nevertheless, the positive association of procedural violations with clients and safety coordinators suggests overlapping responsibilities, particularly in multi-employer or subcontracting contexts, which requires an integrated and multidisciplinary approach to improve compliance [30–32]. This fragmentation can reduce the effectiveness of coordination mechanisms, a well-known challenge in the construction and service sectors [31]. Violations involving workers reflect unsafe behavior and insufficient training, highlighting the need for continuous training and behavioral prevention [33,34]. Strengthening integrated, multidisciplinary prevention strategies that promote communication, collaboration, and shared responsibility among all stakeholders is essential to improving compliance and bridging the gap between policy and practice.

Finally, analysis of the pandemic period revealed significant associations between the health crisis and key variables such as economic sector, security breaches, multiple

non-compliances, and restoration of compliance. The pandemic led to an intensification of inspections in the industrial and healthcare sectors, as the reassessment of workplaces during the reopening phases required greater supervision in these sectors [24]. The pandemic has redefined inspection priorities, with an increase in checks in high-risk sectors reflecting significant operational difficulties. The sharp decline in documental violations is likely due to ongoing digitization and administrative reorganization processes. Conversely, the post-pandemic decline in inspections and staffing suggests a temporary weakening of enforcement capacity, consistent with global evidence of reduced oversight during health emergencies. The reduction in documented violations could indicate a change in the focus of government inspection guidelines, such as a concentration of resources on more significant violations, such as structural and procedural ones, or it could be linked to procedural adjustments made necessary by the pandemic [13]. Interestingly, the lower rate of compliance restoration observed in the post-pandemic period indicates slower or less effective corrective processes, perhaps due to resource constraints, administrative delays, or changes in inspection priorities, with persistent barriers to corrective action. Possible explanations include administrative delays, reduced labor availability, or resource constraints affecting both companies and regulatory bodies. This finding highlights the need to pay greater attention to follow-up actions and active monitoring of safety measures over time. Furthermore, the negative residuals relating to document violations indicate a possible “paper compliance” effect (i.e., formal adherence without corresponding structural or procedural improvements), underscoring the need to strengthen the substantive enforcement of rules and long-term monitoring strategies.

In the post-pandemic period, an increase in multiple non-compliances has been highlighted compared to the pre-pandemic period. To the best of our knowledge, no previously published data or studies report comparable information. According to data from the National Institute for Insurance against Occupational Injuries [1], in the post-pandemic period a decrease in work-related injury notifications was observed, while occupational disease reports increased (from 44,950 in 2020 to 72,610 in 2023, always increasing). These controversial data may be linked to a deterioration in occupational health conditions in Italy in the post-pandemic period. Such information could be connected to the Increase in multiple breaches observed in the sample studied.

Overall, our results indicate that enforcement strategies should be sector-sensitive and adaptable to contextual factors such as labor dynamics and emergency conditions. The heterogeneity of violations and liabilities suggests that uniform inspection models are less effective across different sectors. The predominance of violations in construction and agriculture highlights the need for targeted interventions that complement inspections with training and technical support, as supported by evidence on the effectiveness of prevention and control programs [35]. Moreover, the pandemic experience has shown how emergencies reshape inspection and violation patterns, reinforcing the importance of adaptive and resilient enforcement frameworks capable of sustaining effective control in crisis conditions.

The integrative interpretation of these results highlights the interaction between inspection resources, sectoral risk profiles and external events (e.g., the pandemic). The significant correlation between the volume of inspections and staffing levels confirms that the availability of human resources directly determines the capacity to enforce regulations. Similarly, the association between the number and rate of violations indicates that the intensity of inspections and the probability of detection are interdependent, in line with existing evidence on the effectiveness of controls [36,37]. These results suggest that regulatory enforcement should not rely solely on quantitative metrics (e.g., inspection counts or

sanctions) but prioritize qualitative outcomes—how inspections foster sustained behavioral and organizational improvements. Accordingly, future policy directions should consider:

- Strengthening the integration between enforcement and training, particularly in high-risk sectors such as agriculture and construction.
- Developing risk-based inspection models prioritizing sectors with recurrent procedural or structural violations.
- Reinforcing inter-institutional collaboration among inspection bodies to optimize coverage despite resource constraints
- Implementing digital follow-up systems to monitor compliance restoration over time.

Aligning enforcement, education, and organizational support can shift HSWS activities from a reactive model toward a resilient safety governance framework capable of adapting to evolving socio-economic conditions. Data analysis suggests that maintaining adequate inspection staff is essential to avoid a decline in compliance, particularly during crises. Policies should promote coordination and shared responsibility between employers, safety coordinators and clients, fostering a holistic safety culture and strengthening the accountability of different stakeholders [38]. Also, setting up a European mechanism for continuous compliance monitoring, with a focus on follow-up and long-term support rather than just penalties, could improve safety in a lasting way [39]. These findings highlight the need for adaptive regulatory strategies and contingency planning to ensure robust workplace safety during future disruptions. Developing flexible inspection models that remain effective in emergencies is crucial to preserving occupational health and safety standards in the face of future crises.

Although inferential analysis was partially hindered by the distribution of events within the outcome variables, the results of this study outline a multifactorial framework of occupational safety compliance, highlighting significant associations between violation types and contextual determinants such as sector, inspection type, and organizational responsibility. The proposed classification offers a practical yet robust approach to understanding patterns of regulatory non-compliance and integrates enforcement dynamics, human factors, and the effects of the pandemic into a unified framework. This study presents some limitations. Firstly, no information about the inspections that did not lead to a regulatory violation has been analyzed. We believe that this kind of data could provide further interesting knowledge about the relationship between the considered variables. Comparisons could be made with the aim of highlighting the characteristics that are possibly associated with stricter compliance with Italian occupational safety regulations. Moreover, the study findings are based on a relatively small sample of safety violations; nevertheless, this characteristic is consistent with the size of the HSWSs and the geographical area investigated. Although based on a single territorial dataset, which may limit generalizability, this study proposes a pilot model for standardized data collection to enable comparative analyses of inspection effectiveness and sector-specific risk profiles across institutional contexts.

5. Conclusions

Workplace safety violations are multifactorial phenomena shaped by sector, inspection type, and responsible actors, with emergencies such as pandemics altering inspection dynamics and violation patterns. Effective enforcement should balance reactive controls with proactive prevention through adequate staffing, clear accountability in multi-employer settings, and strengthened training. A risk-based, learning-oriented model integrating inspection, education, and technical support should inform policy design. Future research should investigate the long-term evolution of enforcement systems and the enduring impact of pandemic-related organizational changes on safety culture. Integrating quantitative

surveillance with qualitative analysis can enhance occupational safety governance in Italy and beyond.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/safety12040103/s1>. Table S1: Variables description, from the original information collected to the final categories. Table S2: Adjusted residuals analysis for significant associations highlighted with Chi-square tests. The association between safety violations and economic sector, intervention and responsible party is tested. Significant associations are highlighted. Table S3: Adjusted residuals analysis for significant associations highlighted with Chi-square tests. The association between period and economic sector, safety violation, multiple non compliants and responsible party is tested. Significant associations are highlighted.

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Abbreviations

The following abbreviations are used in this manuscript:

HSWS Health and Safety at Work Service

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