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Assessing the impact of safety assurance practices on telecommunication tower maintenance effectiveness in Malaysia: The moderating role of risk exposure

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Abstract

The purpose of research is to explore the impact of key factors in the Occupational Safety and Health Management System (OSHMS) on the effectiveness of telecommunication tower maintenance in Malaysia, with a particular focus on the moderating role of risk exposure. The study investigates the relationship between Hazard Assessment (HA), Incident Reporting (IR), Safety Training (ST), Compliance Audit (CA), Improvement Evaluation (IE), and Effectiveness of Tower Maintenance OHSAA in this high-risk industry. Based on a sample size of 377 (Rasoft), 258 (68.44 percent) industry professionals responded. A stratified random sampling technique and a 5-point Likert scale questionnaire were used to collect information. The obtained data is validated with a reliability coefficient of 0.8 and analyzed using SmartPLS software for CFA, Discriminant Validity, VIF, and Path Analysis. The results reveal a strong positive relationship between hazard assessments and safety training for improved maintenance and OHSAA compliance outcomes. This study also highlights gaps in incident reporting systems, compliance audits, and improvement evaluations, which were found to have limited effectiveness in enhancing safety based on risk exposure. The findings also demonstrate the negative moderating effect of risk exposure, suggesting that safety measures are less effective in high-risk environments. It was concluded that organizations prioritize robust safety training, comprehensive hazard assessments, and ongoing risk management, while urging policymakers to strengthen regulatory frameworks to ensure regular updates to safety protocols. The practical implication of this study shows valuable insight into the role of OSHMS elements in high-risk industries and offers practical recommendations for improving safety practices and guiding future research in occupational health and safety, aligning with ESG under environmental, social, and governance.

Keywords: Occupational safety and health management, Risk Exposure, Telecommunication.

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1. Introduction

The telecommunication industry plays a vital role in our ecosystem and facilitates global connectivity in supporting both economic growth and social interaction [1]. Over the decades, this infrastructure has progressively transformed compared to the beginning of Morse Code invention (1871 – 1872) [2] to 5G expansion and 6G research [3]. Since then, telecommunication is defined as information transmitted in the form of signals such as voice, data, and video over long distances through various media [4]. And for this telecommunication to transmit information effectively, the essential component required to send data is fiber optic cables, satellites, or radio waves [5, 6]. The backbone for seamless connectivity is the telecommunication towers, which serve as a physical infrastructure to support wireless communications. These towers house antennas, transmitters and receivers, which are especially important for cellular networks, enabling mobile phones to connect internet in exchange for information and make calls [7]. Without these towers, the coverage and reliability of wireless communication will be severely compromised.

These towers are located strategically in various locations, owned and operated by Telecom companies. They manage the entire process, including the construction, maintenance and upgrades to support their network infrastructure and provide services to customers. The position of these towers is based on their purpose, and for example, urban area towers may be shorter and usually fixed on existing structures (refer to Figure 1) compared to rural or remote areas, which are often taller (refer to Figure 2) to maximize coverage. Hence, there is a great risk for Telecom companies handling the towers, particularly during maintenance activities. The primary accidents are often recorded from tower maintenance, falls from great heights, electrical hazards, structural failures, inclement weather, falling objects, and equipment failures [8]. Although there are no recorded major fatalities in this industry, there has been a notable increase in occupational accidents in recent years, and activities on telecommunication towers continue to involve significant risks [9]. This could be attributed to the effectiveness of the telecommunication companies' Occupational Health and Safety Management Systems (OHSMS), which may successfully mitigate the specific risks associated with maintenance work on telecommunication towers [10]. Besides, hazard assessments are often not conducted thoroughly to identify potential risks [11] and ensure the safety of workers, further exacerbating the challenges in maintaining a safe working environment.

Other common issues highlighted in telecommunication tower maintenance work pertain to the OHSMS's responsibility in adhering to safety procedures, providing adequate training, and conducting compliance audits to ensure these measures are effectively implemented. Questions arise regarding the extent to which improvements have been made in evaluating and mitigating risks faced by tower maintenance workers [12]. Additionally, concerns exist about whether these risks are thoroughly documented and whether the documentation aligns with the industry's best practices to comprehensively address worker safety [13].

Figure 1.
Telecommunication Tower Urban Area.

Figure 2.
Telecommunication Tower Rural Area.

The objective of this research is to investigate the relationship between OHSMS fundamentals, hazard assessment, incident reporting, safety training, compliance audits, and improvement evaluation, and the effectiveness of telecommunication tower maintenance OHSAA compliance in Malaysia, moderated by the risk exposure variable.

2. Review of Literature

The Occupational Safety and Health Act Amendments Act (1994) (514) and OHSAA [8] provides a comprehensive framework for organizations to control risk, prevent work-related injuries and improve safety performance. While the OHSAS 18001 focuses only on risks. Research specific to telecommunications maintenance is relatively limited compared to other industries Ali et al. [14], Awang et al. [15] and Ajmal et al. [16]. Ribeiro et al. [17] carry out a case study at Recite, Brazil examining on risk management in telecommunication companies dealing with installing antennas. They found that only 20 percent of occupational safety measures highlighted by OHSAA [8] is in compliance with the regulatory standards emphasizing the need for improved safety procedures and audit compliance. Nguyen et al. [18] studied the correlation between comprehensive safety training programs and the frequency of accidents in telecommunication tower maintenance for 501 Vietnamese employees. They found that companies with mandatory, rigorous training programs had significantly fewer accidents and injuries compared to those without.

Besides, the safety evaluation and improvement methods are also becoming a nuance for telecommunication, although there exists a gap in this industry; however, a study by Liu and Zhang [19] demonstrates that a risk-based safety management system that integrates predictive analytics, worker behavior analysis, and environmental factors can improve hazard detection and prevention. Their research proved that the more integrated and dynamic the evaluation system implemented, the more it could reduce accidents and improve worker safety compliance. There is a persisting gap in terms of how telecommunication companies place their OSHA policies. The unsupervised accidents suggest that these policies may not be adequately implemented or tailored to the specific risks of telecommunication towers [20]. Moreover, most of the previous studies have generally focused on broader industrial safety measures and hazard evaluations without delving deeply into the unique risks associated with telecommunication tower maintenance [21].

2.1. Theoretical Framework

The International Electrotechnical Commission (IEC) provides IEC 61511 Safety Life Cycle for industries like telecommunications, chemical plants, oil & gas, and other process industries. The life cycle is divided into four main phases as illustrated in Figure 3, Management (Clauses 5 and 6.2) and Verification Phase (Clauses 7 and 12.5), Analysis Phase (Clauses 8 and 9), Realization Phase (Clauses 9, 10, 11, 12, 13, 14, and 15), and Operation Phase (Clauses 16, 17, and 18). To achieve a risk-based level of safety in all the operating phases of a safety instrumented system (SIS), telecommunications companies predominantly adopt the functional safety standard of IEC-61511 [22].

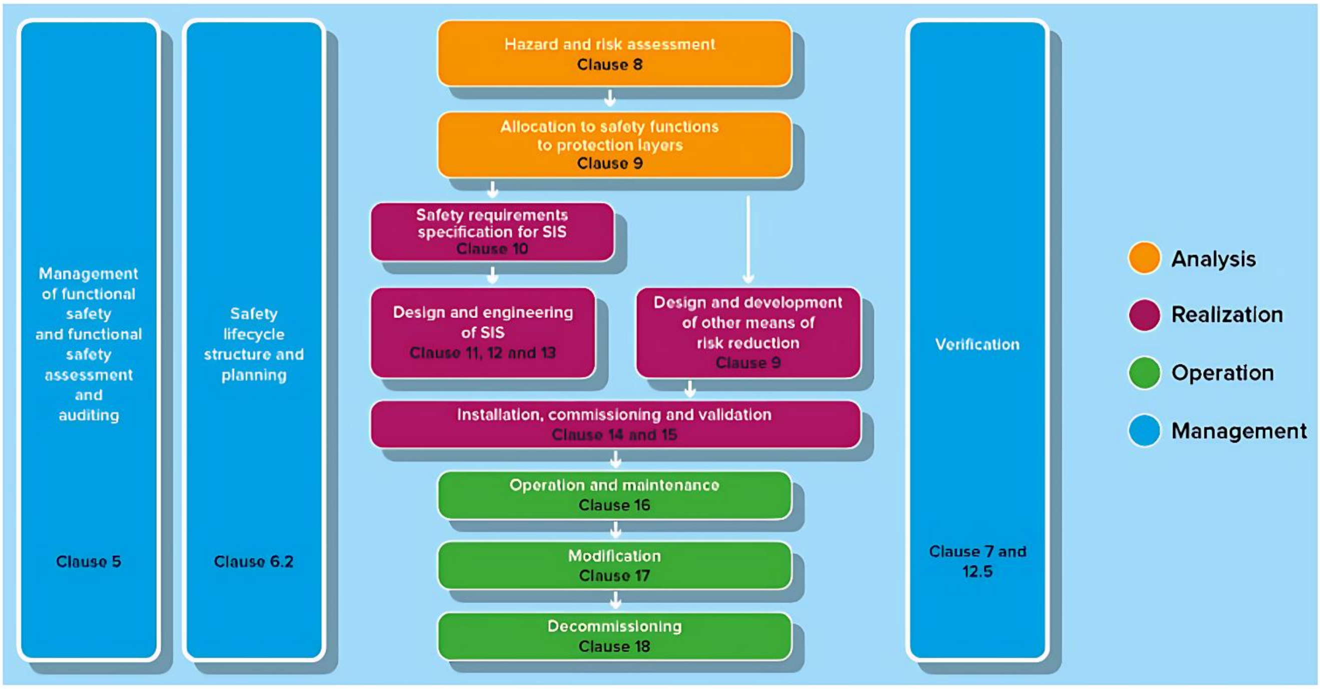

Figure 3.
IEC- 61511 Safety Life Cycle.
Source: Smith and Simpson [23].

The theory of Safety Management Systems (SMS) emphasizes the systematic management of safety through thorough documentation, effective training, strict adherence to standards, and robust communication and monitoring processes. The primary goal of SMS is to create a structured environment that reduces incidents and enhances safety protocols. A study by Ladewski and Al-Bayati [24] it is suggested that integrating quality management principles into safety procedures can lead to improved safety outcomes. The components of the Safety Management System (SMS), as illustrated in Figure 4, are: (i) safety risk management, (ii) safety assurance, and (iii) safety promotion. These must be integrated seamlessly within telecommunication organizations to ensure effective employee safety compliance. These highlighted safety features are necessary to plan and organize activities well prior to conducting any maintenance work [17]. According to Vinodkumar and Bhasi [25] suggest that to promote a safety culture, there must be a reciprocal relationship between safety management and safety behavior.

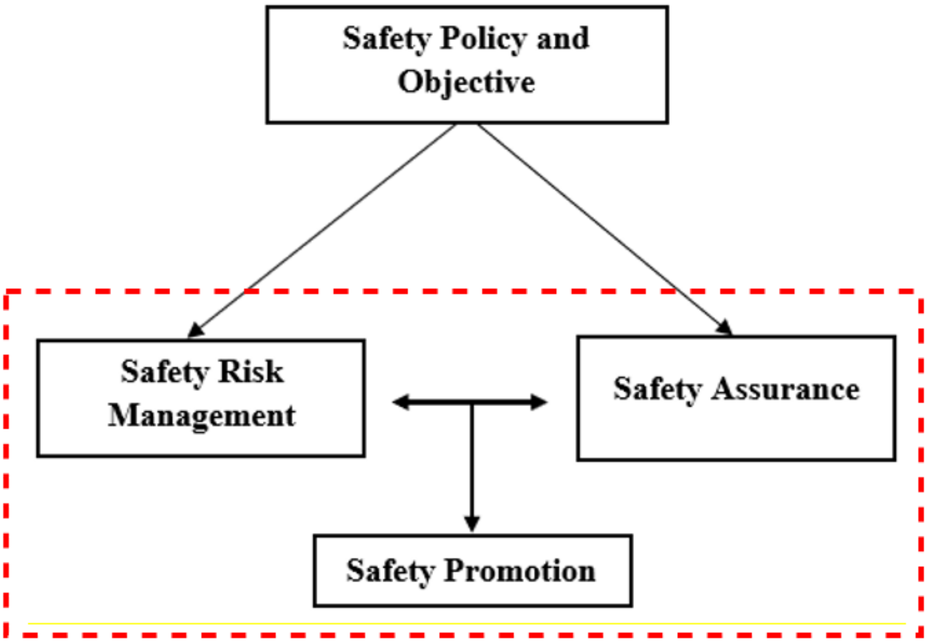

Figure 4.
Theory of Safety Management System (SMS), [26].

Despite various studies focusing on the implementation of integrated health, safety, and environmental management cycles, there is not yet a coherent and managerially effective overview of the common requirements Pauliková et al. [27].

Shimada et al. [28] introduced the Safety Management Cycle as illustrated in Figure 5 mapping closely to IEC- 61511 and OHSAS18001.

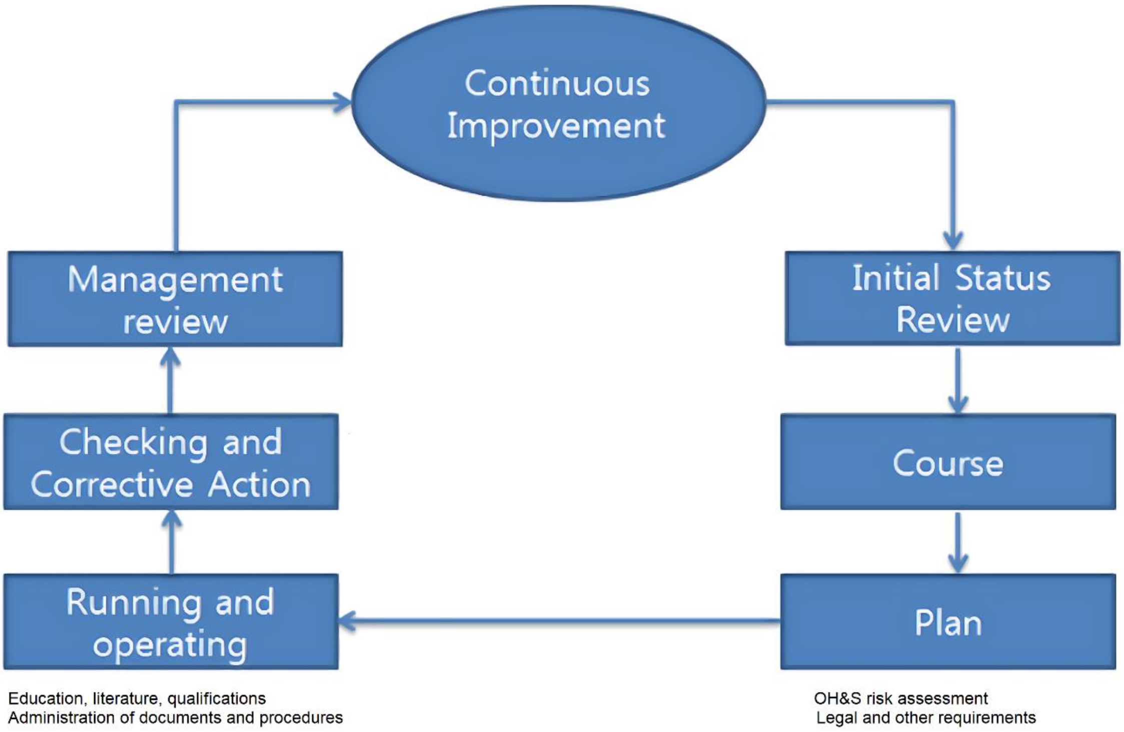

Figure 5.
Cycle of Safety and Health Management System [28].

An integrated Safety Management Cycle for safety measurement is evident in numerous studies [25, 29, 30]. However, studies may not include all the components and treat them separately, especially the need for training and audits due to a broad, multifaceted framework. An excellent Integrated Safety Management Cycle (ISMC) must consist of five regulated stages as illustrated in Figure 6. This is a repeated cycle to ensure new risks are addressed over time to mitigate potential accidents or failures.

1. Hazard assessment stage which is structured to systematically identify and analyze the risks associated with the workplace hazards before the commencement of operations [30].
2. Incident reporting where near misses, accidents, and unsafe conditions are immediately reported in the system [25].
3. Safety training is where organizations are compelled to deliver continuous hands-on education on hazard assessment and past incidents to their employees [31].
4. Compliance audit involves periodic checking and verification against internal policies, national laws, and international standards [29].
5. Improvement evaluation is conducted through post-audit and modifications to safety systems for continuous improvement [29].

Figure 6.
Integrated Safety Management Cycle (ISMC).

Approaching all these 5 components distinctively presents unique inherent challenges in managing safety within the telecommunication sector. Companies are often faced with technical complexities, rapid advancements, and regulatory requirements that create a diverse risk landscape. Yet, the key aspects of safety management are the adequate administration of occupational risk [32]. Figure 7 explains safety risk management based on the ISO 31000: 2018.

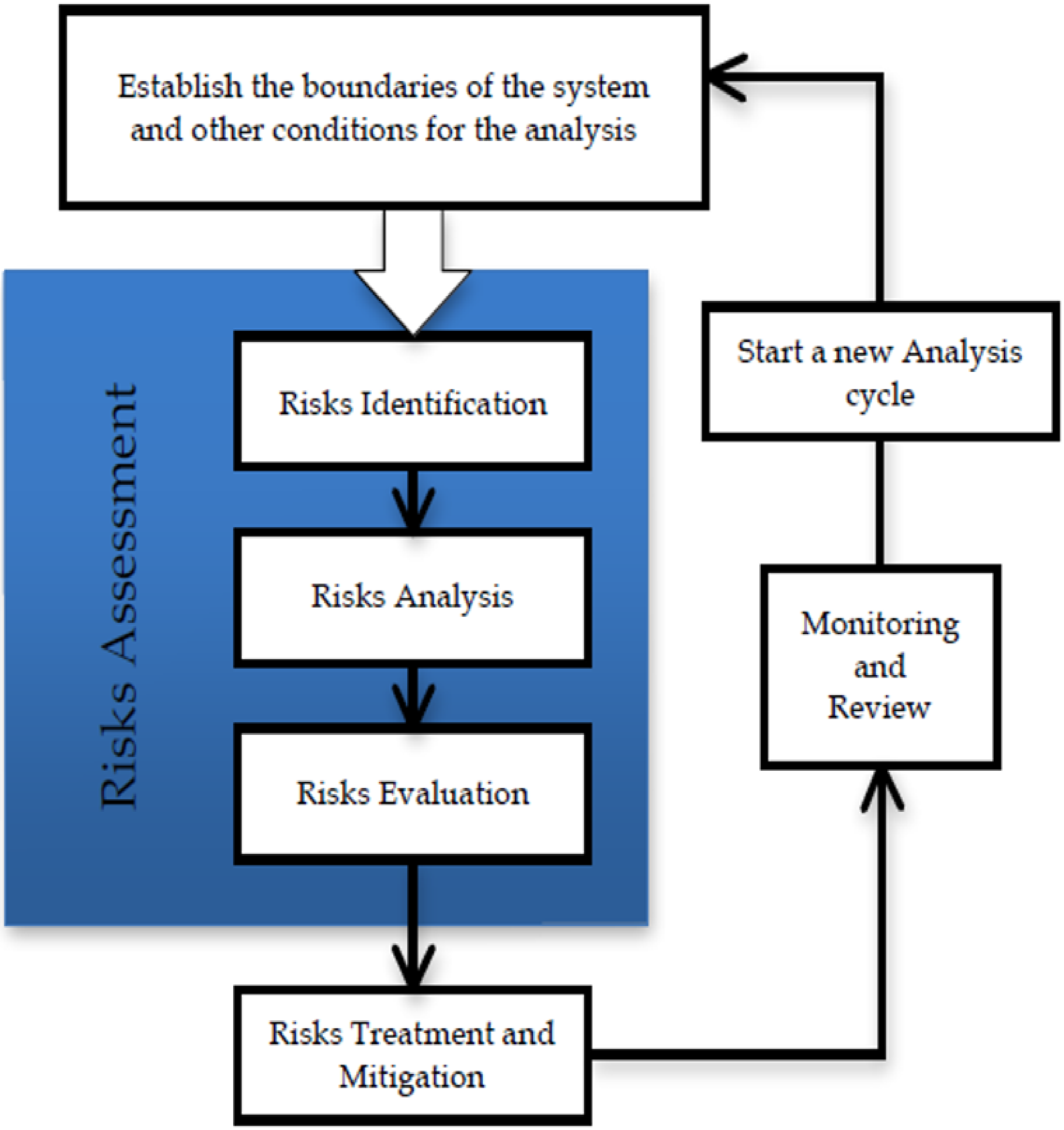

Figure 7.
Risk Management Framework, ISO 31000:2018 [33].

Occupational Health and Safety Act (OHSA) [34] define acceptable risk as "*the risk level that is in compliance with legal obligations and the workplace's prevention policy and does not pose a level of risk that would result in loss or injury*." The ISO 31000:2018 guidelines and the Federal Communications Commission (FCC) [35] Best practices further provide comprehensive principles, frameworks, and processes for managing risk. It is central to highlight that the success of risk identification depends directly on how complete its initial analysis is, which identifies, describes, and classifies them [33]. This framework helps to explain how risk analysis or exposure influences the effectiveness of OSHMS in managing safety outcomes during tower maintenance. According to ISO 31000:2018 standards, management must demonstrate leadership and commitment by ensuring that risk management is integrated into the organization's governance, strategy, and operations [36]. This study includes all three primary typical risks: operational risk, quality risk, and technical/resource risk. Risk exposure (RE) is closely linked to risk analysis (RA) for this study because, based on ISO 31000:2018, RA is defined as "*process to comprehend the nature of risk and to determine the level of risk*." The measurement is done on the basis of how these three mentioned risk dimensions impact maintenance activities, aligning with international standards for risk management and safety assurance.

(i) High-risk activities (such as working at heights) require strict controls: full-body harnesses, fall arrest systems, buddy systems, etc.
(ii) Moderate risk activities require general safety protocols: PPE, proper tools, and training.
(iii) Low-risk tasks (if any) could include ground-level inspections or non-intrusive monitoring.

Hence, for the purposes of this study, the risk levels are measured based on the following grounds:
Risk Exposure = Likelihood × Consequence

- Low Risk (1): Indicates no significant safety issues

- Moderate Risk (2): Indicates occasional safety issues
- High Risk (3): Indicates frequent or severe safety issues

2.2. Conceptual Framework

The following conceptual framework in Figure 8 is designed based on the SMS, ISMC and RMF model provided in the literature.

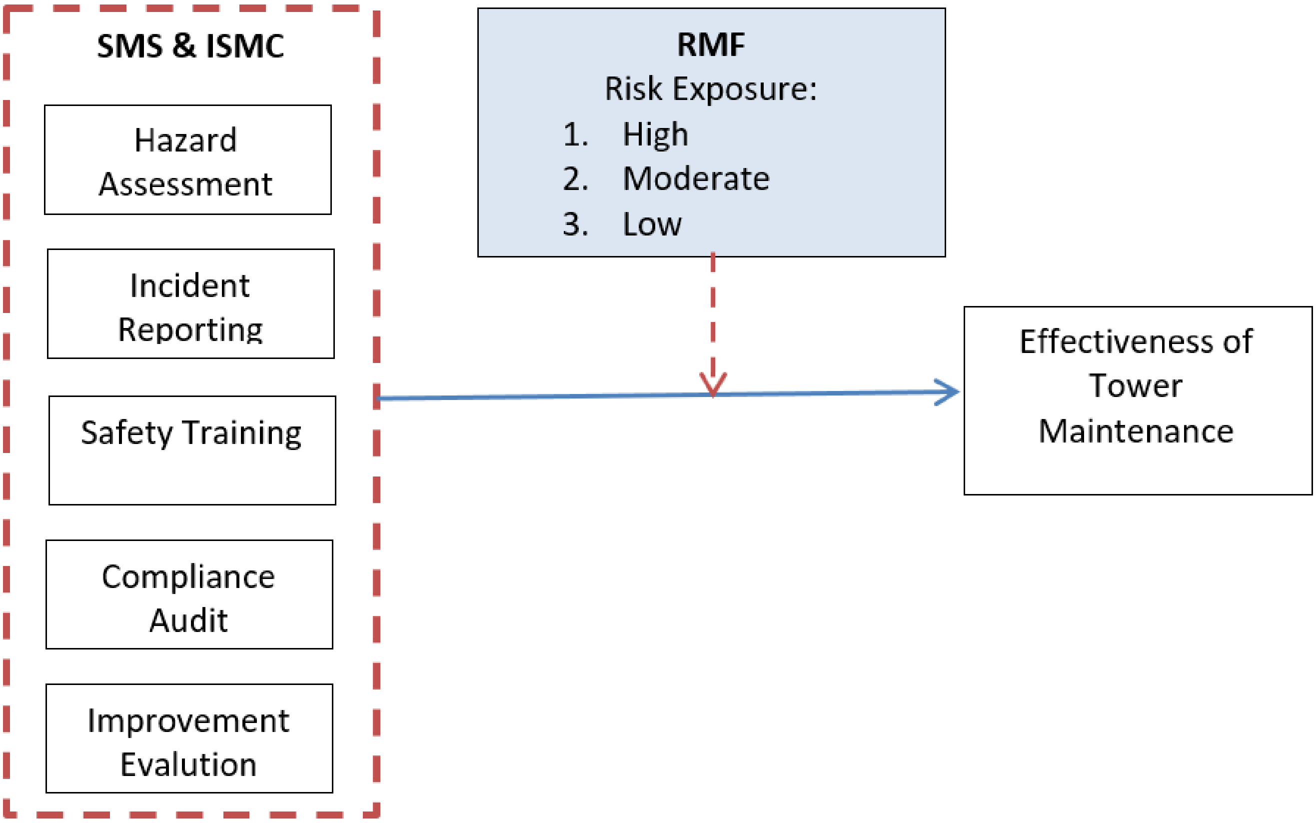

Figure 8.
Conceptual Framework.

This conceptual model is designed to provide a fresh perspective, in contrast to previous, narrow research that predominantly adopted a one-size-fits-all approach. Many prior studies assumed uniform effectiveness without accounting for the diverse operational contexts across industries and the varying levels of risk exposure (ref). Given that most research has focused on the Western context, particularly regarding telecommunication tower maintenance activities, this model considers unique regulatory, cultural, and operational perspectives. By doing so, the conceptual framework aims to address the gaps left by previous studies and offer a more tailored and comprehensive solution.

2.3. Hypothesis

The following hypothesis are framed to guide this study.

1. There is no significant difference between the Hazard Assessment and Effectiveness of Tower Maintenance (HA → EM)
2. There is no significant difference between the Incident Reporting and Effectiveness of Tower Maintenance (IR → EM)
3. There is no significant difference between the Safety Training and Effectiveness of Tower Maintenance (ST → EM)
4. There is no significant difference between the Compliance Audit and Effectiveness of Tower Maintenance (CA → EM)
5. There is no significant difference between the Improvement Evaluation and Effectiveness of Tower Maintenance (IE → EM)
6. There is no interaction between Hazard Assessment and Effectiveness of Tower Maintenance moderated by Risk Exposure (RE x HA → EM).
7. There is no interaction between the Incident Reporting and Effectiveness of Tower Maintenance moderated by Risk Exposure (RE x IR → EM).
8. There is no interaction between the Safety Training and Effectiveness of Tower Maintenance moderated by Risk Exposure (RE x ST → EM).
9. There is no interaction between the Compliance Audit and Effectiveness of Tower Maintenance moderated by Risk

Exposure (RE x CA → EM).
There is no interaction between the Improvement Evaluation and Effectiveness of Tower Maintenance moderated by Risk Exposure (RE x IE → EM).

3. Materials and Methods

An exploratory approach using SmartPLS software was employed to analyze the causal relationships among the study's key variables [37]. In Malaysia, there are relatively few telecommunications players, including TM Malaysia, CelcomDigi, U Mobile, Maxis, and YTL, which participated in this survey. The total estimated population of these companies is approximately 20,000 employees. Respondents for this research study were employees directly involved in telecommunication tower maintenance in Malaysia. The diversity within this population was carefully considered to capture a comprehensive view of how OSHMS is implemented and perceived across various roles and responsibilities within the industry [38].

The sample size for this research was calculated using Raosoft software. For a population of 20,000, with a 5% margin of error, a 95% confidence level, and a 50% response distribution, the recommended statistically significant [39] sample size was approximately 377 respondents. A stratified random sampling technique was utilized to ensure that all critical subgroups within the population were represented in the sample [40] thereby enhancing the reliability and generalizability of the results. The population was divided into distinct strata or subgroups based on relevant characteristics, such as the specific telecommunication company, job roles (e.g., engineers, technicians, safety officers, supervisors, and project managers), and geographic regions where the towers are maintained. A 5-point Likert questionnaire was distributed, achieving 258 responses, i.e., a 68.44% response rate. This is notably higher than the 60% response rate typically considered acceptable for most research endeavors [41].

3.1. Data Analysis and Findings

The summary of demographic data is presented in Table 1. The largest age group among survey participants falls between 18 and 25 years, while the smallest group, those aged 56 and above, may reflect the company's staffing policies due to the physically demanding nature of the job. Among the participants, 36% are site engineers. Additionally, 35% have 7–10 years of work experience, and 32% have more than 10 years of experience. Similarly, 35% of participants have 7–10 years, and 32% have more than 10 years of specific experience in tower maintenance.

Table 1.
Demographic Analysis Data.

Variables	Measurement	Frequency	Percentage (%)
Age	18 - 25	51	19.71
	26 - 35	30	11.62
	36 – 45	44	17.05
	46 - 55	15	5.81
	56 and above	4	1.55
Position in Company	Technician	37	14.34
	Site Engineer/Engineer	94	36.43
	Project Manager/Manager/Supervisor	63	24.42
	Safety Officer	26	10.07
	Compliance Manager	9	3.48
	Others	29	11.24
Years of Company in Telco Industry	Less than a year	13	5.03
	1 - 3 years	26	10.07
	4 - 6 years	46	17.83
	7 - 10 years	91	35.27
	More than 10 years	82	31.78
Years of Company Experience in Tower Maintenance	Less than a year	23	8.91
	1 - 3 years	20	7.75
	4 - 6 years	43	16.66
	7 - 10 years	89	34.49
	More than 10 years	83	32.16
Company Size	Small (Less than 50 employees)	20	7.75
	Medium (50 - 249 employees)	116	44.96
	Large (250 or more employees)	112	43.41

The internal consistency of the constructs in this study was evaluated using Cronbach's Alpha, as shown in Table 2 Zakariya [42]. Hunt et al. [43] stated Cronbach's Alpha strong reliability value ranges between 0.70 and 1.00, signifying that the items within a construct are consistent in measuring the same underlying variable. Cronbach's Alpha values for all constructs exceed the minimum threshold, reflecting excellent internal consistency and reliability.

Table 2.
Construct Reliability and Validity Analysis.

Variables	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
Hazard Assessment	0.836	0.846	0.884	0.603
Incident Reporting	0.841	0.841	0.887	0.612
Safety Training	0.834	0.834	0.890	0.669
Compliance Audit	0.864	0.868	0.902	0.650
Improvement Evaluation	0.875	0.876	0.909	0.667
Effectiveness of Tower Maintenance	0.866	0.875	0.903	0.652

3.2. Confirmatory Factor Analysis

The following code is assigned for the variables introduced: Hazard Assessment – HA, Incident Reporting – IR, Safety Training – ST, Compliance Audit – CA, Improvement Evaluation – IE, Risk Exposure – RE, and Effectiveness of Tower Maintenance OHSAA Compliance – EM. The measurement model was tested by measuring the separate sub-factors, and scale reliability was tracked by the convergent and discriminant analysis of constructs' measures. Primarily, the associations were displayed among the factors. The Smart PLS algorithm was pragmatic, and the subsequent associations, coefficients, and values of loadings were analyzed [44] were shown in Figure 9.

To evaluate the outer model (or measurement model) and determine how well the items (questions) load on the hypothetically defined constructs [45] some constructs were deleted, ensuring the factor loading exceeded the cut-off value of 0.70 [46]. This indicates that the reliability of each item was robust, thereby reinforcing the allocation of each item to its specified latent variables.

3.3. Discriminant Validity

The purpose of discriminant analysis is to determine the relationship between a set of independent variables and a categorical dependent variable, enabling classification and prediction [47]. It is a practical application where the goal is to distinguish between two or more groups based on their characteristics. To further analyze the data and address potential concerns regarding redundancy among interaction terms, a discriminant validity assessment was performed using the Heterotrait-Monotrait Ratio (HTMT) analysis. The HTMT ratio is a valuable method for evaluating discriminant validity, as it helps determine whether distinct constructs are sufficiently different from one another [48]. A high HTMT value indicates a potential issue of redundancy or overlap between constructs, suggesting that they may not be sufficiently distinct.

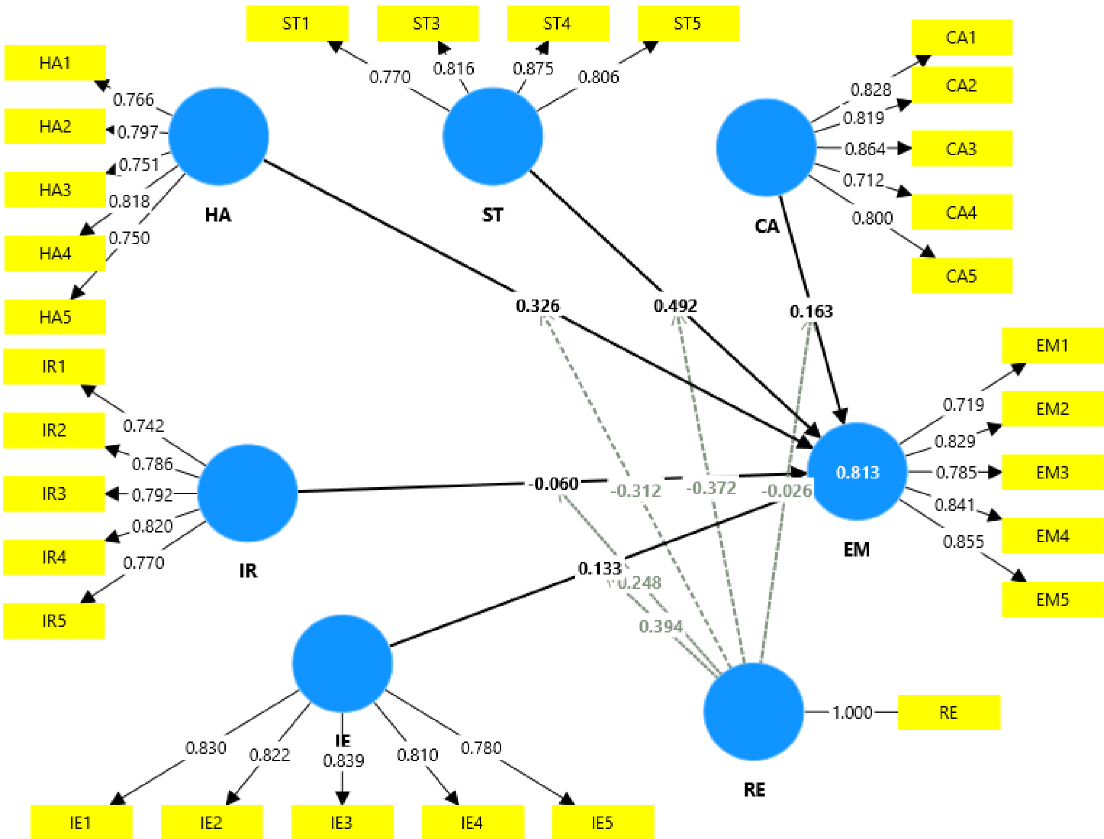

Figure 9.
Final Path Model.

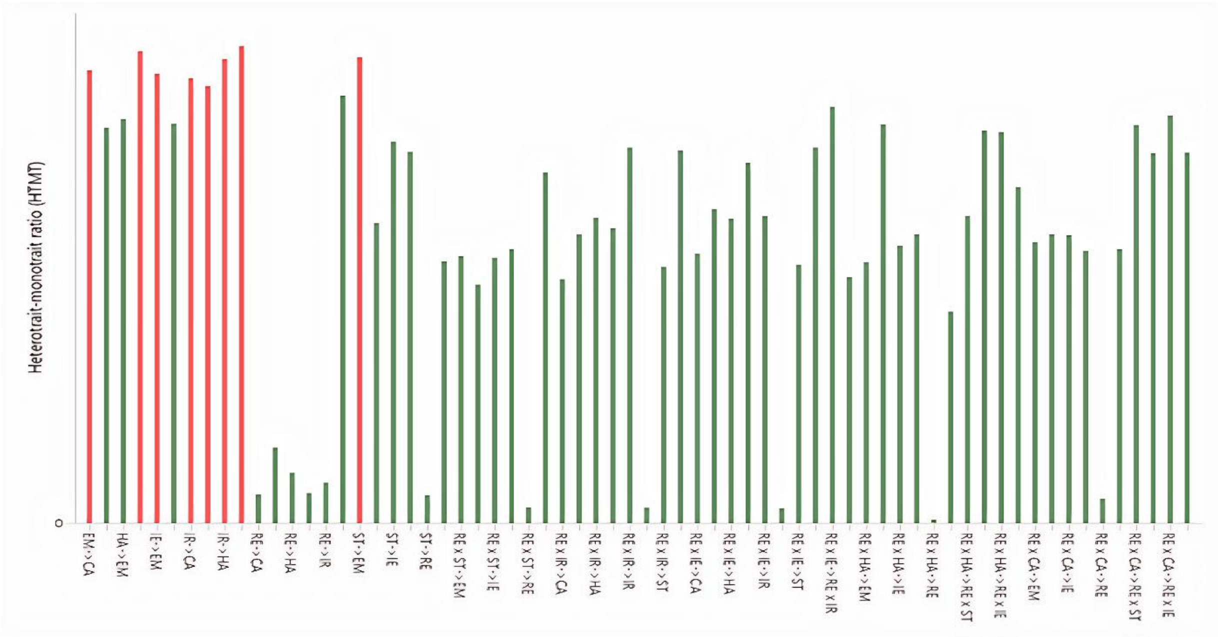

Figure 10.
Heterotrait-Monotrait Ratio (HTMT) Analysis.

Based on the results output, the interaction terms such as RE x ST, RE x IR, etc., the HTMT analysis provides useful insights into whether these interaction terms are closely related to the main constructs they are supposed to interact with, potentially distorting the unique contributions of each variable. If the HTMT values exceed a threshold value often set around 0.85 or 0.9, this could indicate problematic redundancy, meaning that the interaction term may not be capturing unique information. This suggests that some interactions should be adjusted or removed to ensure that each construct and its interaction term contribute distinct and valuable information to the model.

Figure 10 illustrates the HTMT values for the variables and interaction terms used in the model. It shows that the green bars are within acceptable limits, meaning the pairs of constructs or interaction terms are sufficiently distinct. Meanwhile, the red bars are of particular interest as they suggest potential issues with discriminant validity. This overlap can signal that the variables are too similar and might not be contributing distinct information to the model. In the context of this research, the interaction of some variables such as EM-CA, IE-EM, IR-CA, IR-HA, and ST-EM is highlighted with red HTMT values, indicating that there might be redundancy between these interaction terms and their corresponding constructs. This redundancy could distort the findings of the analysis and reduce the clarity of the relationships between the factors. To address these concerns, they may need to be revised, combined, or removed from the model to ensure the analysis reflects meaningful, distinct relationships between constructs and their interaction terms. To further explore these variables, the Variance Inflation Factor (VIF) analysis was carried out.

3.4. Variance Inflation Factor (VIF) Analysis

Table 3.
Variance Inflation Factor Analysis Data.

Factors	VIF	Factors	VIF
CA1	2.332	IE1	2.270
CA2	2.181	IE2	2.179
CA3	2.581	IE3	2.221
CA4	1.614	IE4	1.955
CA5	1.940	IE5	1.786
EM1	1.607	IR1	1.557
EM2	2.264	IR2	1.846
EM3	1.968	IR3	1.996
EM4	2.373	IR4	2.035
EM5	2.344	IR5	1.702
HA1	1.881	RE	1.000
HA2	1.914	ST1	1.559
HA3	1.627	ST3	1.797
HA4	1.814	ST4	2.434
HA5	1.584	ST5	1.850
		RE x HA	1.000
		RE x IR	1.000
		RE x IE	1.000
		RE x ST	1.000
		RE x CA	1.000

VIF is used to evaluate the degree of multicollinearity among independent variables in a regression model. Multicollinearity occurs when predictors are highly correlated, which can distort the estimates of regression coefficients and compromise the validity of the model. The VIF values provided above represent the multicollinearity analysis for this research, focusing on all the constructs for this research study.

All VIF values in Table 3 fall below the critical threshold of 5, indicating low to moderate multicollinearity across the variables. None of the predictors show extreme multicollinearity; for instance, a VIF of 10 or higher confirms that the independent variables and interaction terms provide distinct contributions to the model [47].

The VIF values for Compliance Audit (CA) variables range from 1.614 (CA4) to 2.581 (CA3), which indicates moderate correlations among the predictors. CA3 has the highest VIF (2.581), suggesting that this variable shares more variance with other CA variables but remains within acceptable limits. The VIF values range from 1.607 (EM1) to 2.373 (EM4), indicating a similar pattern of moderate multicollinearity within the EM construct.

The VIF values for Hazard Assessment (HA) variables are relatively low, ranging from 1.584 (HA5) to 1.914 (HA2), and this suggests minimal multicollinearity. Improvement Evaluation (IE) variables exhibit VIF values between 1.786 (IE5) and 2.270 (IE1), reflecting moderate correlations within the construct. VIF values for Incident Reporting (IR) range from 1.557 (IR1) to 2.035 (IR4), while Safety Training (ST) variables have values between 1.559 (ST1) and 2.434 (ST4). Both constructs exhibit low multicollinearity, with ST4 showing a slightly higher but acceptable value. The interaction terms such as RE x HA, RE x IR, RE x IE, RE x ST, and RE x CA, all of which have VIF values of 1.000, indicate no multicollinearity with other variables. This is expected, as interaction terms are often orthogonal and statistically independent during their construction.

The low VIF values across variables confirm that the regression model is stable and the coefficients are interpretable. There is no excessive correlation among predictors that might inflate standard errors or bias results. The acceptable VIF values suggest that the constructs (CA, EM, HA, IE, IR, and ST) are conceptually distinct and provide unique information for predicting or explaining the dependent variable. This supports the validity of the theoretical framework used in the research. Variables like CA3 (VIF = 2.581) and ST4 (VIF = 2.434) exhibit slightly higher VIF values, indicating moderate correlations with other predictors in their respective constructs. Although a few variables, such as CA3 (VIF = 2.581) and ST4 (VIF = 2.434), exhibit relatively higher VIF values compared to others, these values are still within the acceptable range and are not a marker of severe multicollinearity.

3.5. Justification

Each variable represents an essential construct in the research model, and removing any variable may compromise the theoretical completeness and construct validity of the analysis. The slightly higher VIF values, like CA3 and ST4, may stem from shared variance across related items, but this does not undermine their contribution to the overall model, as their values remain far from the critical threshold. Interaction terms such as RE x HA and RE x IR have VIF values of 1.000, which confirm their orthogonality and independence, supporting the decision to maintain all items. Retaining all variables helps maintain the integrity of the research findings by accurately capturing the relationships between constructs. Removing any variables could disrupt the latent variable structure, decrease reliability, and undermine the precision of predictions and interpretations in the model.

3.6. R Square

The R-square and adjusted R-square values provide important information about how well the independent variables (predictors) explain the variation in the dependent variable (outcome). These values are key metrics for understanding the goodness of fit of your regression model [47].

The R-square value is 0.813 for this research study, indicating that 81.3% of the variability in the dependent variable (EM) suggests that the model fits the data relatively well, with a substantial amount of the variation accounted for by the predictors. Whereas the adjusted R-square value is 0.790, which adjusts for the number of independent variables in the model. It is a more reliable measure when comparing models with different numbers of predictors because it penalizes the model for adding variables that do not improve the model significantly. The adjusted R-square means that, after accounting for the number of predictors, about 79% of the variability in the dependent variable is explained by the model. This is slightly lower than the regular R^2 because the adjustment reduces the value when unnecessary variables are included in the model.

3.7. Hypothesis Testing

Table 4.
Path Coefficient Analysis.

No.	Variables	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values	Hypothesis
1.	HA -> EM	0.326	0.324	0.099	3.277	0.001**	Rejected
2.	IR -> EM	-0.060	-0.055	0.127	0.471	0.638	Accepted
3.	ST -> EM	0.492	0.498	0.072	6.804	<0.001**	Rejected
4.	CA -> EM	0.163	0.166	0.123	1.332	0.183	Accepted
5.	IE -> EM	0.133	0.127	0.144	0.922	0.356	Accepted
6.	RE x HA -> EM	-0.312	-0.295	0.156	2.004	0.045 *	Rejected
7.	RE x IR -> EM	0.248	0.242	0.215	1.155	0.248	Accepted
8.	RE x ST -> EM	-0.372	-0.398	0.176	2.116	0.034*	Rejected
9.	RE x CA -> EM	-0.026	0.002	0.219	0.120	0.904	Accepted
10.	RE x IE -> EM	0.394	0.362	0.265	1.484	0.138	Accepted

Note: ** denotes significant at 1% level
*denotes significant at 5% level.

The path coefficient analysis evaluates the strength and significance of relationships between independent variables (predictors) and the dependent variable (EM). Based on the data from Table 4 , the analysis reveals several significant relationships. HA to EM (β = 0.326, p = 0.001) shows a statistically significant relationship at 1% level, indicating that Hazard Assessment directly impacts effectiveness of tower maintenance. A one-unit increase in HA is associated with a 0.326 increase in EM. ST to EM (β = 0.492, p = <0.001) demonstrates the significant impact at 1% level, emphasizing the critical role of Safety Training in influencing effectiveness of tower maintenance. A unit increase in ST is associated with a 0.492 increase in EM. The interaction of moderating variable effects reveal a more complex dynamic. RE × ST to EM (β = -0.372, p = 0.034) indicates a significant influence at 5% level. It implies a negative moderating effect of risk exposure on the relationship between ST and EM. Specifically, higher levels of RE reduce the positive impact of ST on EM by 0.372 units. RE × HA to EM (β = -0.312, p = 0.045) also shows a significant influence at 5% level. It shows a negative moderating effect of risk exposure on the relationship between HA and EM. Specifically, higher levels of RE reduce the positive effect of HA on EM by 0.312 units.

The analysis also highlights several non-significant relationships at 5 % level for CA to EM (β = 0.163, p = 0.183), IE to EM (β = 0.133, p = 0.356), IR to EM (β = -0.060, p = 0.638), RE to EM (β = -0.185, p = 0.081), RE × IR to EM (β = 0.248, p = 0.248) and RE × IE to EM (β = 0.394, p = 0.138) and RE × CA to EM (β = -0.026, p = 0.904).

4. Discussion

The study found a significant positive relationship between hazard assessment and the effectiveness of tower maintenance in complying with OSHA regulations. Well-implemented hazard assessments allow maintenance teams to identify potential risks and hazards [49] associated with tower maintenance tasks. This proactive identification leads to effective mitigation strategies (e.g., use of proper equipment, worksite controls), reducing the likelihood of accidents or non-compliance. Addressing identified risks aligns closely with Occupational Health and Safety Administration (OSHA) standards, ensuring compliance. The results also support the positive relationship between safety training and the effectiveness of tower maintenance, as regular hazard assessments reveal specific training needs for the workforce. This study suggests that customizing training to address the unique needs of maintenance teams can lead to substantial improvements in performance outcomes [50]. Trained personnel are more likely to follow safety protocols, resulting in better adherence to OHSAA standards.

Operational risks have a direct impact that mandates workplaces to maintain safe, uninterrupted operations. The risk exposure is measured in terms of low, moderate, and high safety issues. Risk exposure related to hazard assessments and safety training shows a positive association with the effectiveness of tower maintenance. For instance, failure to adhere to operational timelines or safeguard processes may lead to violations related to worker safety and operational hazards [51]. Conversely, quality risks compromise the ability to meet OHSAA's requirements for maintaining safety standards in workplaces. High-quality maintenance ensures compliance with structural integrity, safety inspections, and hazard elimination guidelines because most identified fatal accidents arise from high-risk activities [17]. OHSAA standards often emphasize the use of proper equipment and skilled personnel to mitigate hazards. Technical and resource risks that lead to unsafe practices or failure to adhere to standards may result in penalties or increased accident rates. However, the negative moderating effect of risk exposure suggests that higher levels of risk may reduce the effectiveness of safety measures and hazard assessments, emphasizing the need for better risk management strategies to mitigate these impacts [52].

As for the compliance audit, incident reporting, and improvement evaluation, there is no significant relationship to telecommunication tower maintenance and OHSAS compliance. The reason could be due to the compliance audit and incident reporting mechanisms within telecommunications often focusing on technical and operational aspects, such as ensuring towers meet national or international engineering standards and regulations. These audits are typically concerned with functionality and safety in a highly technical domain. OHSAS audits, however, are broader in scope and cover the health and safety of workers in various work environments, including construction sites, manufacturing plants, and offices, but may not specifically address issues unique to telecommunication infrastructure maintenance [53]. Besides, improvement evaluation in the context of telecommunication tower maintenance may involve performance metrics tied to operational uptime, equipment reliability, and incident minimization. This evaluation focuses on specific technical outcomes. OHSAS compliance evaluation, by contrast, looks at the overall health and safety management system, such as employee safety training, emergency preparedness, and accident reporting systems [53]. These frameworks often involve different sets of performance indicators, which makes it difficult to draw direct correlations between OHSAS compliance and telecommunication tower maintenance. These findings confirm the relevance of the hypotheses in understanding the relationships between the ISMC and RMF frameworks and maintenance effectiveness but also suggest areas for improvement in incident reporting, audits, and risk management.

5. Recommendation and Contribution

One of the theoretical implications is the reinforcement of the concept of a "safety culture" within organizations. Safety training emerges as a pivotal factor, illustrating that continuous education fosters awareness, skills, and preparedness among employees to address workplace hazards effectively. Similarly, rigorous hazard assessments demonstrate the need for systematic risk identification and evaluation to minimize potential dangers. Together, these elements bolster the theoretical framework of OSHMS, supporting the view that a well-implemented safety system is instrumental in ensuring both employee well-being and organizational efficiency.

In relation to the Occupational Health and Safety Assessment Series (OHSAS), this study provides further validation of the principles underlying standards such as OHSAS 18001 and its successor, ISO 45001. These standards advocate for the integration of hazard identification, employee participation, and ongoing training into organizational practices, aiming to create safer working conditions. Recent studies, such as those by Liu et al. [54] and García-Herrero et al. [55] corroborate these findings by highlighting the positive correlation between robust safety management systems and reduced incident rates in high-risk industries. This research aligns these perspectives, offering practical insights into how OSHMS elements can be tailored to the unique challenges of telecommunication tower maintenance.

OHSAS can play a critical role in addressing the negative impacts of risk exposure by emphasizing proactive risk management tailored to high-risk scenarios. For instance, ISO 45001 introduces the concept of "risk-based thinking," which encourages companies to identify and mitigate not only operational hazards but also environmental risks that can exacerbate safety challenges. Recent studies, such as Liu et al. [54] demonstrating that organizations adhering to OHSAS or ISO 45001 standards report significantly lower accident rates and higher safety compliance in hazardous industries validates the relevance of these frameworks. Furthermore, García-Herrero et al. [55] underscore the importance of ongoing worker engagement and training in sustaining a strong safety culture, which is a core requirement of OHSAS. This study also highlights the need to align ESG with environmental, social, and governance. Under governance and safety culture, having clear safety policies, accountable mechanisms, and transparent incident reporting leads to fewer accidents and better worker engagement.

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