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Application of "WHAT–IF" Analysis in Risk Assessment During Rescue Operations at Traffic Accidents

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Abstract

Technical rescue in traffic accidents represents one of the most dynamic and high-risk interventions for emergency services. This study aimed to apply the WHAT–IF analysis to systematic risk assessment during these operations, with particular focus on hydraulic equipment. Through a structured expert assessment methodology that included the Brainstorming and Delphi methods, 10 key adverse event scenarios were identified. The identified scenarios covered risks related to vehicle instability, fire, electric shock in electric/hybrid electric vehicles, equipment failure, and coordination errors. These were evaluated using three-level scales for probability and consequences. The assessments were integrated into a 3×3 risk matrix, allowing categorization into low, medium, high, and critical risk levels. The results showed that by implementing targeted treatment measures — including the standardization of stabilization procedures, Lockout/Tagout procedures for electric vehicles, the appointment of a safety officer, and the use of thermal imaging equipment — initially high and critical risks can be significantly reduced. Statistical analysis using the Wilcoxon signed-rank test confirmed that this reduction was statistically significant ($p < 0.01$), with a large effect size ($r = 0.59$), demonstrating a shift of risks into an acceptable zone in accordance with the ALARP (As Low as Reasonably Practicable) principle. It is concluded that the WHAT–IF analysis provides a clear, operational, and adaptable framework for improving the safety of rescuers and casualties, offering directly applicable guidelines for procedural and technological interventions, as detailed in the attached tabular manuals.

Keywords: Technical rescue, traffic accidents, risk assessment, WHAT-IF analysis, risk matrix, Delphi method, ALARP principle, hydraulic equipment.

1. Introduction

Rescue operations in traffic accidents represent one of the most complex, dynamic, and hazardous interventions within the protection and rescue system. During such actions, rescue teams operate under conditions of high uncertainty, limited time for decision-making, and exposure to numerous mechanical, thermal, chemical, and electrical hazards [1], [2]. The modern development of automotive technologies, particularly electrification and the use of high-voltage battery systems, further complicates the safety and tactical aspects of rescue interventions [3], requiring continuous adaptation of operational procedures.

Risk management in such conditions requires methodological tools that enable systematic, rapid, and flexible identification of potential hazards [4], [5].

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Approaches to risk management in traffic have already been analyzed in the context of vehicle technical inspections and their contribution to overall traffic safety, highlighting the importance of systematic risk analyses in this field [6]. Although numerous standardized risk analysis approaches exist—such as FMEA (Failure Mode and Effects Analysis) [7], [8], HAZOP (Hazard and Operability Study) [9], [10], Bowtie analysis [11], [12], or formal scenario analyses—their application in emergency interventions is often limited due to the need for extensive preparation and complex analytical structures, which conflicts with the dynamic nature of traffic accident scenes.

Unlike the aforementioned methods, WHAT-IF analysis stands out as a technique that enables the rapid generation of adverse event scenarios and their evaluation through the simple formulation of questions such as “What if…?” [5], [13]. This method relies heavily on the expertise of operational personnel, making it particularly suitable for domains in which experience and tactical knowledge play a decisive role, such as technical rescue operations [1], [2].

Despite its practical suitability, the WHAT-IF method is insufficiently documented in professional and scientific literature when it comes to technical rescue from traffic accidents. Although individual aspects of technical rescue—such as vehicle stabilization [14], access to casualties [15], fire tactics [16], [17], or procedures involving electric and hybrid vehicles (EV/HEV) [18]—are relatively well covered, the formal integration of risk analysis, particularly qualitative methods such as WHAT-IF analysis, remains a significantly neglected area. This gap opens research opportunities that can contribute to the standardization and improvement of safety procedures.

The main objectives of this paper are:

- To apply a structured WHAT-IF analysis to the operational process of technical rescue in traffic accidents;
- To identify key high-risk scenarios that primarily affect the safety of rescuers and casualties;
- To assess the impact of proposed risk treatment measures on the reduction of overall risk levels;
- To formally document expert assessments through the synthesis of perspectives from professional rescuers and safety engineers.

The contribution of this research is reflected in both the scientific and practical domains. On one hand, the study fills a gap in the literature by providing a detailed case study of the application of WHAT-IF analysis in the context of technical rescue. On the other hand, an operationally applicable framework has been developed, featuring clear assessment scales, a risk matrix, and specific intervention measures aligned with the ALARP principle [19]. This approach enables rescue services to improve their procedures, reduce the likelihood of incidents, and enhance the level of protection for all parties involved during critical rescue operations [1], [2].

2. Literature Review and Theoretical Framework

2.1. Risk Management in emergency interventions

Technical rescue operations in traffic accidents represent one of the most demanding and complex activities within the protection and rescue domain, characterized by a high degree of uncertainty, time pressure, and dynamic changes in on-site conditions [20]. The modern approach to managing these complex operations is based on internationally accepted risk management principles, as defined in standards such as ISO 31000:2018 [21]. According to this standard, risk is viewed as the effect of uncertainty on the achievement of objectives and is often quantified as a combination of the likelihood of an event occurring and the severity of its consequences.

In the specific context of technical rescue, the ISO 31000 framework is complemented by sector-specific standards and guidelines. Of particular importance are the standards of the National Fire Protection Association (NFPA), especially NFPA 1670: Standard on Operations and Training for Technical Search and Rescue Incidents [1] and NFPA 1006: Standard for Technical Rescuer Professional Qualifications [2]. These documents establish the minimum requirements for training and operations, emphasizing the necessity of hazard identification and risk management during rescue interventions.

Additional specifics are described in ISO 17840: Road Vehicles — Information for First and Second Responders

[3], which addresses the critical issue of identifying and handling new vehicle technologies, particularly those with alternative propulsion systems. The increasing market penetration of electric and hybrid vehicles significantly changes the risk profile at accident scenes, introducing hazards related to high-voltage systems, battery thermal runaway, and complex cutting points, necessitating continuous updates to tactics and procedures.

2.2. Risk assessment methods: advantages and limitations in the emergency context

In the field of risk assessment, there is a wide range of established methods that have found application in industry and process safety. The most commonly used include:

- FMEA: A method focused on identifying possible failure modes of system components and analyzing their effects [7], [8];
- HAZOP: A structured technique that uses guide-words to identify potential deviations from intended operations [9], [10];
- Event Tree Analysis and Fault Tree Analysis: Deductive and inductive methods for modeling cause-and-effect chains of complex incidents [22], [11];
- Bowtie analysis: A visual method linking the causes of a potential hazardous event to preventive measures and mitigation measures [11], [12].

Although these methods are extremely useful for risk analysis in stable and predictable environments [5], their application in emergency interventions—such as traffic accident rescues—faces significant challenges and limitations [23]. Most of these methods require detailed input data, engagement of a larger team of analysts, extended preparation time, and relatively stable operational conditions. These characteristics conflict with the nature of emergency interventions, which are defined by high operational pressure, incomplete information, and the imperative of rapid real-time decision-making.

2.3. WHAT-IF analysis: theoretical foundations

WHAT-IF analysis belongs to the group of qualitative methods for hazard identification and risk assessment. Its conceptual foundation lies in the use of structured brainstorming [5], where questions beginning with "What if…?" are used to explore potential failures, operator errors, or adverse conditions that may lead to undesired events. This methodology is particularly suitable for analyzing complex operational procedures and dynamic systems.

Compared to other methods, WHAT-IF analysis stands out with the following advantages [24], [25], making it especially suitable for the domain of technical rescue:

- Simplicity and understandability: The logical structure of the method is intuitive and easily accessible to operational personnel without deep analytical training;
- Flexibility: It can be easily adapted to different scenarios, types of vehicles, and field conditions, allowing for the generation of a wide range of potential risks;
- Suitability for expert workshops: Encourages active participation and experience sharing among all team members, using their collective tactical knowledge to uncover "hidden" or non-obvious risks;
- Speed of execution: Allows relatively rapid assessment compared to more formal methods, aligning with the need for quick decision-making in emergencies;
- Integration capability: Results can be directly integrated into standard operating procedures, command protocols (e.g., Incident Command System – ICS), and training plans.

2.4. Gaps in scientific and professional literature

Although individual aspects of technical rescue are relatively well documented in both standards and professional literature, a critical synthesis of these elements through the lens of formal risk analysis remains insufficiently addressed [18], [29], [27], [28], [29].

Specifically, the formal integration of risk analyses, particularly qualitative methods such as WHAT-IF analysis, within the operational process of technical rescue in traffic accidents represents a significant gap in existing literature. Current research often focuses on describing individual techniques or hazards and rarely provides a structured, comprehensive, and methodologically grounded framework for systematic risk assessment and management throughout the entire intervention. General frameworks and methods exist in the literature [18], [26], [27], but they are seldom applied in the context of technical rescue.

This gap is reflected in the lack of studies that:

- Apply a structured WHAT-IF analysis across all phases of the rescue process (from arrival at the scene to final extraction);
- Combine expert assessments from operational personnel with the analytical approach of safety engineers;
- Quantitatively or semi-quantitatively evaluate the effectiveness of proposed risk treatment measures;
- Integrate principles such as ALARP into on-scene decision-making regarding the acceptability of risk.

This paper aims to contribute to addressing these deficiencies by applying and thoroughly explaining the WHAT-IF analysis, providing a structured, expert-based risk assessment, integrating the ALARP principle, and offering scaled treatment measures, thus contributing both to scientific knowledge and the improvement of operational practice.

3. Methodology

3.1. Research design

The research is based on the methodology of Structured Expert Elicitation (SEE) [30], [31], [32]. This approach is recommended in cases where empirical data on risks are limited or insufficient, which is characteristic of complex [1], [2] and dynamic operations such as technical rescue [14], where each intervention occurs under unique conditions. Structured Expert Elicitation allows for systematic collection and synthesis of experts' knowledge and experience through rigorously defined procedures, minimizing biases and improving the validity and reliability of the assessments obtained [31], [32]. Conceptually and methodologically, it is grounded in [18], [26], [27].

The expert panel was established based on predefined selection criteria to ensure the relevance and comprehensiveness of the collected data. The criteria applied in the expert selection process are presented in Table 1.

Table 1. Criteria for expert selection.

Criteria	Safety Engineers	Operational Experts
Professional qualifications	Higher education degree – Master's or PhD in: – Mechanical Engineering, – Transport Engineering, – Occupational Safety, or related scientific fields	Possession of valid certifications for vehicle technical rescue in accordance with standards such as NFPA 1006 or NFPA 1670
Professional experience	Minimum of 6 years of experience in risk assessment, emergency management, or the application of risk analysis methods (FMEA, HAZOP)	– Minimum of 8 years of professional experience in emergency response units – At least 40 completed vehicle extrication interventions in road traffic accidents – Candidates with experience in incident command or intervention leadership positions were given preference
Geographical and organizational representation	The team was composed of experts from different organizations and regions in order to minimize local bias.	

Table 2. Composition of the expert panel.

Expert ID	Professional Position	Experience	Qualifications / Specialization
E1	Shift supervisor in a professional fire and rescue unit	12 years	Certified instructor for technical rescue
E2	Senior associate for protection and rescue	10 years	M.Sc. in Safety Engineering
E3	Team leader in a volunteer fire department	15 years	Specialization in interventions involving electric and hybrid vehicles
E4	Traffic accident forensic consultant	7 years	B.Sc. in Mechanical Engineering
E5	University researcher / academic expert	20 years	Ph.D. in Technical Sciences; specialization in risk management

Based on the defined selection criteria, an interdisciplinary team of five experts was formed, which is consistent with recommendations for studies applying the Delphi method that focus on a homogeneous group of highly qualified individuals [32]. Prior to the research, an introductory workshop was conducted to familiarize the team members with the methodology in order to minimize potential differences in interpretation. The composition of the expert panel is presented in Table 2.

The research comprised three consecutive phases:

1. Hazard identification: A comprehensive review of potential hazards across all phases of technical rescue;
2. Generation of WHAT-IF scenarios: Transforming identified hazards into concrete, testable scenarios by formulating "What if…" questions;
3. Assessment of likelihood, consequences, and measures: Quantitative and qualitative evaluation of the generated scenarios, including the development of risk management measures.

3.2. Data collection procedure

The data collection process was organized through a series of workshops, consisting of several consecutive steps designed to gradually expand, then focus and refine the risk list. The risk identification process, illustrated in Figure 1, began with an open brainstorming session. Participants were encouraged, based on their operational experience and professional knowledge, to propose all potential hazards and problems they had encountered or could imagine during technical rescue interventions, without prior criticism or filtering. The goal of this phase was to create as comprehensive and diverse an initial risk list as possible. The session was moderated, and all suggestions were recorded anonymously on a visible board to encourage honesty and avoid group pressure. After the brainstorming session, the generated list of over 40 individual hazards underwent a process of thematic grouping. Participants jointly reviewed all proposals and identified common themes and causes. This resulted in a consolidated list by merging similar items and eliminating clear duplicates. The list was reduced to 15 key risk categories, allowing for a more focused analysis. In the third phase, the consolidated risk categories were transformed into precisely formulated "What if…" questions. The 10 most critical scenarios were selected, covering all key phases of the intervention—from arrival at the scene, through stabilization and access, to extraction and final actions.

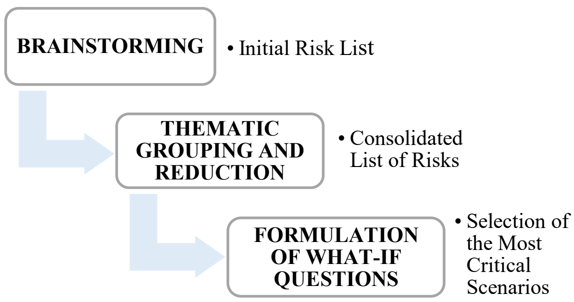

Figure 1. Risk identification process.

For the assessment of likelihood and consequences for each of the 10 final scenarios, the Delphi method was applied [31], [32]. This iterative method of anonymous surveying is designed to achieve expert consensus while minimizing the influence of dominant personalities and group biases. The procedure was conducted in two rounds**:**

1. First round (Anonymous individual assessment): Experts independently rated the likelihood and consequences for each scenario using predefined three-level scales. Responses were collected and statistically analyzed (median, interquartile range).
2. Second round (Consensus discussion): Results from the first round were presented to the group. Discussion focused on scenarios with the widest range of ratings. Experts with extreme ratings were invited to explain their reasoning, followed by an open exchange of opinions. The goal was not to force agreement, but to understand differing perspectives and achieve an informed consensus. After the discussion, participants were allowed to revise their initial ratings.

3.3. Instruments

3.3.1. Assessment scales

Explicitly defined three-level scales were used to ensure consistency among experts and reduce subjectivity in risk evaluation. Likelihood scale was defined based on the appropriate methodology [8], with thresholds adapted to the specifics of technical rescue in traffic accidents:

- **Low (L):** Probability of occurrence < 1% (rarely recorded, usually under very specific conditions).
- **Medium (M):** Probability of occurrence between 1% and 10% (occasionally present in operational practice; experts have encountered this type of incident).
- **High (H):** Probability of occurrence > 10% (frequently documented and expected in operational work).

The consequence scale was defined according to relevant principles and severity evaluation concepts [33]:

- **Minor (M):**
  - Response delay: less than 10 minutes
  - Injuries: None or very minor injuries not requiring medical attention
  - Material damage: Minor damage to equipment or vehicles, easily repairable
  - Operational impact: No or negligible interruption
- **Moderate (S)**
  - Response delay: 10–30 minutes
  - Injuries: Minor injuries to rescuers or casualties requiring medical care, not life-threatening
  - Material damage: Significant damage to equipment, requiring repair
  - Operational impact: Notable interruption during which the condition of the casualty could worsen
- **Severe (V):**
  - Response delay: more than 30 minutes or complete interruption of intervention
  - Injuries: Severe injuries, permanent disability, or fatal outcome
  - Material damage: Destruction of critical equipment or vehicles, extensive damage
  - Operational impact: Catastrophic interruption of the operation, escalation of the incident (fire, explosion).

3.3.2. Risk matrix

A 3×3 risk matrix was used to classify the overall level of risk by combining likelihood and consequence ratings [4], [34], [35]. The matrix is visually presented in Table 3, with color coding for quick identification of priorities.

Table 3. Risk matrix.

Consequences / Likelihood	Low	Medium	High
Minor	Medium risk	High risk	Critical risk
Moderate	Low risk	Medium risk	High risk
Severe	Low risk	Low risk	Medium risk

3.4. Data analysis

3.4.1. Consolidation of assessment

After the completion of the second round of the Delphi procedure, the final ratings of likelihood and consequences for each scenario were consolidated into a single representative value. Median was used as the measure of central tendency, as it is more appropriate for ordinal data and less sensitive to extreme values [31]. In cases of bimodal distributions, the mode (most frequent value) was considered to preserve information about the most common expert opinion and potential divergences, which is a common practice in Delphi applications [36].

3.4.2. *Statistical analysis*

Two statistical procedures were employed: Assessment of agreement among experts – Intraclass Correlation Coefficient (ICC) [37], [38] and Evaluation of effectiveness of measures – Wilcoxon signed-rank test [39], [40].To quantify the level of agreement among experts in their ratings before applying mitigation measures, the ICC was calculated. Specifically, the ICC (2,1) model (two-way random-effects, single measurement) was used, which assesses how individual ratings agree within the group while considering variability both between experts and between scenarios.

Interpretation of ICC values:

- < 0.50: Poor agreement
- 0.50 – 0.75: Moderate agreement
- 0.75 – 0.90: Good agreement
- 0.90: Excellent agreement

To test whether the application of proposed risk treatment measures led to a statistically significant reduction in overall risk levels, the Wilcoxon signed-rank test was used. This test was chosen for two main reasons:

1. Ordinal nature of the data: Risk ratings (Low=1, Medium=2, High=3, Critical=4) are ordinal, not interval, and do not meet the normality assumption required for parametric tests (e.g., t-test).
2. Dependent samples: Two measurements were compared on the same objects (scenarios) - risk levels before and after implementation of measures. The Wilcoxon test is the non-parametric equivalent of the paired t-test.

The test was conducted on the ranks of differences between initial and residual risk (after applying measures) for each of the 10 scenarios. The null hypothesis (H_0) stated that there is no difference in the distribution of risk ranks before and after the measures. Rejection of H_0 ($p < 0.05$) would indicate a statistically significant risk reduction.

Additionally, the effect size (r) was calculated to assess the practical significance of the change using the formula [40]:

$$r = \frac{Z}{\sqrt{N}} \tag{1}$$

Where: Z – standardized test statistic, N – number of observations (scenarios).

4. Results

The results of the study are presented through four key analytical subsystems: 1. Identified hazards and generated WHAT-IF questions, 2. Assessment of likelihood and consequences, 3. Initial risk matrix before the application of mitigation measures, and 4. Evaluation of the effect of proposed risk treatment measures.

4.1. Identified critical scenarios

Through a structured process of brainstorming, thematic grouping, and consensus discussion, the expert team generated a final set of 10 most relevant adverse events, formulated as WHAT-IF questions. These scenarios represent the most significant risks encountered by rescue teams during technical rescue in traffic accidents and are presented in Table 4.

Table 4. Identified scenarios.

No.	WHAT-IF Question
1.	What if the vehicle is unstable and threatens to roll over during passenger extraction?
2.	What if a fire occurs due to fuel leakage or sparking of electrical installations?
3.	What if airbags in the vehicle are active and may deploy unexpectedly during the intervention?
4.	What if the vehicle is electric or hybrid, introducing a risk of high-voltage shock?
5.	What if hydraulic equipment fails during technical extraction?
6.	What if access to casualties is impeded due to vehicle deformation or terrain position?
7.	What if hazardous substances leak (fuel, oil, battery acid)?
8.	What if coordination with other services fails or is delayed?
9.	What if environmental conditions are adverse (night, fog, rain, snow, ice)?
10.	What if there is an error in handling equipment?

These scenarios cover all key phases of technical rescue - from arrival and assessment, through stabilization and access, to cutting, extraction, and final actions.

4.2. Assessment of likelihood and consequences

Using expert consensus and the Delphi method [31], [32], the likelihood of occurrence and potential consequences were evaluated for each of the 10 scenarios. The analysis revealed the following distribution:

Likelihood:

- High**:** 3 scenarios (vehicle instability, communication failure, unexpected ignition)
- Medium**:** 5 scenarios (electrical hazards, hydraulic equipment problems)
- Low**:** 2 scenarios (thermal runaway of EV battery, extreme environmental conditions)

Consequences:

- Minor**:** Intervention delays, minor equipment damage
- Moderate**:** Minor injuries, significant interruptions in the extraction process
- Severe**:** Fires, explosions, severe injuries, or fatalities

A detailed assessment for each scenario is presented in Table 5, quantifying the consequences per scenario.

4.3. Initial risk matrix

Based on the consensus assessments of likelihood and consequences, the initial risk matrix was formed. The results clearly highlight the critical points in the rescue process:

- Critical / High Risk (Red and Orange zones): 4 out of 10 scenarios (vehicle fire, unstable vehicle, high-voltage shock in EV/HEV, secondary collision on highways);
- Medium Risk (Yellow zone): 4 scenarios, requiring planning of mitigation measures and continuous monitoring;
- Low Risk (Green zone): 2 scenarios, though these can escalate under specific circumstances.

The most critical scenarios, according to expert assessments, were:

1. Vehicle fire during extraction (Scenario 2),
2. Lifting and moving an unstable vehicle without adequate stabilization (Scenario 1),
3. High-voltage electric shock in EV/HEV vehicles (Scenario 4),
4. Secondary collision when working on highways and major roads (Scenario 8).

These scenarios have a high potential for escalation and directly threaten the lives of rescuers and casualties.

4.4. Effect of proposed risk treatment measures

After identifying the critical scenarios, specific mitigation measures were formulated [1], [2], [4], [41]. Risk assessments before and after applying these measures show significant improvement:

- All scenarios initially in the high or critical risk zones were moved to medium or low risk zones.
- Medium-risk scenarios were shifted to the low-risk zone.
- The difference in risk ratings before and after measures was statistically significant.

To quantify this shift, the Wilcoxon signed-rank test was applied. Test results confirm the significance of risk reduction: $Z = -2.88$, $p < 0.01$. This indicates a statistically significant decrease in risk levels after implementing the proposed measures. Additionally, the calculated effect size ($r = 0.59$) indicates a high practical efficiency of the implemented measures.

The most effective proposed measures that led to the largest risk reduction were:

- Standardization of vehicle stabilization procedures before using hydraulic tools.
- Deployment of mobile protective barriers on highways to prevent secondary collisions.
- Preemptive deactivation of electrical systems in EV/HEV vehicles.
- Establishment of structured communication procedures and appointment of a safety officer.
- Use of thermal imaging cameras for early detection of battery thermal instability and other hot spots.

These measures significantly reduce the likelihood or escalation of the most critical scenarios, thereby improving the overall safety level at the accident scene.

Table 5. Quantified consequences per scenario.

No.	WHAT-IF Question / Adverse Event	Minor Consequences	Moderate Consequences	Severe Consequences
1	What if the vehicle is unstable and threatens to roll over?	Slight movement of the vehicle upon entry; corrected with wedges without delay.	Vehicle unstable; requires additional stabilization (supports); intervention delayed 10–15 min; risk of minor rescuer injuries.	Vehicle rolls/falls during intervention; structural collapse; severe injuries or death of rescuer/casualty; complete interruption of operation.
2	What if a fire occurs due to fuel leakage or electrical sparking?	Small fire on installation; extinguished with fire extinguisher on site; no injuries or delays.	Fire affecting part of the engine/cabin; requires fire line; minor rescuer burns; intervention delayed.	Fully developed fire; explosion hazard; severe injuries or death of casualties; complete interruption of intervention.
3	What if the airbags in the vehicle are active and may deploy unexpectedly	Airbag deployment without rescuer presence; minor delay.	Airbag deployment during work; minor rescuer injuries (bruises, burns); equipment damage.	Uncontrolled explosion (e.g., side curtains) directly impacts rescuer or casualty; severe head/neck injuries.
4	What if the vehicle is electric or hybrid (risk of high-voltage shock)?	Brief contact without consequences due to PPE; administrative delay for verification.	Mild to moderate electric shock; rescuer requires medical check; work paused until HV system secured.	Severe electric shock, life-threatening injuries, or death; battery fire is difficult to extinguish.
5	What if hydraulic equipment fails during technical extraction?	Minor malfunction (e.g., leak at a joint); quick hose replacement; delay <2 min.	Failure of generator or key tool (e.g., cutters); need for backup equipment; 5–10 min delay; patient condition worsens.	Complete hydraulic failure without backup; unable to free casualty; rescue halted; fatal outcome.
6	What if access to casualties is impeded (deformation, terrain position)?	Casualty blocked by minor deformation; freed in <5 min.	Multiple cuts required (pillar, door); extended extraction 15–30 min; casualty condition worsens due to delay.	Complete cabin deformation (e.g., "sandwich" scenario); no access to vital functions; death before or during extraction.
7	What if hazardous substances leak (fuel, oil, acid)?	Minimal oil leak; absorbed without delay.	Moderate fuel leak; fire risk; neutralization required; minor delay.	Massive fuel/acid leak; high risk of explosion/fire; site contamination; chemical injuries to rescuers.
8	Coordination with other services fails or is delayed	Short-term confusion on scene, 2–3 min delay; manual rerouting.	Inadequate traffic control, entry of third parties; 10–15 min delay; risk of minor injuries.	Secondary accident due to uncontrolled traffic flow; blocked access to the technical rescue vehicle; severe injuries/life-threatening.
9	Adverse environmental conditions (night, fog/rain/snow, ice)	Extended positioning and lighting; slower work without injuries	Slips/trips, difficult cutting and access; minor equipment damage; 10–20 min delay	Vehicle/person falls on slope; uncontrolled sliding; severe injuries; operation interrupted
10	Equipment handling error	Short delay to correct or change attachment; no injuries	Tool damage; 5–10 min interruption; minor injuries	Sudden failure under load; uncontrolled opening/collapse of segment; severe injuries; operation halted

5. Discussion

The results of this study clearly demonstrate that the WHAT-IF analysis is a highly suitable and effective method for assessing and managing risks in technical rescue operations involving traffic accidents. Beyond interpreting the key findings in the context of existing literature, the study highlights their practical contribution, discusses methodological limitations, and paves the way for future research.

5.1. Methodological validity and identification of key risks

The complete set of 10 identified scenarios provides a comprehensive overview of critical hazards across all phases of the intervention – from arrival to final extraction – demonstrating the holistic nature of the WHAT-IF analysis [13], [42]. The most critical scenarios (vehicle instability, fire, electrical hazards, secondary collisions) largely align with the priorities established in international standards such as NFPA 1670 [1] and ISO 17840 [3], confirming the validity of the applied methodological framework. This convergence between field expertise and formal standards indicates that a structured WHAT-IF analysis can reliably identify the risks with the greatest impact on safety and intervention outcomes, providing a basis for targeted preventive and operational measures.

5.2. Effectiveness of proposed measures and practical implications

The proposed mitigation measures demonstrated high effectiveness, leading to a statistically significant reduction in risk levels (details in Table A1 in the Appendix). These measures can be grouped into three key domains, each with clear practical implications:

- Enhancement of procedural safety: Standardized vehicle stabilization procedures [41], [14] and the implementation of LOTO (LockOut/TagOut) protocols for electric vehicles [43], [44] directly reduce the likelihood of the two most critical scenarios – mechanical collapse and electrical hazards, through clear and repeatable procedures.
- Improvement of organizational control: Establishing a clear command structure according to ICS principles [45] and appointing a safety officer [24], [25], [46] addresses systemic weaknesses in coordination and communication, preventing secondary collisions and decision-making errors under pressure.
- Integration of technological solutions: The use of thermal imaging cameras for early detection of battery overheating [47] and other hotspots [48] provides critical real-time data, enabling intervention before incident escalation [49].

All measures are fully aligned with the ALARP principle [50], representing reasonable, proportionate, and cost-effective actions that significantly improve the operational safety profile. Practical feasibility is ensured through interdisciplinary collaboration during their development, guaranteeing that theoretically sound measures are applicable under the chaotic conditions of real interventions.

5.3. Specific risks of EV/HEV vehicles and emerging operational challenges

The study clearly highlighted the specific and increasingly important risk profile associated with EV/HEV vehicles [29], [51], [52], [53]. Non-compliance with traffic regulations further complicates the operational rescue context [54]. Scenarios such as battery “thermal runaway” present a medium likelihood of occurrence but critical consequences, requiring a dedicated risk management approach in preparation for rare yet catastrophic events [26], [27].

The development of autonomous vehicles and the implementation of IoT/AI technologies further alter the risk landscape, necessitating new approaches to maintenance and safety [55]. These findings have immediate practical implications, emphasizing the urgent need to update training, procedures, and equipment. The recommended measures (presented in Table A1 in the Appendix) provide a concrete pathway forward, from vehicle identification to full electrical isolation, thereby enhancing the overall safety profile of the intervention.

5.4. Methodological limitations and directions for future research

Although this study represents a significant contribution, it is important to acknowledge its limitations.

The assessments are based on qualitative expert evaluations rather than extensive historical data, and the results are partially dependent on the experience and operational culture of the participating experts [30]. Although structured expert elicitation is widely accepted in situations where empirical data are limited, such an approach inevitably involves a certain degree of subjectivity.

An additional limitation concerns the spatial scope of the study, as the analyzed scenarios primarily reflect conditions characteristic of the observed region. Different geographical and organizational contexts may influence the relative importance of specific risks. Furthermore, the number of iterations in the Delphi process may potentially limit the level of consensus achieved compared to studies using more rounds.

It is also important to emphasize that the scenarios were defined within the domain of technical rescue in traffic accidents, meaning that the identified risks and proposed measures are specific to this type of intervention. In other situations, the structure of risks and scenarios may differ and require additional operational procedures.

These limitations simultaneously open avenues for future research:

- Quantitative validation: Collecting empirical data from real interventions to quantify scenario frequency and verify the effectiveness of mitigation measures [26].
- Development of digital tools: The checklists presented in Table A2 provide a solid foundation for developing a digital application to support on-site decision-making [27].
- Methodology extension: The WHAT-IF analysis can be applied to other complex emergency interventions, such as industrial rescue operations or natural disaster response [26].

6. Conclusion

The results of the conducted study indicate that the application of What-If Analysis in the context of technical rescue from road traffic accidents provides a robust and operationally applicable framework for systematic risk identification and assessment. Through a structured and expert-guided procedure, ten key adverse event scenarios were identified, encompassing risks characteristic of this type of intervention: vehicle instability, fire, electrical hazards in EV/HEV vehicles, equipment failures, and errors in coordination and communication. The distribution of scenarios across all phases of the intervention—from arrival on scene to final extraction—demonstrates a comprehensive approach to risk identification and confirms the ability of What-If Analysis to capture complex operational workflows.

The implementation of targeted risk treatment measures led to a significant reduction of initially high and critical risks. Particularly effective were the standardization of vehicle stabilization procedures**,** the application of Lockout–Tagout (LOTO) procedures for EV/HEV vehicles**,** the designation of a responsible safety officer, and the use of thermal imaging equipment for early detection of battery thermal instability and other critical points. Statistical analysis using the Wilcoxon signed-rank test, together with effect size estimation, indicated a statistically significant risk reduction, while the Intraclass Correlation Coefficient (ICC) demonstrated high consistency in expert assessments across different rounds of evaluation. These results align with relevant technical rescue standards and practices, further confirming the validity and practical applicability of the methodological framework.

In the context of the ALARP principle (As Low As Reasonably Practicable), the finding that risks can be reduced to an acceptable zone through pragmatic and expert-guided interventions highlights the balance between safety rigor and operational feasibility. This confirms that systematic risk assessment, supported by expert judgment and statistical verification, can be an effective tool for improving the safety of rescuers and victims in dynamic and high-risk environments.

The contribution of this research lies in filling gaps in the literature through the detailed application of What-If Analysis in technical rescue, integrating the Delphi method and quantitative verification of results. From a practical perspective, the developed set of tools and corresponding tables can serve as a framework for planning, training, and rapid on-site decision-making, enhancing operational readiness and safety culture. This emphasizes the potential of What-If Analysis for standardization and improvement of operational procedures in technical rescue from road traffic accidents.

Declaration of Competing Interests

The authors declare that there are no known competing financial interests or personal relationships that could influence the work reported in this paper.

Declaration of Data Availability

Additional materials and data used in this research are available upon request. For access, please contact the corresponding author at [fuad.k@ipi.ba].

Author Contributions

- **Marinko Aleksić**: Conceptualization, Investigation, Writing – Original Draft
- **Fuad Klisura**: Methodology, Investigation
- **Luka Maljević**: Supervision, Project Administration
- **Teodora Kovačević**: Investigation, Validation, Writing – Review & Editing

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Appendix A: Specific Measures and Checklists for Risk Management

Table A1. Specific Recommended Risk Treatment Measures for Identified Critical Scenarios

Scenario No.	WHAT-IF question	Risk category	Recommended Risk Treatment Measures	Measure category
1	Vehicle instability before or during intervention	Mechanical hazard	1. Mandatory use of at least 4 chock blocks and straps per vehicle before approach. 2. Use of hydraulic/pneumatic support systems for heavily overturned/tilted vehicles. 3. Additional stabilization after each cut or lift; continuous assessment of stability.	Procedural/ Equipment
2	Fire due to fuel leakage or electrical failure	Fire hazard	1. Mandatory presence of a fire team with a prepared hose line (min. 1 inch) throughout the intervention. 2. Placement of a fire extinguisher (portable) at every access point. 3. Use of a thermal imaging camera for continuous monitoring of engine, battery, and fuel system temperatures.	Procedural/ Technological
3	Explosion of active airbags	Mechanical hazard	1. Identify and mark zones with active airbags during the initial assessment. 2. Disconnect the 12V battery according to procedure. 3. Avoid working directly in front of or near undeployed airbags.	Procedural
4	High-voltage shock in EV/HEV vehicles	Electrical hazard	1. Identify vehicles using blue tape markings, labels, and VINs. 2. Follow the procedure to deactivate the 12V battery (interrupt “power belts”). 3. Apply the LOTO (LockOut-TagOut) procedure to the HV system after deactivation. 4. Maintain a safe distance (recommended 0.5–1 m) from marked HV components (orange color).	Procedural/ Equipment
5	Hydraulic equipment failure	Operational hazard	1. Pre-intervention equipment test (functionality, pressure). 2. Keep a set of spare hoses and quick connectors on-site. 3. Controlled, two-handed handling of tools to avoid overloading and “snapping.”	Procedural/ Maintenance Equipment
6	Difficult access due to deformation/position	Operational hazard	1. Additional stabilization before complex cutting. 2. Use multiple access points (e.g., roof and doors simultaneously). 3. Use specialized deep-penetration tools (e.g., "Gladiator").	Procedural/ Equipment
7	Leakage of hazardous materials	Chemical/ Environmental Hazard	1. Rapid identification of liquids (fuel = transparent, oil = brown, acid =green). 2. Immediate application of absorbents (sawdust, pads). 3. Eliminate ignition sources; prepare for neutralization.	Procedural/ Equipment

Table A1. Continued on next page.

Table A1. Specific recommended risk treatment measures for identified critical scenarios (continued)

Scenario No.	WHAT-IF question	Risk category	Recommended Risk Treatment Measures	Measure category
8	Poor coordination with other services	Organizational hazard	1. Establish ICS command structure and clearly defined work zones (Hot/Warm/Cold). 2. Appoint a “safety officer” with the exclusive role of safety oversight. 3. Collaborate with police to set up protective barriers and redirect traffic at a safe distance.	Organizational
9	Adverse environmental conditions (night, rain, ice)	Natural/Environmental hazard	1. Early deployment of adequate working lighting. 2. Use non-slip mats under equipment and operators. 3. Increase personnel for stabilization and securing.	Procedural/ Equipment
10	Equipment handling error	Human factor	1. Mandatory presence of an experienced operator for complex tasks. 2. Two-way communication before each critical action (e.g., "Lifting – is everything clear?"). 3. Regular training on simulated scenarios under stress.	Training/ Procedural

Table A2. Incident Commander Checklist (Rapid On-Scene Risk Assessment)

Intervention Phase	Critical Assessment Questions	Yes	No	Action (if “No”)
Initial Arrival & Assessment	Is the zone secured (Hot/Warm/Cold zones)?	☐	☐	Establish a perimeter with police assistance.
	Is the vehicle identified as EV/HEV?	☐	☐	Apply EV/HEV procedure: look for blue tape, labels, and deactivate the 12V battery.
	Have initial hazards been identified and marked (leakage, smoke, vehicle position)?	☐	☐	Communicate hazards to the entire team; deploy fire extinguishers.
Stabilization & Preparation	Is the vehicle fully stabilized (wedges, straps, supports)?	☐	☐	Stop work and place additional supports before continuing.
	Is access to the victims ensured for the medical team?	☐	☐	Provide access for emergency care while maintaining safety.
Access & Extraction	Are all electrical systems (12V and HV) deactivated and LOTO applied?	☐	☐	Perform the LOTO procedure before any cutting.
	Is the firefighting line ready and directed at critical points?	☐	☐	Call firefighters to position and deploy the line.
	Is the safety officer continuously monitoring the scene?	☐	☐	Appoint a safety officer and ensure clear visibility of the scene.
Final actions	Has the victim’s condition been assessed before final extraction?	☐	☐	Synchronize the final lift with the medical team.
	Is the equipment safely dismantled and prepared for removal?	☐	☐	Pack and secure equipment carefully, in a controlled manner.

Appendix B: Statistical Methods and Calculations

This appendix provides a detailed overview of the statistical methods used for data analysis, along with explanations intended to facilitate understanding for readers who are not statistical experts.

B.1. Assessment of agreement among experts: intraclass correlation coefficient (ICC)

B.1.1. Purpose and methodology

The ICC was used to quantify the degree of agreement among experts in their assessments. This measure indicates how consistent the experts were in their risk evaluations across different scenarios.

The ICC (2,1) model was applied, taking into account:

- Variability between different scenarios
- Variability between different experts
- Random effects influencing the assessments

B.1.2. Illustrative calculation example

For better understanding, below is a simplified example of how the ICC is calculated:

Table B1. Example of probability ratings (1 = low, 2 = medium, 3 = high).

Ekspert	Scenario 1	Scenario 2	Scenario 3
A	3	2	1
B	3	2	2
C	2	2	1
D	3	3	2
E	2	2	1

Calculation Steps:

1. ANOVA Analysis:
   The data are analyzed using analysis of variance (ANOVA), which decomposes the total variability into:
   o Variability between scenarios
   o Variability between experts
   o Residual (error) variability
2. Calculation of the ICC Value:
   ICC = (Between-scenario variability − Error variability) /
   (Between-scenario variability + Between-expert variability + Error variability)
3. Interpretation of Results:
   o The ICC value ranges from 0 to 1
   o Higher values indicate better agreement

B.1.3. Results

After calculating all ratings for all 10 scenarios, a final ICC (2,1) value of 0.87 was obtained.

Interpretation: According to commonly accepted standards (Koo & Li, 2016), this value indicates good agreement among experts, confirming the reliability and validity of the consensus assessments used in the analysis.

B.2. Assessment of measure effectiveness: Wilcoxon Signed-Rank Test

B.2.1. Purpose and justification for test selection

The Wilcoxon signed-rank test was used to determine whether there was a statistically significant reduction in risk levels after the implementation of the proposed measures.

Why this test?

1. **Ordinal data:** Risk ratings (Low = 1, Medium = 2, High = 3, Critical = 4) are categorical in nature
2. **Paired data:** The same scenarios are compared before and after the measures
   3. Non-parametric: The test does not require the data to follow a normal distribution

B.2.2. Simplified Illustration of the Calculation

Table B2. Hypothetical data for 5 scenarios (shortened for clarity)

Scenario	Risk (before)	Risk (after)	Difference	Absolute	Rank
1	4	2	-2	2	4.5
2	3	2	-1	1	2.5
3	3	1	-2	2	4.5
4	2	1	-1	1	2.5
5	2	1	-1	1	2.5

Calculation Steps:

1. **Calculation of Differences:** For each scenario, the post-measure rating is subtracted from the pre-measure rating.
2. **Ranking of Absolute Values:** The absolute values of the differences are ranked from smallest to largest.
3. **Assignment of Signs:** Ranks are assigned positive or negative signs according to the direction of change.
4. **Sum of Ranks:** The sums of positive and negative ranks are calculated.

B.2.3. Results in Our Study

After performing the calculations for all 10 scenarios, the following results were obtained:

- $Z = -2.88$ (standardized test statistic)
- $p < 0.01$ (level of statistical significance)

Statistical Interpretation:

- $p < 0.01$ indicates that there is less than a 1% chance that the observed reduction in risk occurred by random chance.
- The null hypothesis that there is no difference between the pre- and post-measure conditions is rejected.

B.2.4. Practical significance: effect size

To assess how practically meaningful the risk reduction is, the effect size was calculated:

$r = |Z| / \sqrt{N}$
$r = 2.88 / \sqrt{10}$
$r = 2.88 / 3.16$
$r = 0.59$

Interpretation of Effect Size: According to Cohen's guidelines (1988):

- 0.10 = small effect
- 0.30 = medium effect
- 0.50 = large effect

The obtained value of 0.59 indicates a large practical significance of the risk reduction resulting from the implementation of the proposed measures.

B.3. Conclusion of the statistical analysis

The statistical analysis confirmed the following:

1. **Reliability of assessments:** Experts demonstrated a high level of agreement (ICC = 0.87).
2. **Effectiveness of measures:** The reduction in risk is statistically significant ($p < 0.01$).
3. **Practical value:** The effect of the measures is large ($r = 0.59$).

These findings provide strong statistical support for the conclusions presented in the main body of the paper.