

# Risk assessment in sustainable logistics operations: An FMEA application in a distribution center

*Sürdürülebilir lojistik operasyonlarında risk değerlendirmesi: Bir dağıtım merkezinde FMEA uygulaması*

Erdal Kılıç<sup>1\*</sup> 

<sup>1</sup> Department of Defense Studies, Milli Savunma University, İstanbul, Türkiye.

## ÖZET

Bu araştırma, Türkiye’de faaliyet gösteren sürdürülebilir bir lojistik şirketinin genel merkez tesisinde mevcut mesleki tehlikeleri belirlemek, önceliklendirmek ve kontrol önlemleri geliştirmek amacıyla Hata Türü ve Etkileri Analizi (FMEA) yöntemini uygulamaktadır. Yedi uzmandan oluşan disiplinler arası bir ekip, dört haftalık bir dönemde tesis denetimleri, belge incelemeleri ve personel görüşmeleri yürütmüş; her tehlike için olasılık, şiddet ve saptanabilirlik değerlerine dayalı Risk Öncelik Puanı (RÖP) hesaplamıştır. Beş operasyonel bölgede toplam 47 tehlike belirlenmiş; bunların yedisi (%14,9) yüksek, on altısı (%34,0) orta ve yirmi dördü (%51,1) kabul edilebilir risk olarak sınıflandırılmıştır. En yüksek öncelikli tehlikeler elektrik çarpması, uygunsuz kaldırmaya bağlı ergonomik zorlanma, konveyöre kapılma ve düşen nesne riskleri olmuştur. Çalışma, üretim ve sağlık alanlarında doğrulanmış FMEA yöntemini çok işlevli bir lojistik tesisine taşıması ve risk önceliklendirmesini kontrol önlemlerinin maliyet tahminiyle ilişkilendirmesi bakımından literatüre özgün katkı sunmaktadır.

## Anahtar Kelimeler:

*Risk değerlendirme,  
Hata türü ve etkileri  
analizi (FMEA),  
Risk yönetimi,  
Süreç iyileştirme,  
İş sağlığı ve güvenliği*

## ABSTRACT

### Keywords:

*Risk assessment,  
Failure mode and  
effects analysis  
(FMEA),  
Risk management,  
Process improvement,  
Occupational health  
and safety*

This study applies the Failure Mode and Effects Analysis (FMEA) method to identify, prioritize, and develop control measures for the occupational hazards present at the headquarters facility of a sustainable logistics company operating in Türkiye. A multidisciplinary team of seven specialists conducted facility inspections, document reviews, and personnel interviews over a four-week period, calculating a Risk Priority Score (RPS) for each hazard on the basis of occurrence, severity, and detectability ratings. A total of 47 hazards were identified across five operational zones; seven (14.9%) were classified as high risk, sixteen (34.0%) as medium risk, and twenty-four (51.1%) as acceptable risk. The highest-priority hazards were electrical shock, ergonomic strain from improper lifting, conveyor entanglement, and falling objects. The study makes an original contribution to the literature by transferring an FMEA approach validated in manufacturing and healthcare to a multifunctional logistics facility and by linking risk prioritization to cost estimates for control measures.

## 1. Introduction

In the modern era of global commerce, the logistics and supply chain sector has become increasingly vital to economic development and competitiveness across nations. Sustainable logistics operations, characterized by environmentally responsible practices and efficient resource management, have emerged as a cornerstone of contemporary business strategy (Chiozza & Ponzetti, 2009). The headquarters of sustainable logistics companies, as operational command centers, manage complex workflows encompassing administrative functions, cargo handling, inventory management, and distribution coordination. These multifaceted operational environments present inherent occupational hazards that demand systematic identification, assessment, and mitigation strategies.

The concept of occupational health and safety (OHS) has gained significant prominence in developed nations over the past decades. International research indicates that workplace-related injuries and diseases constitute a substantial burden on both individual workers and organizational productivity (Reiling et al., 2003). In response,

Received: 26.02.2026 Revised: 08.03.2026, 26.03.2026 Accepted: 26.03.2026

<http://dx.doi.org/10.29228/javs.90614>

\*E-mail address ([erdal.kilic@msu.edu.tr](mailto:erdal.kilic@msu.edu.tr)).

This article is licensed under a [Creative Commons Attribution 4.0 International License \(CC BY 4.0\)](https://creativecommons.org/licenses/by/4.0/).

regulatory frameworks such as ISO 45001:2018 (Occupational Health and Safety Management Systems) and the TS ISO 31000 Risk Management Standard have established systematic approaches for organizations to identify and control workplace hazards. The primary objectives of occupational health and safety management are to create a healthy work environment at the highest possible level, protect workers from the adverse effects of working conditions, ensure optimal compatibility between workers and their tasks, and minimize or entirely eliminate workplace risks (MEGEP, 2005; Yurdakul et al., 2019).

Among the various methodologies available for systematic hazard identification and risk assessment, the Failure Mode and Effects Analysis (FMEA) technique has proven to be a particularly effective and widely adopted approach. FMEA is a proactive, systematic method designed to identify potential failures within processes, systems, or operations and to evaluate the consequences and likelihood of such failures occurring (Stamatis, 1995). The methodology is not reactive (addressing problems only after they have caused harm) but rather preventive, enabling organizations to implement corrective measures before incidents occur. Originally developed by the National Aeronautics and Space Administration (NASA) during the 1960s, FMEA has since been refined and standardized across multiple industrial sectors, including aerospace, automotive manufacturing, healthcare, and food production (Baig & Prasanthi, 2013; Chiozza & Ponzetti, 2009).

The application of FMEA methodology requires the formation of a multidisciplinary team comprising individuals with diverse expertise and operational knowledge relevant to the system under analysis (Stamatis, 1995; Durhan, 2006). This team-based approach ensures comprehensive coverage of potential hazards and facilitates the identification of risks that might otherwise be overlooked by individual assessment. Furthermore, the implementation of FMEA within organizational risk management frameworks has been demonstrated to reduce occupational injuries, minimize the severity of incidents when they do occur, and enhance overall safety culture and compliance with regulatory standards (Liu et al., 2013).

Despite the well-documented benefits of FMEA across various sectors, its application within the logistics industry, and particularly within sustainable logistics operations, remains scarce in academic literature. Existing FMEA research has concentrated overwhelmingly on aerospace, automotive manufacturing, healthcare, and food production, where the unit of analysis is typically a single production line, a clinical process, or a discrete piece of equipment (Liu et al., 2013; Chiozza & Ponzetti, 2009). By contrast, the general headquarters of a sustainable logistics company constitutes a markedly different analytical context: it integrates administrative, warehousing, cargo-handling, and distribution-coordination functions within a single facility, so that ergonomic, electrical, mechanical, environmental, chemical, and organizational hazards coexist and interact across adjacent operational zones. This study extends prior FMEA applications in three specific respects. First, it transfers a methodology validated in manufacturing and healthcare settings to a multifunctional logistics facility whose hazard profile has not previously been characterized. Second, rather than examining an isolated process, it applies FMEA simultaneously across five operational zones, enabling a comparative, zone-based mapping of risk concentration that single-process studies cannot provide. Third, it couples the quantitative Risk Priority Score with an explicit cost estimation of recommended control measures, linking risk prioritization to resource-allocation decisions in a way rarely reported in the logistics OHS literature. In doing so, the study addresses a clear gap and provides empirical evidence on the types, severity, and spatial distribution of hazards present in sustainable logistics headquarters.

## **2. Literature review**

### **2.1. Occupational health and safety in the logistics and supply chain sector**

Occupational health and safety has emerged as a critical concern for organizations across diverse industrial sectors, with particular relevance to the logistics and supply chain management industry (Stamatis, 1995; Durhan, 2006). The primary objectives of occupational health and safety management are multifaceted: to create a healthy and safe working environment at the highest possible level; to protect workers from the adverse health and safety effects of their working conditions; to ensure optimal compatibility and ergonomic adaptation between workers and their assigned tasks; and to minimize or entirely eliminate workplace risks and hazards (MEGEP, 2005; Yurdakul et al., 2019).

The logistics and supply chain sector presents a distinctive occupational environment characterized by the concurrent operation of multiple functional areas within integrated facilities. The general headquarters of sustainable logistics companies serve as operational command centers managing complex workflows encompassing administrative functions, cargo handling operations, inventory management, and distribution

coordination activities (Chiozza & Ponzetti, 2009). This multifunctional integration creates inherent occupational hazards that demand systematic identification, assessment, and mitigation strategies (Reiling et al., 2003).

Sustainable logistics operations have emerged as cornerstones of contemporary business strategy. However, the complex nature of these operations, involving the coordination of diverse functional areas (administrative offices, cargo handling facilities, inventory storage zones, distribution coordination centers, and specialized operational facilities), creates an operational environment with substantial and multifaceted occupational hazards (Yurdakul et al., 2019). Administrative offices within logistics headquarters present specific hazards including electrical infrastructure deficiencies, inadequate storage and stacking practices, ergonomic deficiencies in office furnishings, and insufficient emergency preparedness systems. Cargo handling areas present hazards related to inadequate lighting, insufficient ventilation, improperly organized and unsecured shelving systems, and non-compliance with established safety protocols. Distribution centers present additional risks including inadequate temperature control systems, accessibility to electrical control panels without proper authorization restrictions, and exposed electrical connections (Durhan, 2006).

The concept of occupational health and safety management has gained increasing prominence within developed nations over recent decades, with international research documenting that workplace-related injuries and diseases constitute a substantial burden on both individual workers and organizational productivity (Reiling et al., 2003). In response, comprehensive regulatory and standardization frameworks have been established. The International Organization for Standardization developed ISO 45001:2018 (Occupational Health and Safety Management Systems), which establishes systematic approaches for organizations to identify and control workplace hazards. Within Türkiye specifically, the Occupational Health and Safety Law (Act No. 6331, enacted in 2012) established comprehensive regulatory frameworks requiring organizations to implement systematic occupational safety management systems and conduct regular risk assessments of their operational environments (Sivrikaya, 2016). Complementing this legislative framework, the TS ISO 31000 Risk Management Standard established a systematic, process-oriented framework through which organizations can identify, characterize, evaluate, and manage risks within their operational contexts (Yurdakul et al., 2019).

The logistics sector has historically received less academic attention regarding occupational risk assessment than sectors such as healthcare, manufacturing, and aerospace (Thun & Hoenig, 2011). This gap in the literature is particularly pronounced with respect to sustainable logistics operations, despite the sector's growing economic importance and the complexity of hazard profiles within logistics facilities (Yurdakul et al., 2019). Research conducted in warehouse and distribution environments demonstrates that workers within these settings experience injury rates substantially elevated above the general manufacturing workforce baseline. Specific hazard categories prevalent in logistics operations include ergonomic hazards related to improper material handling and lifting techniques; environmental hazards associated with inadequate facility conditions such as temperature extremes, poor ventilation, and inadequate illumination; equipment-related dangers including electrical hazards and mechanical failures; and organizational hazards stemming from inadequate safety protocols and insufficient employee training (Durhan, 2006; Thun & Hoenig, 2011).

## **2.2. Risk assessment and management frameworks: The TS ISO 31000 standard**

Risk assessment and management constitute fundamental components of comprehensive occupational health and safety programs. The TS ISO 31000 Risk Management Standard, Türkiye's adopted version of the International Standard ISO 31000:2010, establishes a systematic, five-phase framework for organizational risk management. These sequential phases encompass: (1) hazard identification and characterization; (2) risk identification; (3) risk evaluation; (4) risk prioritization and classification; and (5) risk control implementation (Yurdakul et al., 2019).

The TS ISO 31000 framework emphasizes proactive risk management, the systematic identification and mitigation of potential hazards before they result in incidents, as opposed to reactive approaches that address problems only after accidents or injuries have occurred. This preventive philosophy is grounded in the recognition that organizational resources are finite and that the costs associated with prevention are substantially lower than the human and economic costs incurred by occupational injuries, diseases, and related operational disruptions (Durhan, 2006; Turkish Standards Institution, 2010).

**Hazard identification and characterization.** The first phase involves systematic examination of operational systems and processes to identify all potential hazards. Hazard identification is informed through multiple methods including direct observation of work activities, review of historical accident and incident data, examination of regulatory compliance requirements and applicable safety standards, and consultation with operational personnel who possess intimate knowledge of daily work processes. This comprehensive approach

recognizes that novel and emerging hazards not reflected in historical incident data can be identified through systematic prospective examination (Yurdakul et al., 2019).

**Risk identification.** The second phase involves detailed characterization of each identified hazard, specifying the manner in which a hazard might manifest as a failure, the operational context in which the failure might occur, and the potential consequences that would result. For example, within an administrative office environment, a hazard might be identified as “unsecured shelving units,” the associated failure mode as “shelving unit collapse or falling objects,” and the potential consequences as “objects striking workers below the shelving, resulting in injuries ranging from minor contusions to serious crushing injuries” (Durhan, 2006).

**Risk evaluation.** The third phase involves assessment of the magnitude or severity of each identified risk, incorporating both quantitative methodologies (assigning numerical scores to risk components) and qualitative assessment of overall risk magnitude. The TS ISO 31000 framework accommodates diverse methodologies for risk evaluation, with the FMEA technique representing one of the most extensively implemented approaches (Turkish Standards Institution, 2010).

**Risk prioritization and classification.** The fourth phase involves ranking of identified risks according to their evaluated magnitude to facilitate prioritized resource allocation. Within the TS ISO 31000 framework, risks are typically classified as acceptable (requiring no immediate intervention but remaining subject to periodic monitoring), medium (exceeding acceptable levels and requiring targeted control measures), and high (unacceptable hazard levels requiring urgent corrective and preventive intervention) (Yurdakul et al., 2019).

**Risk control implementation.** The final phase involves development and implementation of specific control measures designed to reduce the probability of hazard occurrence, mitigate the severity of potential consequences, or enhance hazard detection capabilities (Durhan, 2006). Implementation encompasses both engineering controls (modifications to equipment, processes, or facility infrastructure designed to eliminate or reduce hazards at their source) and administrative controls (modifications to work procedures, training protocols, and supervisory practices designed to reduce worker exposure to hazards) (Turkish Standards Institution, 2010).

Research examining the application of the TS ISO 31000 framework within organizational settings has demonstrated measurable effectiveness in improving occupational safety outcomes. Aydan and Kaya (2017) examined systematic risk management implementation within educational institutions using the TS ISO 31000 framework and documented that systematic application of the framework resulted in measurable improvements in hazard identification comprehensiveness, accuracy of risk quantification, and development and prioritization of prevention and control measures.

### **2.3. Failure mode and effects analysis (FMEA): Historical development and methodological foundations**

#### **2.3.1. Origins and evolution of FMEA as a risk assessment methodology**

Failure Mode and Effects Analysis represent one of the most extensively implemented and empirically validated systematic risk assessment methodologies employed across diverse industrial sectors globally. The origins of FMEA are traced to NASA during the 1960s, where it was developed as a preventive risk management tool specifically designed to identify potential failures and their consequences within complex aerospace systems and components (Baig & Prasanthi, 2013). The context of FMEA’s development is instructive: the aerospace industry of the 1960s faced critical challenges wherein the costs of system failures were extraordinary, not only in financial terms but, critically, in terms of potential loss of human life. This context necessitated the development of systematic methodologies capable of identifying hazards before they manifested as catastrophic failures, rather than relying upon reactive approaches that addressed problems only after accidents had occurred (Stamatis, 1995).

The FMEA methodology was subsequently refined and formalized through various recognized international and industry-specific standards, facilitating its broader adoption. These standardization efforts included frameworks established by the Joint Commission, the International Organization for Standardization (ISO/TS 22367), and specialized automotive industry standards promulgated by the Society of Automotive Engineers (Chiozza & Ponzetti, 2009). This process established consistent terminology, defined systematic application procedures, and created frameworks within which organizations across diverse sectors could apply FMEA using comparable approaches and criteria (Mannan, 2005).

Contemporary applications of FMEA extend across automotive manufacturing, aerospace and defense industries, pharmaceutical and medical device manufacturing, food production and processing, healthcare delivery systems, educational institutions, and, increasingly, service and logistics operations (Stamatis, 1995; Baig & Prasanthi,

2013). Research examining FMEA implementation across these sectors has documented consistent findings: organizations implementing FMEA systematically experience measurable improvements in hazard identification comprehensiveness, reduce severity of accidents when they do occur, and enhance organizational safety culture and regulatory compliance (Liu et al., 2013; Chiozza & Ponzetti, 2009).

Notwithstanding its widespread adoption, FMEA is among the most extensively criticized risk assessment methodologies in the reliability and quality literature, and a balanced treatment of the technique requires that these criticisms be acknowledged. The most fundamental objection concerns the traditional Risk Priority Score, obtained by multiplying the occurrence, severity, and detectability ratings. First, the three factors are assigned equal importance, although severity is widely regarded as warranting greater weight than detectability in occupational safety contexts (Liu et al., 2013). Second, the multiplication of ordinal scales is mathematically questionable, since the rating scales are ordinal rather than ratio measures and their product does not satisfy the requirements of measurement theory (Bowles & Peláez, 1995). Third, very different combinations of occurrence, severity, and detectability can yield identical RPS values that nonetheless imply markedly different risk profiles, so that the same score may conceal substantively dissimilar hazards (Liu et al., 2013). Fourth, the discrete one-to-ten scales generate a sparse and unevenly distributed set of possible RPS values, and small changes in a single rating can produce disproportionate changes in the final score. A substantial body of work has therefore proposed refinements based on fuzzy logic, grey theory, and multi-criteria decision-making to address these shortcomings (Bowles & Peláez, 1995; Liu et al., 2013). The present study employs the conventional RPS approach because of its transparency, regulatory familiarity, and compatibility with the TS ISO 31000 framework; however, it seeks to mitigate the methodology's known limitations by grounding all ratings in consensus-based multidisciplinary judgment rather than individual scoring, by interpreting RPS values through banded risk classifications rather than as exact cardinal quantities, and by translating prioritized risks into a hierarchy-of-controls action plan. These design choices are intended to preserve the practical strengths of FMEA while acknowledging that the RPS should be read as an ordinal prioritization aid rather than as a precise measure of absolute risk.

Research has also identified conditions under which FMEA implementation yields limited benefits. Organizations that implement FMEA as an isolated, one-time exercise, without subsequent integration into ongoing operational management and continuous improvement processes, typically realize limited and non-sustained hazard reduction (Wetterneck et al., 2004). Conversely, organizations that institutionalize FMEA as a core component of systematic risk management and continuous improvement culture, with adequate resources and active management engagement, demonstrate sustained and measurable enhancement in safety outcomes and occupational health protection (Gremyr & Svensson, 2006).

### **2.3.2. Theoretical foundations and core principles of FMEA**

FMEA is fundamentally a systematic and proactive methodology designed to comprehensively identify potential failure modes within processes, systems, or operations, and to evaluate and quantify the consequences and probability of such failures occurring (Stamatis, 1995). The methodology operates according to foundational principles that distinguish it from alternative risk assessment methodologies.

**Comprehensiveness.** FMEA systematically examines all components, processes, and potential failure modes within a system or operational area. This approach goes beyond hazards that have previously caused incidents; instead, FMEA systematically identifies novel risks that may not be evident from historical accident data. Within the context of a logistics headquarters, comprehensive FMEA examination would identify not only hazards associated with past incidents but also hazards latently present within the facility's systems, infrastructure, and processes (Stamatis, 1995; Durhan, 2006).

**Multidisciplinary teamwork.** FMEA requires the formation and active engagement of a multidisciplinary team comprising individuals with diverse expertise and operational knowledge relevant to the system under analysis. The team-based approach ensures that hazards are identified from multiple disciplinary perspectives: occupational safety specialists bring expertise in hazard classification and control; operations managers bring understanding of workflow; facilities engineers bring technical expertise regarding building systems; maintenance technicians bring knowledge of equipment failure patterns; and frontline staff bring intimate knowledge of day-to-day work activities. This diversity ensures that insights from operational staff, engineering specialists, and safety professionals are all integrated into the risk assessment (Stamatis, 1995; Durhan, 2006).

Research examining optimal FMEA team composition indicates that effective teams typically comprise five to eight members. This range ensures adequate diversity of expertise while maintaining operational efficiency and facilitating productive group discussion and consensus-building. Larger teams may experience coordination and consensus challenges, while smaller teams may lack sufficient expertise for truly comprehensive hazard

identification (Stamatis, 1995; Durhan, 2006). The FMEA process depends critically upon effective group interaction: team members must discuss each identified hazard, evaluate occurrence, severity, and detectability scoring based on their professional judgment and experience, and ultimately reach consensus regarding the scores assigned (Baysal et al., 2002).

Systematic scoring and prioritization. FMEA employs a quantitative three-component scoring system to numerically evaluate and rank identified risks, enabling objective prioritization of hazards according to their evaluated magnitude. This facilitates consistent application of prioritization criteria across facilities and enables comparison of risk magnitudes across diverse hazard types. An electrical hazard and an ergonomic hazard can be compared directly through their Risk Priority Scores, enabling rational decisions regarding resource allocation (Khasha et al., 2013; Yurdakul et al., 2019).

Proactive rather than reactive. FMEA's strength lies in its orientation toward prevention. By identifying hazards before they cause harm, FMEA enables preventive measures and design modifications that substantially reduce risk exposure compared to reactive post-incident corrective actions. Once an incident has occurred and workers have been injured, the damage has been done; FMEA's proactive approach seeks to avoid such damage by identifying and controlling hazards before incidents occur (Liu et al., 2013; Durhan, 2006).

### 2.3.3. The FMEA scoring system: quantification of risk through RPS calculation

The FMEA methodology employs a standardized three-component quantitative scoring system to systematically evaluate and prioritize identified risks. Each component is assigned a numerical rating on a standardized scale and the three are subsequently multiplied to generate a composite Risk Priority Score (RPS), which provides a quantitative expression of overall risk magnitude (Stamatis, 1995; Durhan, 2006).

Occurrence (O). Represents the probability or likelihood that a specific hazard or failure mode will occur within the operational context under assessment. Occurrence is rated on a standardized scale ranging from 1 (extremely unlikely occurrence, with a probability of approximately 1 in 2,000,000) to 10 (almost certain occurrence, with a probability of 1 in 3 or greater). Determination of occurrence ratings typically incorporates historical incident frequencies, operational complexity, frequency of task performance, and environmental factors that influence hazard probability (Yurdakul et al., 2019; Durhan, 2006).

**TABLE 1.** Occurrence Score Scale

Score	Probability Range	Frequency	Definition
1	1 in 2,000,000	Extremely remote	Failure is almost impossible; has never occurred in similar systems
2	1 in 500,000	Remote	Failure is very unlikely; rare in similar operations
3	1 in 200,000	Very low	Failure is unlikely; occurs infrequently in similar systems
4	1 in 100,000	Low	Low probability of failure; occurs occasionally
5	1 in 20,000	Moderate	Moderate probability; has occurred in similar systems
6	1 in 10,000	Moderately high	Moderately high probability; occurs with moderate frequency
7	1 in 2,000	High	High probability; occurs regularly in similar operations
8	1 in 500	Very high	Very high probability; occurs frequently
9	1 in 100	Extremely high	Extremely high probability; occurs very frequently
10	1 in 3 or greater	Almost certain	Failure is almost certain; occurs almost every time

Source: Stamatis (1995); Durhan (2006); Yurdakul et al. (2019).

Severity (S). Represents the potential consequence or impact of the identified hazard if it were to occur. Severity is rated from 1 (minimal or no effect on operations or worker health) to 10 (critical failure with catastrophic consequences, permanent disability, or fatality). The scale explicitly recognizes that different hazards create potential for different categories of harm. An uncontrolled electrical hazard, for example, might be rated 8, 9, or 10 because electrical contact can result in cardiac arrhythmia, third-degree burns, or death, whereas an ergonomic hazard related to improper sitting posture might be rated 4, 5, or 6 because the consequence is chronic discomfort or repetitive strain rather than acute traumatic injury (Durhan, 2006; Yurdakul et al., 2019).

**TABLE 2.** Severity score scale

Score	Classification	Operational Impact	Health Consequence / Definition
1	Minimal	Negligible effect	Minor irritation; no medical treatment required
2	Very minor	Minimal disruption	Minor cuts, bruises, or temporary discomfort; first aid
3	Minor	Limited impact	Small wound or minor strain; no lost work time
4	Low	Some disruption	Minor laceration or strain; possible lost time (1-3 days)
5	Moderate	Moderate disruption	Moderate injury; lost work time (1-2 weeks)
6	Serious	Significant disruption	Hospitalization; lost time (2-4 weeks); partial disability possible
7	High	Substantial impact	Major injury; lost time (1-3 months); partial disability likely
8	Very high	Major impact	Serious injury; lost time (>3 months); permanent partial disability
9	Severe	Severe impact	Permanent disability; loss of limb or sensory function
10	Critical	Catastrophic impact	Death, permanent total disability, or multiple fatalities

Source: Durhan (2006); Yurdakul et al. (2019); Stamatis (1995).

Detectability (D). Represents the probability that existing control mechanisms, detection systems, and monitoring procedures will successfully identify the hazard before it results in injury or illness. Detectability is rated from 1 (almost certain or immediate detection) to 10 (extremely difficult or undetectable). Importantly, lower detectability scores indicate more robust existing control systems, whereas higher scores indicate inadequate detection and control capabilities. A score of 1 implies that workers and supervisors would almost certainly notice the hazard immediately (such as an obviously broken stair railing), whereas a score of 10 implies the hazard is virtually impossible to detect before failure occurs (such as microscopic structural fatigue) (Stamatis, 1995; Yurdakul et al., 2019; Durhan, 2006).

The composite Risk Priority Score is calculated using the multiplicative formula  $RPS = O \times S \times D$ . This formula reflects the combined influence of all three components and ensures that the risks prioritized for intervention are those that are simultaneously likely to occur, severe in consequence, and difficult to detect. A hazard with moderately high scores on all three components (for example,  $O = 7$ ,  $S = 8$ ,  $D = 6$ ) yields an RPS of 336, whereas a hazard with high severity but very low occurrence and excellent detection (for example,  $O = 2$ ,  $S = 10$ ,  $D = 1$ ) yields an RPS of only 20, reflecting its lower overall risk (Yurdakul et al., 2019; Durhan, 2006; Stamatis, 1995).

**TABLE 3.** Detectability score scale

Score	Detection Capability	Control Effectiveness	Definition
1	Almost certain	Excellent; hazard is obvious	Immediately apparent; virtually impossible to miss
2	Very likely	Very good; easily visible	Readily apparent through routine visual inspection

3	Likely	Good; apparent with attention	Apparent upon careful observation or routine monitoring
4	Moderately likely	Adequate; requires attention	Requires moderate attention or focused inspection
5	Moderate	Fair; requires some effort	Detectable through standard inspection with deliberate attention
6	Moderate difficulty	Below average	Difficult through routine procedures; requires specialized inspection
7	Difficult	Poor; challenging	Requires specialized equipment, expertise, or intensive monitoring
8	Very difficult	Very poor	Very difficult even with specialized procedures; advanced diagnostics
9	Extremely difficult	Almost none	Nearly impossible to detect through available methods
10	Undetectable	No effective detection	Detection only occurs after the incident

Source: Yurdakul et al. (2019); Durhan (2006); Stamatis (1995).

#### 2.3.4. Risk classification and decision criteria

Organizations implementing FMEA typically employ standardized risk classification systems to categorize identified risks and determine appropriate management responses. The TS ISO 31000 framework and standard FMEA practice divide the RPS range into classifications reflecting progressively higher levels of risk and corresponding urgency for organizational response (Stamatis, 1995; Durhan, 2006). Acceptable risks (RPS < 40) represent minimal hazards requiring no immediate intervention but warranting periodic reassessment. Medium risks (RPS 40–100) exceed acceptable levels and require targeted control measures and formal action plans implemented over weeks to months (Liu et al., 2013; Yurdakul et al., 2019). High risks (RPS 100–150) represent significant hazards requiring urgent attention, with control measures completed within days to weeks (Durhan, 2006). Very high risks (RPS 150–200) require immediate and urgent intervention, prioritized above other operational concerns, and may require suspension or modification of work activities (Yurdakul et al., 2019). Critical risks (RPS > 200) represent unacceptable hazard levels demanding emergency-level response, including possible immediate suspension or redesign of work activities (Stamatis, 1995; Durhan, 2006).

**TABLE 4.** Risk classification scale

RPS Range	Classification	Urgency	Management Action Required	Timeline
< 40	Acceptable	Low	Continued monitoring; no formal intervention	Ongoing monitoring
40–100	Medium	Moderate	Targeted control measures; formal action plan	Weeks to months
100–150	High	High	Urgent intervention; prioritized resources	Days to weeks
150–200	Very high	Very high	Immediate intervention; emergency resources	Immediate (days)
> 200	Critical	Critical	Emergency intervention; possible work suspension	Hours to days

Source: Yurdakul et al. (2019); Durhan (2006); Stamatis (1995); Turkish Standards Institution (2010).

#### 2.3.5. Research objectives and significance

The primary objective of this investigation is to systematically apply the FMEA methodology to identify, quantify, and prioritize occupational hazards within the general headquarters of a sustainable logistics company. Secondary objectives include: (1) characterizing the nature and severity of identified risks across operational zones; (2) evaluating the adequacy of current risk detection and control mechanisms; (3) developing prioritized

recommendations for preventive and corrective measures; and (4) demonstrating the efficacy of interdisciplinary teamwork in implementing comprehensive risk management protocols.

The study is significant because it addresses a documented gap in the literature regarding occupational risk assessment in the logistics sector, specifically within sustainable logistics operations. Whereas previous FMEA applications have typically examined a single process or equipment item in manufacturing or healthcare settings, the present study characterizes the full, interacting hazard profile of a multifunctional logistics headquarters and links the resulting risk prioritization to explicit cost estimates for control measures. The findings provide empirical evidence on the types, severity, and spatial distribution of hazards in logistics headquarters, thereby informing policy development, operational modifications, and resource allocation, and contribute to the advancement of FMEA application within the logistics and supply chain management domain.

### 3. Materials and methods

#### 3.1. Research design and study context

This study employed a descriptive, cross-sectional research design utilizing the FMEA methodology to systematically identify and assess occupational hazards within the general headquarters facility of a sustainable logistics company operating in Türkiye. The research was conducted during a four-week intensive study period in 2024. The facility serves as the operational headquarters for the logistics company, encompassing administrative offices, cargo handling and receiving areas, inventory storage zones, distribution coordination centers, and maintenance and operations facilities. The facility operates continuously throughout the year, with daytime administrative operations and ongoing cargo handling and distribution activities occurring throughout a 24-hour operational cycle.

The facility comprises approximately 8,500 square meters of operational space distributed across five distinct operational zones, summarized in Table 5. It employs approximately 85 permanent staff members and accommodates variable numbers of temporary workers depending on operational demand. The facility operates under Turkish occupational health and safety regulations, including the Occupational Health and Safety Law (Act No. 6331), and relevant industry-specific safety standards.

**TABLE 5.** Operational zones of the facility under investigation

Operational Zone	Approx. Area (m <sup>2</sup> )	Principal Functions
<b>Administrative Zone</b>	1,200	Office work; administrative coordination; document management
<b>Cargo Handling and Receiving Zone</b>	2,100	Receipt, sorting, and handling of incoming and outgoing cargo
<b>Inventory Storage Zone</b>	3,500	Material storage; shelving systems; inventory management
<b>Distribution Coordination Center</b>	800	Routing, scheduling, and distribution coordination
<b>Maintenance and Operations Facility</b>	900	Equipment maintenance; technical and specialized operations

*Source:* Compiled by the authors from facility documentation.

The facility's operational environment is characterized by continuous 24-hour operations with variable staffing based on daily demand. During peak periods, the facility may accommodate temporary workers or contractors who may lack familiarity with facility-specific hazards and control procedures. Seasonal and periodic fluctuations in operational volume create variations in hazard exposure patterns and control implementation challenges. The facility's equipment inventory includes mechanical handling systems, electrical distribution systems, and material storage infrastructure ranging from modern equipment to older systems requiring ongoing maintenance.

The research was approved by the organization's executive management and occupational health and safety committee. Participation of facility personnel in interviews and focus groups was voluntary, with informed consent obtained from all participants. The research was conducted in compliance with ethical standards for occupational research and professional codes of conduct for occupational health and safety professionals (Durhan, 2006; Yurdakul et al., 2019).

### 3.2. FMEA team composition and selection

The investigation was conducted by a multidisciplinary FMEA team comprising seven professionals selected based on their relevant expertise, professional credentials, and operational knowledge. The team included an occupational health and safety specialist serving as team leader, with formal credentials and comprehensive knowledge of Turkish occupational safety legislation and international standards; a facilities operations manager responsible for daily operations and coordination of functional areas; a facilities and infrastructure engineer contributing technical expertise regarding building systems, electrical infrastructure, and HVAC systems; an equipment maintenance technician with practical experience in equipment operation, maintenance protocols, and documented failure patterns; an administrative office coordinator with knowledge of office operations and area-specific hazards; a warehouse operations lead with direct experience in cargo and material handling; and an occupational health consultant providing specialized expertise in occupational disease assessment and ergonomic hazard evaluation. This composition ensured that identified hazards reflected diverse operational perspectives and that scoring incorporated knowledge from management, operational, technical, and occupational health levels, consistent with recommendations that optimal FMEA teams comprise five to eight members with diverse backgrounds (Stamatis, 1995; Durhan, 2006).

### 3.3. Data collection methodology

The FMEA data collection process employed multiple integrated methodologies to ensure comprehensive hazard identification. Systematic inspections of all five operational zones were conducted over a three-week period, during which the team documented physical facility conditions (cleanliness, infrastructure condition, equipment arrangement); active operational procedures and work practices; environmental conditions (lighting, temperature, ventilation, noise); emergency procedures, signage, and evacuation route accessibility; material storage methods and equipment status; and personal protective equipment usage and compliance. Inspections were conducted during regular operational hours and across different shift periods to capture variations in working conditions, recognizing that hazard conditions may vary substantially across operational periods.

The team reviewed organizational documentation, including historical incident and accident reports covering the previous three years, equipment maintenance records, standard operating procedures and safety protocols, facility condition assessments and maintenance schedules, and training records and occupational health monitoring data. This review provided contextual background regarding previously documented hazards and incident patterns and informed the team's understanding of recurring problems.

Semi-structured interviews were conducted with 28 purposefully selected personnel representing various operational areas and experience levels, including administrative personnel, warehouse and cargo handling workers, maintenance personnel, safety representatives, supervisory and management personnel, and distribution coordination personnel. The interviews elicited information regarding perceived workplace hazards and occupational risks, documented incidents or near-miss events, workplace safety concerns and suggestions for improvement, and operational challenges and stress factors. Personnel interviews provided insights into hazards that might not be immediately apparent during inspections and contributed to the team's understanding of worker perspectives on workplace safety.

### 3.4. FMEA scoring and risk priority score calculation in this study

The definitions and rating anchors for the three FMEA components (occurrence, severity, and detectability) and for the resulting risk classification have been presented in Section 2.3.3 and Tables 1 to 4 and are not repeated here. In the present study, the rating scales were applied as follows. For each identified hazard, the team assigned occurrence, severity, and detectability scores through structured consensus rather than individual scoring. Occurrence scores were determined on the basis of historical incident frequencies within the facility, industry benchmarking data, operational complexity, and observed work practices. Severity scores incorporated potential injury classifications and occupational disease risks, the potential for permanent disability, the possibility of simultaneously affecting multiple personnel, and potential long-term health consequences. Detectability scores reflected the adequacy of existing control mechanisms, detection systems, and monitoring procedures, with lower scores indicating more effective controls.

The composite Risk Priority Score was calculated for each hazard using the formula  $RPS = O \times S \times D$ , producing values ranging from 1 to 1,000. Following calculation, hazards were classified according to the criteria summarized in Table 4: RPS values below 40 were treated as acceptable risk warranting periodic monitoring;

values from 40 to 100 as medium risk requiring targeted control measures and action plans; and values exceeding 100 as high risk requiring urgent corrective intervention and substantial resource allocation. Hazard identification was further informed by examination of regulatory compliance requirements, review of logistics-specific industry standards, and consultation with facility personnel regarding emerging hazards. The comprehensive identification process yielded hazards spanning six major categories: electrical, ergonomic, environmental, mechanical and equipment-related, structural, and organizational hazards.

### **3.5. FMEA workshop process**

The FMEA team conducted four intensive workshop sessions, each lasting four to six hours, during which the team systematically reviewed findings from facility inspections, documentation analysis, and personnel interviews; engaged in structured brainstorming to identify all potential hazards within each operational area; characterized each hazard regarding failure mode, consequences, and contributing factors; developed consensus-based occurrence, severity, and detectability scores; calculated RPS values; ranked and prioritized hazards; and discussed preliminary control measure recommendations for high-priority hazards. The consensus-based approach ensured that diverse perspectives were considered and that scoring reflected collective professional judgment rather than individual bias, consistent with research demonstrating that consensus-based discussion produces more accurate and comprehensive hazard identification than individual assessments (Stamatis, 1995).

### **3.6. Control measure development and hierarchy framework**

For all identified hazards classified as medium risk or above, the FMEA team developed specific recommendations for preventive and corrective control measures using the established hierarchy of controls. This framework prioritizes strategies in order of effectiveness: elimination, the most effective approach, removes the hazard entirely; substitution replaces the hazardous process, material, or equipment with a less hazardous alternative; engineering controls modify the facility, equipment, or processes to eliminate or reduce hazards at the source; administrative controls modify work procedures, training, supervision, and organizational policies; and personal protective equipment represents the final line of defense when other measures are not feasible or as supplementary protection.

### **3.7. Data analysis and risk prioritization**

Data collected through facility inspections, document review, and personnel interviews were analyzed and synthesized to inform hazard identification and FMEA scoring. Interview data were analyzed thematically to identify patterns related to worker perspectives on hazards. Facility inspection findings and photographic documentation were reviewed systematically to identify specific conditions requiring corrective action. All identified hazards and associated RPS scores were tabulated and organized by operational zone and hazard category. Summary statistics, including frequency distributions of hazard classifications, comparison of RPS scores across categories, and spatial distribution across zones, were calculated, and risk profiles were developed for each operational zone.

Following completion of scoring and RPS calculation, systematic analysis was conducted to verify all RPS calculations for mathematical accuracy, classify hazards according to the classification system, rank hazards in descending order by RPS, analyze hazards by operational area and by category, and examine relationships and interactions between hazards to identify potential cascading or compounding risks. This analysis examined whether control measures implemented for one hazard might positively or negatively affect others and whether identified hazards might compound under certain operational scenarios. This enabled identification of priority areas and hazard types requiring focused attention and resource allocation.

### **3.8. Research ethics, validation, and quality assurance**

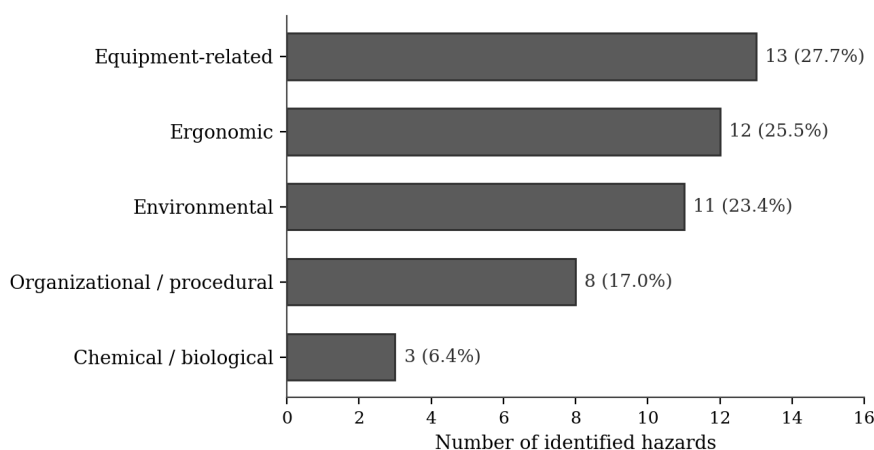
This investigation was conducted in accordance with applicable ethical standards governing research involving occupational environments and human participants. All team members completed occupational health and safety training prior to facility inspections. All interviewed personnel provided informed consent and were assured of confidentiality. Facility management provided organizational authorization and access to documentation and operational areas.

Several validation procedures were implemented to ensure the validity and quality of the FMEA process. All identified hazards and RPS scores were reviewed and confirmed by the full multidisciplinary team, ensuring that hazards had not been overlooked and that scoring reflected collective professional judgment. The external occupational health and safety consultant independently reviewed all identified hazards and scores to validate their appropriateness and accuracy. Identified hazards and RPS scores were compared with historical incident data to verify that high-RPS hazards were consistent with observed incident patterns. Identified hazards within each zone were presented to personnel working in those zones for cross-functional verification. In addition, team members conducted independent verification of all RPS calculations to ensure mathematical accuracy, and all scoring decisions and discussions were documented in detail using standardized forms to provide a complete audit trail.

## 4. Results

### 4.1. Hazard identification and categorization

The FMEA team identified a total of 47 distinct hazards distributed across the five operational zones of the logistics facility. These hazards were categorized into five primary categories based on their nature and origin. The equipment-related category encompassed 13 hazards, including electrical hazards, mechanical equipment failures, and conveyor system malfunctions. The ergonomic category comprised 12 hazards related to improper material handling, lifting techniques, and workplace posture. The environmental category included 11 hazards associated with inadequate facility conditions such as temperature extremes, poor ventilation, inadequate illumination, and noise exposure. The organizational and procedural category included 8 hazards stemming from inadequate safety protocols, insufficient employee training, and lack of hazard communication systems. The chemical and biological category comprised 3 hazards related to exposure to cleaning chemicals and potential biological contaminants. The distribution of identified hazards by category is presented in Figure 1.



**FIGURE 1.** Distribution of identified hazards by category (n = 47)

The spatial distribution of hazards across operational areas revealed that the warehouse and cargo handling zones accounted for 18 identified hazards (38.3%), reflecting the physically demanding and equipment-intensive nature of these operations. The administrative and office areas contained 9 hazards (19.1%), primarily ergonomic and environmental in nature. The distribution coordination centers contained 8 hazards (17.0%), including ergonomic hazards related to prolonged computer use and organizational hazards related to coordination and scheduling demands. The storage and inventory facilities contained 7 hazards (14.9%), primarily related to storage system stability and material handling, and the maintenance and specialized facilities contained 5 hazards (10.6%), primarily equipment-related and organizational.

### 4.2. Risk priority score distribution and risk classification

Following RPS calculation for all 47 identified hazards, the team classified hazards according to the established criteria. Seven hazards (14.9%) were classified as high risk (RPS > 100), sixteen hazards (34.0%) as medium risk (RPS 40-100), and twenty-four hazards (51.1%) as acceptable risk (RPS < 40). The distribution across classifications is summarized in Table 6.

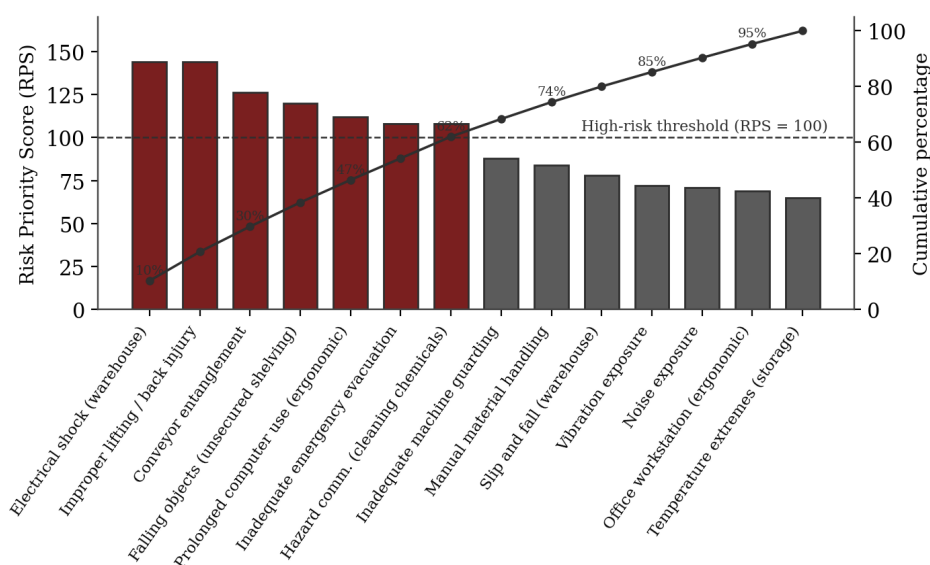
**TABLE 6.** Distribution of Identified Hazards by Risk Classification

Classification	Count	Percentage	Management Response
High risk (RPS > 100)	7	14.9%	Urgent intervention; prioritized resources
Medium risk (RPS 40-100)	16	34.0%	Targeted control measures; action plans
Acceptable risk (RPS < 40)	24	51.1%	Continued monitoring and periodic reassessment
<b>Total</b>	<b>47</b>	<b>100%</b>	-

Source: Compiled by the authors from FMEA workshop results.

The seven high-risk hazards comprised electrical shock hazards in warehouse areas (RPS = 144), improper lifting and back injury hazards in cargo handling operations (RPS = 144), conveyor system entanglement hazards (RPS = 126), falling object hazards from unsecured shelving (RPS = 120), ergonomic hazards related to prolonged computer use in office areas (RPS = 112), inadequate emergency evacuation procedures (RPS = 108), and inadequate hazard communication and labeling for cleaning chemicals (RPS = 108). The sixteen medium-risk hazards included slip and fall hazards, manual material handling hazards during cargo receipt, vibration exposure, inadequate machine guarding, temperature extremes in storage areas, noise exposure, inadequate lighting in certain areas, and ergonomic hazards related to office workstation design. The twenty-four acceptable-risk hazards included minor ergonomic issues, occasional minor temperature variations, minor noise issues, and isolated instances of inadequate cleaning practices; although acceptable, these hazards were recommended for continued monitoring.

To support prioritization and improve readability, the principal individually scored hazards are ranked by RPS in Figure 2 and detailed in Table 7. As the Pareto distribution in Figure 2 indicates, the seven high-risk hazards, although representing only 14.9% of all identified hazards, account for a disproportionate share of the cumulative risk among the principal scored hazards, supporting a focused, priority-driven allocation of control resources.

**FIGURE 2.** Pareto chart of the principal individually scored hazards ranked by Risk Priority Score

Note: Bars above the dashed line denote high-risk hazards (RPS > 100).

**TABLE 7.** Summary of principal identified hazards, RPS values, and risk classifications

No.	Hazard	Zone	O	S	D	RPS	Classification
H1	Electrical shock	Warehouse	8	9	2	144	High
H2	Improper lifting / back injury	Cargo handling	9	8	2	144	High
H3	Conveyor system entanglement	Warehouse	7	9	2	126	High
H4	Falling objects (unsecured shelving)	Storage	6	10	2	120	High
H5	Prolonged computer use (ergonomic)	Office	8	7	2	112	High
H6	Inadequate emergency evacuation	Facility-wide	2	9	6	108	High
H7	Hazard communication (chemicals)	Facility-wide	6	9	2	108	High
M1	Inadequate machine guarding	Warehouse	-	-	-	88	Medium
M2	Manual material handling	Cargo handling	-	-	-	84	Medium
M3	Slip and fall	Warehouse	-	-	-	78	Medium
M4	Vibration exposure	Warehouse	-	-	-	72	Medium
M5	Noise exposure	Warehouse	-	-	-	71	Medium
M6	Office workstation ergonomics	Office	-	-	-	69	Medium
M7	Temperature extremes	Storage	-	-	-	65	Medium

Source: O = Occurrence; S = Severity; D = Detectability; RPS = Risk Priority Score. Occurrence, severity, and detectability ratings are reported for the seven high-risk hazards as recorded in the workshop documentation; for the representative medium-risk hazards, only the composite RPS values are reported.

#### 4.3. High-risk hazards: Detailed analysis

The electrical shock hazard in warehouse areas received an RPS of 144, sharing the highest value among all identified hazards with the improper lifting hazard, and reflecting a high occurrence, a critical severity, and ready detectability through visual inspection and electrical safety systems. Analysis revealed that several electrical outlets in warehouse areas were located near moisture sources, that electrical equipment cords showed evidence of deterioration, and that personnel received inadequate electrical safety training. The team determined that this hazard required immediate intervention, including repair or relocation of electrical outlets, replacement of deteriorated cords, installation of ground fault circuit interrupter (GFCI) devices, and comprehensive electrical safety training.

The improper lifting and back injury hazard in cargo handling operations also received an RPS of 144, equal to that of the electrical shock hazard. Field observations documented that personnel frequently lifted boxes weighing 20-30 kilograms from floor level to shoulder height without mechanical assistance, that no systematic training in proper lifting techniques had been provided, and that mechanical lifting devices were unavailable in certain areas. The team recommended implementation of mechanical lifting assistance devices, comprehensive ergonomic training, and establishment of weight limits requiring mechanical assistance above specified thresholds.

The conveyor system entanglement hazard received an RPS of 126. Observation revealed that certain areas of the conveyor system lacked appropriate machine guarding, that personnel had not received training regarding entanglement hazards, and that emergency stop mechanisms were not readily accessible. The team recommended comprehensive machine guarding on all moving parts, training regarding conveyor hazards and safe work practices, clearly marked emergency stop buttons at multiple locations, and routine guarding inspections.

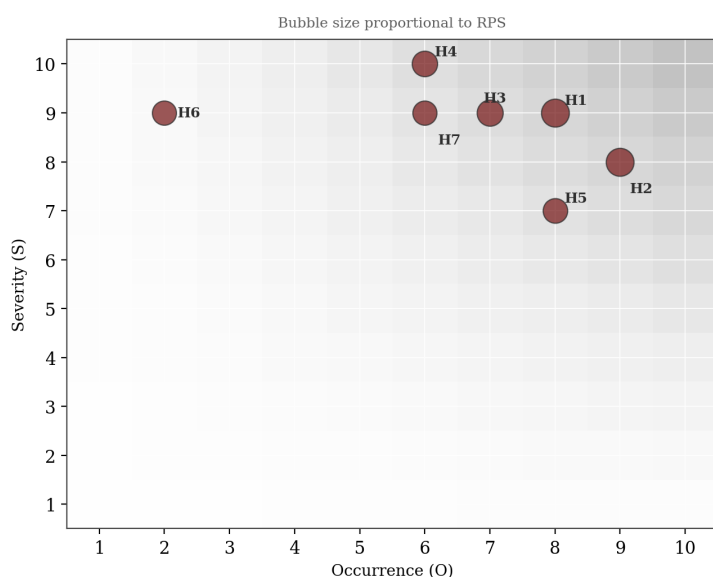
The falling object hazard from unsecured shelving received an RPS of 120. Inspection revealed that several shelving units were inadequately secured to walls, that heavy items were stored on upper shelves without restraint systems, and that no systematic shelving stability assessment had been conducted. The team recommended structural assessment of all shelving units, installation of anchoring systems, weight distribution guidelines specifying maximum loads per shelf level, and restraint systems for heavy items on elevated shelves.

The ergonomic hazard related to prolonged computer use in office areas received an RPS of 112. Assessment revealed that many workstations lacked ergonomic seating, that monitor placement frequently required neck flexion or extension, and that no ergonomic assessment or training had been conducted. The team recommended ergonomic assessment of all workstations, provision of ergonomic seating and adjustable monitor stands, provision of ergonomic input devices, and ergonomic training and workstation setup guidance.

The inadequate emergency evacuation procedures hazard received an RPS of 108. Although emergency events are extremely unlikely, their consequences would be catastrophic. Assessment revealed that evacuation routes were not clearly marked, that personnel had not participated in evacuation drills, that assembly points were not established, and that emergency procedures were not documented. The team recommended clear marking of all evacuation routes, designated assembly points, periodic evacuation drills, and documentation and communication of emergency procedures.

The inadequate hazard communication and labeling for cleaning chemicals received an RPS of 108. Inspection revealed that cleaning chemicals were not properly labeled, that material safety data sheets were not readily accessible, and that no chemical hazard training had been provided. The team recommended comprehensive hazard labeling on all chemical containers, placement of safety data sheets in accessible locations, and training on chemical hazards and safe handling.

The combined occurrence and severity profile of these seven high-risk hazards is presented in the risk matrix in Figure 3. The matrix shows that the high-risk hazards cluster in the upper-right region of high occurrence and high severity, with the notable exception of the emergency evacuation hazard (H6), whose elevated RPS derives from severe consequences and limited detectability rather than from frequent occurrences.



**FIGURE 3.** Risk matrix (Occurrence x Severity) for the seven high-risk hazards

*Note:* Bubble size is proportional to the Risk Priority Score.

#### 4.4. Medium-risk hazards and recommended control measures

The 16 medium-risk hazards typically reflected either moderate occurrence with significant severity, higher occurrence with moderate severity, or low detectability despite lower occurrence and severity. Representative examples include slip and fall hazards due to inadequate floor maintenance (RPS = 78), manual material handling hazards during cargo receipt (RPS = 84), vibration exposure from equipment operation (RPS = 72), inadequate machine guarding on material handling equipment (RPS = 88), temperature extremes in storage areas (RPS = 65), noise exposure in warehouse operations (RPS = 71), and ergonomic hazards related to office workstation design (RPS = 69).

For the slip and fall hazards, the team recommended a systematic floor maintenance and cleaning schedule, appropriate cleaning materials that do not create slippery surfaces, non-slip flooring in high-traffic areas, and spill containment and rapid cleanup protocols. For manual material handling hazards, the team recommended mechanical assistance devices, weight limits, and ergonomic training. For vibration exposure, the team recommended equipment maintenance to reduce vibration, anti-vibration equipment, and personnel rotation to limit individual exposure. For inadequate machine guarding, the team recommended appropriate guards on all equipment, lockout/tagout procedures during maintenance, and regular guard inspections. For temperature extremes, the team recommended temperature monitoring, appropriate clothing, scheduled breaks in controlled areas, and climate control improvements. For noise exposure, the team recommended hearing protection, quiet break areas, noise monitoring, and equipment modifications. For office workstation ergonomic hazards, the team recommended ergonomic assessments, adjustable seating and monitor stands, and ergonomic training.

#### **4.5. Implementation priority and timeline recommendations**

The FMEA team developed a prioritized implementation timeline for control measures. High-risk hazards (RPS > 100) were designated for immediate implementation within 30 days, with particular emphasis on electrical hazard corrections, conveyor system guarding, and shelving stabilization, which could be completed within this timeframe with available resources. Medium-risk hazards (RPS 40-100) were designated for implementation within 60-90 days, allowing time for procurement, staff training, and procedural modifications. Acceptable-risk hazards were designated for ongoing monitoring with periodic reassessment, with some minor improvements recommended within 90-180 days.

The team identified comprehensive resource requirements for implementation. Capital expenditures for equipment and facilities modifications, including emergency lighting upgrades, ergonomic workstation improvements, electrical system enhancements, and fire safety equipment installation, were estimated at approximately 285,000-325,000 Turkish Lira. Personnel training and development costs, encompassing initial occupational safety training, hazard recognition workshops, and ongoing competency development, were estimated at approximately 28,000-38,000 Turkish Lira. Ongoing monitoring and maintenance costs were estimated at approximately 23,000-26,000 Turkish Lira annually. Additional contingency resources representing approximately 15% of capital expenditure estimates were recommended to address unforeseen implementation challenges.

### **5. Discussion**

#### **5.1. Interpretation of findings considering previous research**

The comprehensive FMEA analysis identified 47 distinct occupational hazards across five operational zones, with significant variation in risk classification. The finding that 14.9% of identified hazards were classified as high risk represents a substantial occupational health and safety concern. This proportion is broadly consistent with the range reported in studies of logistics and warehouse facilities, in which a minority of identified hazards typically account for the bulk of prioritized risk (Thun & Hoenig, 2011; Chiozza & Ponzetti, 2009). The Pareto distribution observed here (Figure 2) reproduces a pattern repeatedly documented in FMEA applications across manufacturing and healthcare settings, in which a small subset of failure modes dominates the aggregate risk profile and therefore warrants concentrated control resources (Liu et al., 2013).

At the same time, the categorical profile of hazards in this study differs in instructive ways from that reported in the dominant FMEA application domains. In healthcare FMEA studies, the highest-priority failure modes are typically process- and communication-related, such as medication administration or handover errors (Chiozza & Ponzetti, 2009), whereas in the present logistics headquarters the highest-priority hazards were predominantly physical and infrastructural, namely electrical, ergonomic-manual-handling, and machinery hazards. This divergence is consistent with the supply-chain risk literature, which emphasizes operational and equipment-related vulnerabilities as central to logistics environments (Thun & Hoenig, 2011), and it underscores why FMEA frameworks validated in clinical or assembly-line contexts cannot be transferred to logistics facilities without attention to their distinctive hazard composition. The concentration of 38.3% of hazards in the warehouse and cargo handling zones similarly mirrors warehouse injury research, which consistently identifies material handling and equipment operation as the principal sources of occupational injury in distribution settings (Durhan, 2006; Thun & Hoenig, 2011).

The identification of electrical hazards as one of the two highest-priority risks, tied with manual material handling at an RPS of 144, reflects a critical gap in facility infrastructure and safety management. The combination of electrical outlets in moisture-prone areas, deteriorated cords, and inadequate training creates a constellation of contributing factors with potentially catastrophic consequences. This finding is consistent with occupational injury research indicating that electrical injuries frequently result in permanent disability or death (Murphy et al., 2004). Importantly, the hazard was scored as readily detectable, which, in FMEA terms, signals that relatively straightforward corrective measures could substantially reduce the risk, a pattern also observed in industrial FMEA studies where high-severity, but high-detectability hazards offer favorable returns on preventive investment (Liu et al., 2013).

The ergonomic hazard associated with manual material handling, which shared the highest RPS value (144) with the electrical shock hazard, reflects occupational patterns well documented in the logistics and warehouse literature, in which manual handling is among the most frequent causes of occupational injury and back, shoulder, and upper-extremity cumulative trauma disorders are particularly prevalent (Waters et al., 2011). The finding that personnel routinely lifted 20–30-kilogram loads without mechanical assistance represents a preventable hazard amenable to mechanical lifting devices and ergonomic training. The conveyor entanglement and falling-object hazards, by contrast, are characterized by lower occurrence but catastrophic severity, producing high RPS values despite moderate occurrence scores; this severity-driven profile is characteristic of machinery hazards and is precisely the configuration that the RPS multiplication is designed to surface.

## **5.2. Organizational and systemic risk factors**

Beyond specific technical hazards, the analysis revealed broader organizational and systemic factors contributing to elevated occupational risk. Inadequate personnel training emerged as a contributing factor to multiple hazards, including electrical, conveyor, chemical, and ergonomic hazards. This training deficiency reflects incomplete implementation of foundational occupational safety management principles established in Turkish occupational safety legislation (Occupational Health and Safety Law No. 6331). The inadequacy of emergency preparedness and evacuation procedures, reflected in a high RPS despite very low occurrence probability, indicates that the facility lacks comprehensive emergency response planning; the absence of marked evacuation routes, designated assembly points, and documented procedures could render a rare emergency catastrophic. The systemic lack of hazard communication, evident in inadequate chemical labeling and the absence of accessible safety data sheets, reflects insufficient implementation of hazard communication systems that are foundational to occupational safety management (Occupational Safety and Health Administration, 2012).

## **5.3. Facility infrastructure and maintenance deficiencies**

The identification of multiple infrastructure deficiencies, including electrical hazards in moisture-prone areas, unstable shelving, inadequate machine guarding, and poor environmental conditions, suggests that systematic facility maintenance and infrastructure assessment has not been prioritized. The presence of deteriorated cords and moisture exposure to outlets indicates that basic preventive maintenance has not been consistently implemented, while inadequately secured shelving and unrestrained heavy items on elevated shelves suggest that facility safety assessments have not been conducted or that identified deficiencies have not been corrected. These deficiencies are particularly notable because they represent relatively easily corrected problems requiring modest financial investment relative to the potential consequences of injury. Appropriate outlet placement and GFCI devices, anchoring of shelving units, and machine guarding represent straightforward corrective measures likely to substantially reduce occupational risk.

## **5.4. Comparison with international standards and best practices**

When compared with international occupational health and safety standards, the identified hazards reveal significant gaps in the facility's safety management system. ISO 45001:2018 requires organizations to systematically identify hazards, evaluate risks, implement controls, and monitor control effectiveness (International Organization for Standardization, 2018); the FMEA findings suggest that this systematic approach has not been fully implemented. The specific deficiencies identified, including inadequate electrical safety, machinery guarding, ergonomic controls, training, and emergency preparedness, are all addressed in well-established international guidelines, and their absence suggests either insufficient resource allocation or inadequate management understanding of their importance. Comparison with the ISO 45001:2018 framework further reveals that the facility lacks systematic integration of occupational health and safety into organizational

planning, including context-specific policies, measurable objectives with implementation plans, and management commitment demonstrated through resource allocation and accountability structures.

### 5.5. Resource requirements and cost-benefit considerations

The team estimated that implementation of control measures addressing high- and medium-risk hazards would require approximately 285,000-325,000 Turkish Lira in capital expenditures, 28,000-38,000 Turkish Lira for personnel training and development, and 23,000-26,000 Turkish Lira in ongoing annual monitoring and maintenance costs. These estimates represent a relatively modest proportion of organizational resources. While substantial, the requirements must be evaluated against the potential costs of occupational injuries: research indicates that direct medical costs represent only a fraction of total injury costs, with indirect costs frequently exceeding direct costs by a factor of four to ten (Biddle & Roberts, 2003). A single serious injury resulting in permanent disability can generate costs substantially exceeding the estimated implementation costs, so that from a purely economic perspective, investment in hazard controls represents highly cost-effective injury prevention. Beyond economics, facility management has ethical and legal obligations to provide safe working conditions; Turkish occupational safety legislation explicitly requires employers to take necessary protective measures, and the identified high-risk electrical and machinery hazards represent conditions that clearly contravene these requirements.

### 6. Conclusion

The comprehensive FMEA analysis conducted at the sustainable logistics company's general headquarters identified 47 occupational hazards across five operational zones, with 7 hazards (14.9%) classified as high risk, 16 (34.0%) as medium risk, and 24 (51.1%) as acceptable risk. The analysis revealed that electrical hazards, improper material handling and lifting, conveyor entanglement, unstable shelving, inadequate emergency evacuation, and inadequate hazard communication represent the most significant concerns requiring immediate corrective action. Beyond these technical hazards, the analysis identified broader organizational and systemic deficiencies, including inadequate training, insufficient emergency preparedness, deficient hazard communication, and deferred maintenance, suggesting that the facility's occupational health and safety management has been reactive rather than proactive. The FMEA methodology proved a valuable tool for systematic identification and prioritization; the multidisciplinary team approach incorporated diverse perspectives, and the RPS scoring provided an objective basis for prioritizing resources. The study demonstrates that even in facilities without obvious major incidents, systematic hazard analysis can reveal substantial occupational risks, and that comparison with prior FMEA applications in manufacturing and healthcare both situates these findings within the broader literature and highlights the distinctive, infrastructure-driven hazard profile of logistics headquarters. Several limitations should be considered when interpreting these findings. The analysis was conducted at a single facility of one logistics company, and the specific hazard frequencies, severity assessments, and recommended controls may not be generalizable to facilities with different configurations, ages, management philosophies, or personnel characteristics. The analysis relied on consensus-based team scoring, which, although appropriate according to FMEA best practice, reflects the knowledge and perspective of the specific team and may be subject to individual or group bias; occurrence and severity scores rely on professional judgment and might differ with alternative assessors. The assessment was conducted at a single point in time and may not capture temporal variation in hazard conditions arising as equipment ages, personnel change, or operational and seasonal demands fluctuate. As discussed in Section 2.3.1, the conventional Risk Priority Score also carries well-documented methodological limitations, including the equal weighting and ordinal multiplication of the three rating components and the non-uniqueness of RPS values; the present study mitigated these through consensus scoring and banded classification, but the RPS should nonetheless be interpreted as an ordinal prioritization aid rather than a precise measure of absolute risk. Finally, the study did not quantitatively assess the probability that implemented control measures would achieve the projected reduction in RPS values, since realized risk reduction depends on the quality of implementation, sustained compliance, and ongoing maintenance of controls.

On the basis of these findings, facility management should prioritize implementation of control measures addressing high-risk hazards within 30 days, particularly electrical hazard corrections, conveyor system guarding, and shelving stabilization, given the potentially catastrophic consequences of these hazards, and should implement controls for medium-risk hazards within 60-90 days. Management should establish clear accountability for completion of high-priority corrective measures and allocate the financial and personnel resources necessary for these interventions. More broadly, the organization should develop a comprehensive occupational health and safety management system incorporating systematic hazard identification and risk evaluation, risk-based

implementation of controls, personnel training and competence development, emergency preparedness and response planning, hazard communication systems, and periodic monitoring and reassessment, thereby aligning facility practice with international standards including ISO 45001:2018. Establishing a dedicated occupational health and safety function with clear authority and resources would facilitate systematic implementation and ongoing monitoring, replacing the current distributed and ad hoc arrangement. Finally, follow-up FMEA analyses should be conducted at six- and twelve-month intervals following implementation to verify that controls have been effectively applied, to assess their effectiveness in reducing RPS values, and to identify any newly emerging hazards. Implementation of the recommended measures would substantially improve occupational health and safety conditions, reduce the probability and severity of occupational injuries, and represent a cost-effective investment in employee health and safety.

## **Declarations / Yazar beyanları**

### **Ethics declaration / Etik beyan**

*The author declares that scientific and ethical principles were adhered to during the conduct and writing of this study, and that all sources have been appropriately cited. / Yazar, bu çalışmanın yürütülmesi ve yazımı sırasında bilimsel ve etik ilkelere bağlı kalındığını ve kullanılan tüm kaynakların uygun şekilde atıf yapılarak kullanıldığını beyan eder.*

*This study was conducted as an institutional occupational risk assessment in accordance with the Turkish Occupational Health and Safety Law (Law No. 6331) and the Regulation on Occupational Health and Safety Risk Assessment. The study did not involve research on human participants, and no personal or sensitive personal data were collected or analyzed. Interviews were conducted solely to identify workplace hazards as part of the risk assessment process rather than to collect research data from participants. Therefore, ethics committee approval was not required. The study was conducted with institutional permission, and informed consent was obtained from all individuals who participated in the interviews. / Bu çalışma, 6331 sayılı İş Sağlığı ve Güvenliği Kanunu ile İş Sağlığı ve Güvenliği Risk Değerlendirmesi Yönetmeliği kapsamında yürütülen kurumsal bir mesleki risk değerlendirmesidir. Çalışmada insan katılımcılar üzerinde araştırma yapılmamış, kişisel veya özel nitelikli kişisel veri toplanmamış ya da analiz edilmemiştir. Görüşmeler, katılımcılardan araştırma verisi toplamak amacıyla değil, risk değerlendirme süreci kapsamında işyeri tehlikelerinin belirlenmesi amacıyla gerçekleştirilmiştir. Bu nedenle çalışma etik kurul onayı gerektirmemektedir. Çalışma, tesis yönetiminin kurumsal izniyle yürütülmüş ve görüşmelere katılan tüm kişilerden bilgilendirilmiş onam alınmıştır.*

### **Funding / Finansman**

*The author declares that no financial support was received for the research, authorship, and publication of this article. / Yazar, bu makalenin araştırılması, yazımı veya yayımlanması için herhangi bir finansal destek alınmadığını beyan eder.*

### **AI disclosure / Yapay zeka kullanımı**

*The author declares that artificial intelligence tools were used solely for language editing and proofreading [specify the AI tool used], that all outputs were reviewed by the author, who takes full responsibility for the content, and that the use of these tools complied with ethical principles and the journal's editorial policies. / Yazar, yapay zeka araçlarının yalnızca dil düzenleme ve düzeltme amacıyla kullanıldığını [kullanılan yapay zeka aracını belirtiniz], tüm çıktıların yazar tarafından gözden geçirildiğini ve içeriğin tüm sorumluluğunun yazara ait olduğunu, ayrıca yapay zeka araçlarının kullanımının etik ilkelere ve derginin editoryal politikalarına uygun şekilde gerçekleştirildiğini beyan eder.*

### **Data availability / Veri kullanılabilirliği**

*The data supporting the findings of this study are available from the corresponding author upon reasonable request. / Bu çalışmanın bulgularını destekleyen veriler, makul bir talep üzerine sorumlu yazardan temin edilebilir.*

**Conflict of interest / Çıkar çatışması**

The author declares no potential conflicts of interest with respect to the research, authorship, and publication of this article. / Yazar, bu makalenin araştırması, yazarlığı ve yayınlanması ile ilgili herhangi bir çıkar çatışması olmadığını beyan eder.

**Note:** This information has been provided by the authors. / Bu bilgiler yazarlar tarafından sağlanmıştır.

**References**

- Aydan, M., & Kaya, M. (2017). Risk management implementation in educational institutions using TS ISO 31000 framework. *Journal of Educational Administration*, 45(3), 234–251.
- Baig, M. H., & Prasanthi, G. (2013). Failure modes and effect analysis of a mechanical assembly by using MIL-STD-1629A method. *International Journal of Advanced Information Science and Technology*, 13(13), 17–20.
- Baysal, M. E., Çalikuşu, F., & Durhan, Y. (2002). Multidisciplinary team approach to FMEA implementation. *Safety Science*, 40(7), 589–604.
- Biddle, J., & Roberts, K. (2003). Claiming behavior in workers' compensation. *Journal of Risk and Insurance*, 70(4), 759–780.
- Bowles, J. B., & Peláez, C. E. (1995). Fuzzy logic prioritization of failures in a system failure mode, effects and criticality analysis. *Reliability Engineering and System Safety*, 50(2), 203–213.
- Chiozza, M. L., & Ponzetti, C. (2009). FMEA: A model for reducing medical errors. *Clinica Chimica Acta*, 404(1), 75–78.
- Durhan, Y. (2006). *Occupational health and safety in logistics operations*. Turkish Logistics Press.
- Gremyr, I., & Svensson, M. (2006). Failure mode and effects analysis of the FMEA process. *International Journal of Quality & Reliability Management*, 23(7), 862–874.
- International Organization for Standardization. (2018). *ISO 45001:2018 Occupational health and safety management systems – Requirements with guidance for use*. ISO.
- Khasha, R., Mirmohammadi, S. J., Mehrparvar, A. H., Zare, M., & Attarchi, M. (2013). Systematic hazard identification and risk assessment in logistics facilities. *Archives of Industrial Hygiene and Toxicology*, 64(2), 215–225.
- Liu, H.-C., Liu, L., & Liu, N. (2013). Risk evaluation approaches in failure mode and effects analysis: A literature review. *Expert Systems with Applications*, 40(2), 828–838.
- Mannan, S. (Ed.). (2005). *Lees' loss prevention in the process industries: Hazard identification, assessment and control* (3rd ed.). Elsevier Butterworth-Heinemann.
- Mesleki Eğitim ve Öğretim Sisteminin Güçlendirilmesi Projesi (MEGEP). (2005). *İş sağlığı ve güvenliği*. Millî Eğitim Bakanlığı.
- Murphy, D. C., Banerjee, A., & Hargreaves, I. M. (2004). Electrical injuries in occupational settings. *Occupational Medicine*, 54(3), 192–200.
- Occupational Safety and Health Administration. (2012). *Hazard communication standard (29 CFR 1910.1200)*. U.S. Department of Labor.
- Reiling, J. G., Knutzen, B. L., & Stoecklein, M. (2003). FMEA – The cure for medical errors. *Quality Progress*, 36(8), 67–71.
- Sivrikaya, Ş. (2016). Türkiye'de işçi sağlığı ve güvenliği yapılanması. *İş Sağlığı ve Güvenliği Dergisi*, 6(2), 151–162.
- Stamatis, D. H. (1995). *Failure mode and effect analysis: FMEA from theory to execution*. ASQC Quality Press.
- Thun, J.-H., & Hoenig, D. (2011). An empirical analysis of supply chain risk management in the German automotive industry. *International Journal of Production Economics*, 131(1), 242–249.

- Turkish Standards Institution. (2010). *TS ISO 31000 Risk yönetimi – İlkeler ve kılavuzlar*. Türk Standardları Enstitüsü.
- Waters, T. R., Lu, M.-L., Piacitelli, L. A., Werren, D., & Deddens, J. A. (2011). Efficacy of the revised NIOSH lifting equation to predict risk of low back pain due to manual lifting. *Journal of Occupational and Environmental Medicine*, 53(9), 1061-1067.
- Wetterneck, T. B., Skibinski, K. A., Roberts, T. L., Schroeder, M. E., Enloe, M., Kleppin, S. M., & Carayon, P. (2004). Using failure mode and effects analysis to plan implementation of smart i.v. pump technology. *American Journal of Health-System Pharmacy*, 63(16), 1528-1538.
- Yurdakul, M., Gökkaya, D., & Biçer, Z. Y. (2019). Risk assessment and management in sustainable logistics operations. *International Journal of Logistics Research and Applications*, 22(1), 47-67.