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Engineering-Oriented Mitigation and System Optimization of Occupational Safety Risks in Textile Manufacturing using Grey DEMATEL

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ABSTRACT

Occupational safety risk management in textile manufacturing has predominantly relied on descriptive evaluations and administrative measures, which often fall short in supporting engineering-based decision-making and system-level interventions. To address this limitation, the present study introduces an engineering-oriented framework for occupational safety risk mitigation and system optimization by integrating the Grey Decision-Making Trial and Evaluation Laboratory (Grey DEMATEL) method to analyze causal relationships among safety risk factors. The Grey DEMATEL technique is applied to accommodate uncertainty in expert judgments while enabling the identification of key causal drivers that can serve as leverage points for engineering controls and process redesign. Drawing on evaluations by 12 experts in occupational safety and engineering, this study assesses 25 safety risk factors in textile manufacturing operations. It structures them into a comprehensive causal network. The analysis identifies ten dominant causal factors, including the operation of electrical equipment in wet environments, improper chemical storage practices, manual material handling without mechanical assistance, insufficient fire detection systems, and procedural weaknesses affecting system performance. These factors demonstrate high prominence and positive net influence values, indicating their significant role in triggering and amplifying secondary risks, including excessive noise exposure, chemical hazards, airborne dust, and worker fatigue. Moving beyond conventional risk identification, the study translates analytical findings into engineering-based mitigation strategies, encompassing process redesign, equipment modification, and system-level safety interventions. The results illustrate the effectiveness of Grey DEMATEL as a decision-support tool for prioritizing engineering controls, enabling risk reduction at the source of hazard generation. From an engineering standpoint, the proposed framework facilitates the development of sustainable, measurable, and integrated safety solutions tailored to labor-intensive manufacturing environments.

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1. Introduction

Occupational Safety and Health (OSH) remains a major challenge in labor-intensive manufacturing sectors, particularly in the textile industry, which contributes substantially to the economic growth of many nations. Data reported by the International Labor Organization indicate that more than 2.8 million fatalities occur each year as a result of occupational accidents and work-related diseases, while an estimated 374 million workers experience non-fatal occupational injuries [54]. Textile manufacturing involves complex, interconnected production processes that expose workers to a wide range of hazards, including hazardous chemicals, electrically operated machinery, manual handling of materials, high noise levels, and substandard working conditions [44]. These persistent hazards suggest that existing safety practices have not yet delivered sustainable reductions in occupational risk, underscoring the need for more structured and systematic risk management approaches [13].

Conventional OSH risk assessment techniques such as qualitative descriptions, safety checklists, and probability–severity matrices are commonly used to identify workplace hazards. Despite their widespread adoption, these methods often fail to capture the causal interdependencies among multiple risk factors, thereby limiting their effectiveness in prioritizing control measures within complex industrial systems [42,46]. Recent studies emphasize that a comprehensive understanding of cause–and–effect interactions among risk factors is crucial for identifying upstream drivers that initiate cascading safety failures across production systems [8].

In response to these limitations, causality-oriented analytical methods have gained prominence in occupational safety research. Among them, the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method has been extensively applied to model causal relationships and to distinguish between driving and dependent risk factors, supporting more focused and effective intervention strategies [60]. However, traditional DEMATEL approaches face challenges in addressing uncertainty and subjectivity, particularly when expert judgments are expressed in linguistic terms, a common practice in OSH evaluations [15,53].

To overcome these challenges, the Grey DEMATEL method incorporates principles of grey systems theory into the DEMATEL framework, allowing linguistic assessments to be represented as interval-valued grey numbers that explicitly reflect uncertainty [14,45,64]. Prior research has demonstrated the effectiveness of Grey DEMATEL across a range of engineering and industrial applications, including construction safety analysis, manufacturing risk evaluation, and supply chain management [11,37]. Nevertheless, studies applying Grey DEMATEL within the textile sector have predominantly focused on risk identification and ranking, with limited emphasis on translating causal insights into engineering-based mitigation strategies and system-level optimization.

To address this research gap, the present study employs the Grey DEMATEL approach to examine occupational safety risks in the textile industry from an engineering-oriented perspective. Rather than focusing solely on hazard identification, this study seeks to identify the dominant causal risk factors that serve as engineering leverage points for process redesign, equipment modification, and integrated safety system interventions. By utilizing causal dominance indicators derived from Grey DEMATEL analysis, this research aims to support engineering decision-making in safety system optimization. The results are expected to advance engineering-focused safety analysis frameworks while providing practical guidance for developing systematic, measurable, and sustainable safety solutions in textile manufacturing environments.

2. Methods

2.1 Research Approach

This study uses a quantitative approach with the Grey Decision-Making Trial and Evaluation Laboratory (Grey DEMATEL) method to identify and analyze the causal relationship between occupational safety and Health (OSH) risk factors in the textile industry. The Grey DEMATEL method was employed due to its ability to handle uncertainty in expert assessment data, which is typically linguistic and subjective. By combining the theory of grey systems and DEMATEL, this approach can yield a more comprehensive and accurate representation of cause-and-effect structures.

2.2 Research Design

This research is designed as **an explanatory case study** with a focus on the textile industry. Research design as shown in Figure 1

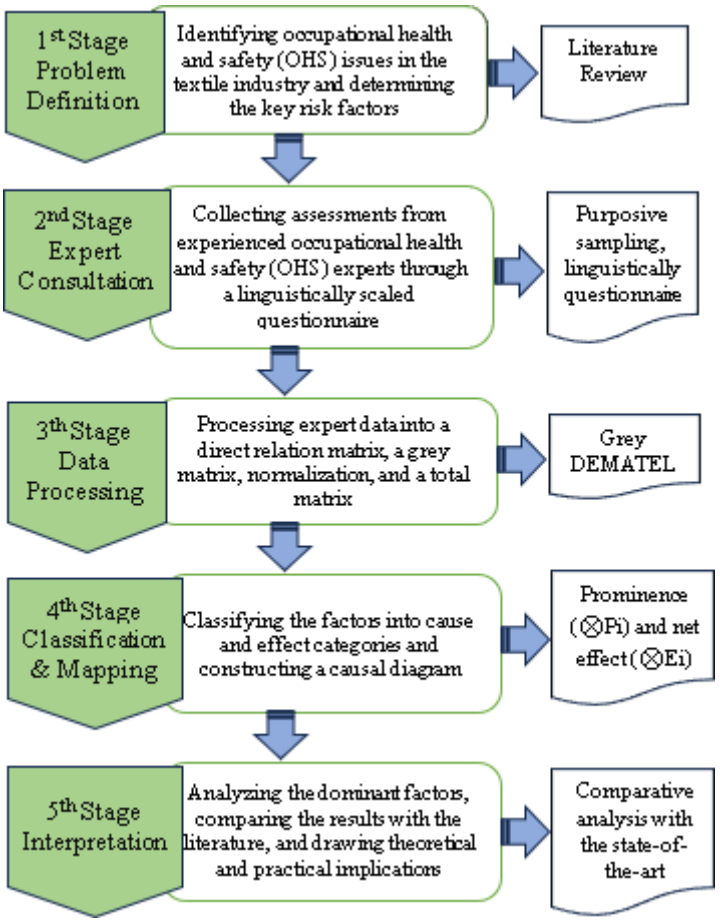


Fig. 1. Research design

Based on Figure 1, the research flow is as follows:

1. **Problem Definition**
   a. Identify OSH issues in the textile industry through literature studies and field observations.
   b. Determine 25 risk factors based on international OSH standards and previous research.
2. **Expert Consulting**

a. Recruited 12 OSH experts using the purposive sampling method.
b. Provide a linguistic scale-based questionnaire to assess the relationship between factors.

3. Data Processing with Grey DEMATEL

a. Convert linguistic data into grey numbers.
b. Combine data into a global matrix.
c. Calculate the normalization matrix and the total matrix.
d. Estimating the values of ⊗Ri, ⊗Ci, ⊗Pi, and ⊗Ei.

4. Classification and Mapping

a. Classify risk factors into the cause group and the effect group.
b. Visualize the cause-and-effect relationship through causal diagrams.

5. Interpretation

a. Analyze the dominant factors with high prominence and high net effect.
b. Comparison of the results with previous literature.
c. Interesting, practical, and theoretical implications.

2.3 Population and Sampling

The research population comprises OSH experts, textile industry practitioners, and academics with experience in OSH risk management. Through purposive sampling, this study involved 12 experts who met the criteria: (i) have at least 10 years of experience in the textile industry or in the field of OSH, (ii) understand the application of OSH standards, and (iii) have been involved in occupational risk management or evaluation.

2.4 Data Collection

The main instrument is a linguistic-scale questionnaire in which experts assess the degree of influence of one risk factor on another. The linguistic scale is then transformed into grey numbers to accommodate the assessment's ambiguity. The risk factors evaluated included up to 25 factors, including technical and organizational risks, as shown in Table 1.

Table 1
For risk factors related to occupational safety and health

Code	OHS Risk factor	Sources
RU1	Excessive noise from weaving/spinning machines	(Ak et al., 2022; Awais-E-Yazdan et al., 2022; Hamid et al., 2020; Herrero et al., 2022; Karasan & Erdogan, 2021; Kgh et al., 2023; Kumar Deepak & Muthukumar, 2018; Mohamadinejad et al., 2019; Muhib et al., 2021; Mutlu & Altuntas, 2019; Pang et al., 2011; Raghu Natha Reddy & Gokulachandran, 2020; Rahman et al., 2020; Shah, 2015; Shukla et al., 2021; Supciller & Abali, 2015; Wu et al., 2015)
RU2	Wet or slippery floors due to chemicals	(Adolph, 2019; Ferdous et al., 2020; Hamid et al., 2020; Karanikas & Hasan, 2022; Kumar Deepak & Muthukumar, 2018; Mohamadinejad et al., 2019; Mutlu & Altuntas, 2019; Raghu Natha Reddy & Gokulachandran, 2020; Shah, 2015; Shaikh et al., 2018; Ummah, 2019)
RU3	Exposed or damaged electrical cables	(Hamid et al., 2020; Mohamadinejad et al., 2019)
RU4	Electrical equipment without proper grounding	(Hamid et al., 2020)
RU5	Overload in electrical panels	(Khandan, M., Koohpaei, A., Hosseinzadeh, Z., & Sadeghi, 2019)
RU6	Use of electrical equipment in wet areas	(Khoshakhlagh et al., 2023)

Code	OHS Risk factor	Sources
RU7	Use of organic solvents such as toluene and benzene	(Anwar et al., 2018; Hamid et al., 2020; Lee et al., 2018; Mutlu & Altuntas, 2019, 2024; Rahman et al., 2020; Shaikh et al., 2018; Uddin & Alam, 2023)
RU8	Exposure to heavy metals such as chromium/lead	(Anwar et al., 2018; Ferdous et al., 2020; Karanikas & Hasan, 2022; Kumar Deepak & Muthukumar, 2018; Li et al., 2021; Mutlu & Altuntas, 2019, 2024; Raghu Natha Reddy & Gokulachandran, 2020; Shah, 2015; Shaikh et al., 2018; Shukla et al., 2021; Uddin & Alam, 2023; van den Brandhof & Wösten, 2022)
RU9	Use of hazardous chemicals containing ammonia	(Oturakci, 2019; Shaikh et al., 2018; Uddin & Alam, 2023; Wu et al., 2015)
RU10	Uncontrolled chemical reactions due to mixing incompatible materials	(Hamid et al., 2020; Khandan, M., Koohpaei, A., Hosseinzadeh, Z. & Sadeghi, 2019; Mutlu & Altuntas, 2019; Oturakci, 2019)
RU11	Exposure to cotton dust containing endotoxins	(Adolph, 2019; Ak et al., 2022; Anwar et al., 2018; Ferdous et al., 2020; Hamid et al., 2020; Herrero et al., 2022; Kgh et al., 2023; Kumar Deepak & Muthukumar, 2018; R. Liu et al., 2021; Mohamadinejad et al., 2019; Muhib et al., 2021; Mutlu & Altuntas, 2019; Pang et al., 2011; Raghu Natha Reddy & Gokulachandran, 2020; Shah, 2015; Shaikh et al., 2018; Shukla et al., 2021; Supciller & Abali, 2015; Uddin & Alam, 2023; Wu et al., 2016)
RU12	Cross-contamination between hazardous chemicals and finished products	(Lee et al., 2018; Oturakci, 2019; Uddin & Alam, 2023)
RU13	Unprotected moving machine parts	(Ahmad et al., 2021; Ak et al., 2022; Awais-E-Yazdan et al., 2022; Ferdous et al., 2020; Hamid et al., 2020; Herrero et al., 2022; Kumar Deepak & Muthukumar, 2018; Mohamadinejad et al., 2019; Muhib et al., 2021; Murugan et al., 2023; Mutlu & Altuntas, 2019; Raghu Natha Reddy & Gokulachandran, 2020; Shah, 2015; Shaikh et al., 2018; Supciller & Abali, 2015; Ugur, 2006; Ummah, 2019; Yucesan & Gul, 2021)
RU14	Use of cutting tools without safety guards	(Ferdous et al., 2020; Herrero et al., 2022; Karasan & Erdogan, 2021; Mutlu & Altuntas, 2019; Ummah, 2019; Yucesan & Gul, 2021)
RU15	Lifting heavy loads without assistive devices	(Adolph, 2019; Ahmad et al., 2021; Ak et al., 2022; Ferdous et al., 2020; Hamid et al., 2020; Kgh et al., 2023; khoshakhlagh et al., 2022; R. Liu et al., 2021; Mohamadinejad et al., 2019; Muhib et al., 2021; Murugan et al., 2023; Mutlu & Altuntas, 2019; Rahman et al., 2020; Ugur, 2006; Ummah, 2019; Wu et al., 2015)
RU16	Long working hours without adequate breaks	(Ahmad et al., 2021; Ak et al., 2022; Hamid et al., 2020; Kgh et al., 2023; Khoshakhlagh et al., 2023; Kumar Deepak & Muthukumar, 2018; J. Liu & Li, 2022; Muhib et al., 2021; Murugan et al., 2023; Raghu Natha Reddy & Gokulachandran, 2020; Shah, 2015; Shaikh et al., 2018)
RU17	Storage of flammable chemicals without proper safety measures	(Awais-E-Yazdan et al., 2022; Ferdous et al., 2020; Karanikas & Hasan, 2022; Mutlu & Altuntas, 2019; Oturakci, 2019; Shaikh et al., 2018)
RU18	Accumulation of flammable fabric fibers	(Ferdous et al., 2020; Hamid et al., 2020; Mutlu & Altuntas, 2019)
RU19	Use of electrical equipment that does not meet safety standards	(Ferdous et al., 2020; Mutlu & Altuntas, 2019)
RU20	Lack of effective fire detection and suppression systems	(Awais-E-Yazdan et al., 2022; Ferdous et al., 2020; Hamid et al., 2020; Karanikas & Hasan, 2022; Khandan, M., Koohpaei, A., Hosseinzadeh, Z. & Sadeghi, 2019; Kumar Deepak & Muthukumar, 2018; Mutlu & Altuntas, 2019; Oturakci, 2019; Raghu Natha Reddy & Gokulachandran, 2020; Shah, 2015; Shaikh et al., 2018)
RU21	Untrained emergency evacuation procedures	(Ferdous et al., 2020; Hamid et al., 2020; Mutlu & Altuntas, 2019)
RU22	Employees not understanding Standard	(Hamid et al., 2020; Ummah, 2019; Wirawati et al., 2020)

Code	OHS Risk factor	Sources
	Operating Procedures (SOPs)	
RU23	Improper or non-use of personal protective equipment (PPE)	(Ak et al., 2022; Ferdous et al., 2020; Gonçalves et al., 2019; Hamid et al., 2020; Herrero et al., 2022; khoshakhlagh et al., 2022; Khoshakhlagh et al., 2023; Kumar Deepak & Muthukumar, 2018; Mohamadinejad et al., 2019; Muhib et al., 2021; Murugan et al., 2023; Mutlu & Altuntas, 2019; Raghu Natha Reddy & Gokulachandran, 2020; Rahman et al., 2020; Shah, 2015; Shaikh et al., 2018; Shukla et al., 2021; Wirawati et al., 2020; Yucesan & Gul, 2021)
RU24	Incorrect measurements leading to hazardous chemical reactions	(Mohamadinejad et al., 2019)
RU25	Mold growth in textile materials stored in damp conditions	(Kumar Deepak & Muthukumar, 2018; Mohamadinejad et al., 2019; Raghu Natha Reddy & Gokulachandran, 2020; Shah, 2015; Yucesan & Gul, 2021)

2.5 Analytical Procedure

The Grey DEMATEL approach combines grey system theory with the DEMATEL method to address risk factors associated with uncertain information, subjective perspectives, and potential bias in expert opinions. Additionally, this methodology enhances the accuracy of the analysis. The procedural steps to apply Grey DEMATEL are outlined as follows [17,51].

Step 1: Build an initial direct relationship matrix.

Create an initial direct relationship matrix for risk factors ($c = \{ci\ I\ i = 1, 2, \dots, n\}$) related to OSH risk factors in the textile industry. The matrix was established using a five-point grey linguistic scale (see Table 2), ranging from "no influence" to "very high influence", as evaluated by the K experts through paired comparisons.

Table 2
Linguistic terms and their corresponding grey scales

Linguistics Term	Grey Number
No influence (No)	[0,0]
Very low influence (VL)	[0,1]
Low influence (L)	[1,2]
High influence (H)	[2,3]
Very high influence (VH)	[3,4]

Step 2: Develop a grey direct-relation matrix

The linguistic terms are replaced with their corresponding grey numbers to transform the initial direct-relation matrix into the grey direct-relation matrix. Since K experts responded, K grey direct-relation matrices were obtained, denoted X1, X2, X3, ..., XK. The grey direct-relation matrix is represented as shown in Equation (1).

$$x^K = \begin{bmatrix} 0 & \otimes x_{12k} & \otimes x_{13k} & \cdots & \otimes x_{1nk} \\ \otimes x_{21k} & 0 & \otimes x_{23k} & \cdots & \otimes x_{2nk} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \otimes x_{(n-1)1k} & \otimes x_{n2k} & \cdots & 0 & \otimes x_{(n-1)nk} \\ \otimes x_{n1k} & \otimes x_{n2k} & & & 0 \end{bmatrix} \quad (1)$$

Step 3: Develop the overall grey relation matrix

To construct the overall grey relation matrix, all individual grey direct relation matrices are combined using Equation (2).

$$X = \sum_{i=0}^{K} \left(\frac{\sum \otimes x_{ijk}}{K}, \frac{\sum \otimes x_{ijk}}{K}\right) \quad (2)$$

Step 4: Express the normalised grey direct-relation matrix
To transform the grey relation matrix into the normalized grey direct relationship matrix (N), equations (3)–(5) are applied

$$\boldsymbol{s} = [s, s] = \frac{1}{\max\limits_{0 \le i \le n} \sum_{j=0}^{n} \otimes x_{ij}} \quad (3)$$

$$\mathrm{N} = \otimes\, s.X \quad (4)$$

$$\otimes\, n_{ij} = [\underline{s}.\otimes\, x_{ij}, \overline{s}.\otimes\, x_{ij}] \quad (5)$$

Step 5: Calculate the total relation matrix
The total relation matrix (T) is derived from the normalized grey direct-relation matrix using Equation (6)

$$\otimes\, T = \otimes\, N(\otimes\, I - \otimes\, N)^{-1} \quad (6)$$

where " $\otimes$ I" denotes the grey identity matrix

Step 6: Compute the causal parameters.

Equations (7) and (8) are applied to determine the causal parameters.

$$\otimes\, R_i = \sum_{j=1}^{n} T_{ij} \forall_i \quad (7)$$

$$\otimes\, C_j = \sum_{i=1}^{n} T_{ij} \forall_j \quad (8)$$

The influence of risk factor "*i*" is represented by $\otimes$Ri, which denotes the total impact exerted on all other risk factors, while $\otimes$Cj indicates the influence received by risk factor "*j*" from the others.

Step 7: Calculate the prominence ($\otimes$Pi) and net effect ($\otimes$Ei)
The prominence ($\otimes$Pi) and net effect ($\otimes$Ei) scores of each risk factor are calculated using Equations (9) and (10)

$$P_i = \otimes\, R_i + \otimes\, C_j \mid i = j \quad (9)$$

$$E_i = \otimes\, R_i - \otimes\, C_j \mid i = j \quad (10)$$

The causal relationship diagram is constructed based on the prominence ($\otimes$Pi) and net effect ($\otimes$Ei) scores. A positive $\otimes$Ei indicates the net causal influence of a risk factor on the system, while a negative $\otimes$Ei represents the net influence of the system on that risk factor.

3. Results and Discussion

3.1 Grey DEMATEL Analysis

Grey DEMATEL analysis was conducted to identify causal relationships among Occupational Safety and Health (OSH) risk factors for occupational safety and health (OSH) in the textile industry. To ensure that the experts clearly understood the study research process, the objectives were first explained using the Grey DEMATEL framework. The experts were then asked to assess the cause–and–effect relationships among the identified OSH risk factors using a linguistic scale in the form of a direct-relation matrix. The initial direct-relation matrices were subsequently converted into grey matrices via grey-number transformation. As twelve experts participated in the assessment, twelve grey relation matrices were obtained. These matrices were then aggregated to form the overall grey relation matrix, presented in Table 3.

Table 3
Overall grey relation matrix of OSH risk factors in the textile industry

RU	RU1	RU2	RU3	.....	RU23	RU24	RU25
RU1	[0,0]	[0.58, 1.42]	[0, 0.08]	.....	[0.5, 0.83]	[0, 0.08]	[0, 0.08]
RU2	[0,0.08]	[0,0]	[0.67, 0.91]	.....	[0.33, 0.5]	[0.25, 0.5]	[0.58, 1.33]
RU3	[0,0.08]	[0.5, 0.67]	[0, 0]	.....	[0.25, 0.42]	[0.92, 1.67]	[0, 0.08]
RU4	[0.08, 0.17]	[1.08, 1.92]	[0.33, 0.5]	.....	[0.17, 0.33]	[0.92, 1.67]	[0, 0.08]
RU5	[0.08,0.17]	[0.75, 1.58]	[1.08, 1.92]	.....	[0.25 ,0.42]	[0.92, 1.67]	[0, 0.08]
RU6	[0.58, 1.42]	[1.5, 2.5]	[1.5, 2.42]	.....	[0.25, 0.42	[1, 1.83]	[0.08, 0.25
RU7	[0, 0.08]	[0.33, 0.5]	[0.17, 0.33]	.....	[1.33, 2.25]	[0.33, 0.5]	[0.67, 1.42]
RU8	[0,0.08]	[0.08, 0.25]	[0.08, 0.25]	.....	[1.08, 2.08]	[0.33, 0.5]	[0, 0.08]
RU9	[0, 0.08]	[0.25, 0.42]	[0.17, 0.33]	.....	[1.33, 2.33]	[0.33, 0.58]	[0.58, 1.33]
RU10	[0, 0.08]	[0.25, 0.42]	[0.08, 0.25]	.....	[1.58, 2.5]	[0.5, 0.67]	[1.75, 2.5]
RU11	[0, 0.08	[0, 0.08]	[0, 0.08]	.....	[0.58, 0.83]	[0.08, 0.17]	[0.08, 0.17]
RU12	[0, 0.08]	[0.25, 0.42]	[0, 0.08]	.....	[0.5, 0.83]	[1.42, 2.25]	[0.08, 0.17]
RU13	[0.25, 0.42]	[0.08, 17]	[0.17, 0.25]	.....	[0.5, 0.75]	[0.08, 0.17]	[0.08, 0.17]
RU14	[0.17, 0.25]	[0.08, 0.16]	[0.17, 0.25],	.....	[0.25, 0.42]	[0.08, 0.17]	[0, 0.08]
RU15	[0.08, 0.17	[0.33, 0.5]	[0.08, 0.17]	.....	[0.25, 0.42]	[0, 0.08]	[0, 0.08]
RU16	[0.5,] 0.75]	[0.17, 0.25]	[0.08, 0.17]	.....	[0.33, 0.5]	[0.08, 0.17]	[0.08, 0.17]
RU17	[0, 0.08]	[0.33, 0.5]	[0.17, 0.33]	.....	[1.08, 2]	[0.5, 0.75]	[1.08, 1.83]
RU18	[0, 0.08]	[0.08, 0.25	[0.17, 0.33]	.....	[0.33, 0.5]	[0.42, 0.67]	[0.08, 0.17]
RU19	[0.08, 0.16]	[0.33, 0.5]	[1.17, 2]	.....	0.25, 0.42]	[0.17, 0.33]	[0, 0.08]
RU20	[0, 0.08]	[0.25, 0.42]	[0.08, 0.25]	.....	[1, 1.92]	[0.08, 0.17]	[0.17, 0.33]
RU21	[0.08, 0.25]	[0.25, 0.42]	[0.17, 0.33]	.....	[0.25, 0.42]	[0.08, 0.25]	[0, 0.08]
RU22	[0.67, 1.58]	[0.83, 1.75]	[0.8, 1.75]	.....	[1.67, 2.67]	[1, 2]	[0.33, 0.58]
RU23	[0.92, 1.83]	[0.83, 1.75]	[0.75, 1.67]	.....	[0, 0]	[0.75, 1.67	[0.08, 0.25]
RU24	[0, 0.08]	[0.25, 0.42]	[0, 0.08]	.....	[1.08, 1,92]	[0, 0]	[0.42, 1.17]
RU25	[0, 0.08]	[0.08, 0.25]	[0, 0.08]	.....	[0, 0.08]	[0, 0.08]	[0, 0]

The normalized grey direct-relation matrix was then obtained from the grey direct-relation matrix using Equations (3)–(5). Subsequently, Equation (1) was applied to transform the normalized grey relation matrix (Table 4) into the total relation matrix, as presented in Table 5.

Table 4
Normalized grey direct-relation matrix (N) of OSH risk factors in the textile industry

RU	RU1	RU2	RU3	·····	RU23	RU24	RU25
RU1	[0.00, 0.00]	[0.01, 0.03]	[0.00, 0.00]	·····	[0.01, 0.02]	[0.00, 0.00]	[0.00, 0.00]
RU2	[0.00, 0.00]	[0.00, 0.00]	[0.02, 0.02]	·····	[0.01, 0.01]	[0.01, 0.01]	[0.01, 0.03]
RU3	[0.00, 0.00]	[0.01, 0.02]	[0.00, 0.00]	·····	[0.01, 0.01]	[0.02, 0.04]	[0.00, 0.00]
RU4	[0.00, 0.00]	[0.02, 0.04]	[0.01, 0.01]	·····	[0.00, 0.01]	[0.02, 0.04]	[0.00, 0.00]
RU5	[0.00, 0.00]	[0.02, 0.04]	[0.02, 0.04]	·····	[0.01, 0.01]	[0.02, 0.04]	[0.00, 0.00]
RU6	[0.01, 0.03]	[0.04, 0.06]	[0.04, 0.06]	·····	[0.01, 0.01]	[0.02, 0.04]	[0.00, 0.01]
RU7	[0.00, 0.00]	[0.01, 0.01]	[0.00, 0.01]	·····	[0.03, 0.05]	[0.01, 0.01]	[0.02, 0.03]
RU8	[0.00, 0.00]	[0.00, 0.01]	[0.00, 0.01]	·····	[0.02, 0.05]	[0.01, 0.01]	[0.00, 0.00]
RU9	[0.00, 0.00]	[0.01, 0.01]	[0.00, 0.01]	·····	[0.03, 0.05]	[0.01, 0.01]	[0.01, 0.03]
RU10	[0.00, 0.00]	[0.01, 0.01]	[0.00, 0.01]	·····	[0.04, 0.06]	[0.01, 0.02]	[0.04, 0.06]
RU11	[0.00, 0.00]	[0.00, 0.00]	[0.00, 0.00]	·····	[0.01, 0.02]	[0.00, 0.00]	[0.00, 0.00]
RU12	[0.00, 0.00]	[0.01, 0.01]	[0.00, 0.00]	·····	[0.01, 0.02]	[0.03, 0.05]	[0.00, 0.00]
RU13	[0.01, 0.01]	[0.00, 0.00]	[0.00, 0.01]	·····	[0.01, 0.02]	[0.00, 0.00]	[0.00, 0.00]
RU14	[0.00, 0.01]	[0.00, 0.00]	[0.00, 0.01]	·····	[0.01, 0.01]	[0.00, 0.00]	[0.00, 0.00]
RU15	[0.00, 0.00]	[0.01, 0.01]	[0.00, 0.00]	·····	[0.01, 0.01]	[0.00, 0.00]	[0.00, 0.00]
RU16	[0.01, 0.02]	[0.00, 0.01]	[0.00, 0.00]	·····	[0.01, 0.01]	[0.00, 0.00]	[0.00, 0.00]
RU17	[0.00, 0.00]	[0.01, 0.01]	[0.00, 0.01]	·····	[0.02, 0.05]	[0.01, 0.02]	[0.02, 0.04]
RU18	[0.00, 0.00]	[0.00, 0.01]	[0.00, 0.01]	·····	[0.01, 0.01]	[0.01, 0.02]	[0.00, 0.00]
RU19	[0.00, 0.00]	[0.01, 0.01]	[0.03, 0.05]	·····	[0.01, 0.01]	[0.00, 0.01]	[0.00, 0.00]
RU20	[0.00, 0.00]	[0.01, 0.01]	[0.00, 0.01]	·····	[0.02, 0.04]	[0.00, 0.00]	[0.00, 0.01]
RU21	[0.00, 0.01]	[0.01, 0.01]	[0.00, 0.01]	·····	[0.01, 0.01]	[0.00, 0.01]	[0.00, 0.00]
RU22	[0.02, 0.04]	[0.02, 0.04]	[0.02, 0.04]	·····	[0.04, 0.06]	[0.02, 0.05]	[0.01, 0.01]
RU23	[0.02, 0.04]	[0.02, 0.04]	[0.02, 0.04]	·····	[0.00, 0.00]	[0.02, 0.04]	[0.00, 0.01]
RU24	[0.00, 0.00]	[0.01, 0.01]	[0.00, 0.00]	·····	[0.02, 0.04]	[0.00, 0.00]	[0.01, 0.03]
RU25	[0.00, 0.00]	[0.00, 0.01]	[0.00, 0.00]	·····	[0.00, 0.00]	[0.00, 0.00]	[0.00, 0.00]

Table 5
Total relation matrix of the enablers (T) of OSH risk factors in the textile industry

RU	RU1	RU2	RU3	·····	RU23	RU24	RU25
RU1	[0.00, 0.00]	[0.01, 0.04]	[0.00, 0.01]	.....	[0.01, 0.02]	[0.00, 0.01]	[0.00, 0.04]
RU2	[0.00, 0.01]	[0.00, 0.01]	[0.02, 0.03]	.....	[0.01, 0.02]	[0.01, 0.02]	[0.01, 0.02]
RU3	[0.00, 0.01]	[0.01, 0.03]	[0.00, 0.01]	.....	[0.01, 0.02]	[0.02, 0.05]	[0.00, 0.01]
RU4	[0.00, 0.01]	[0.03, 0.06]	[0.01, 0.02]	.....	[0.01, 0.02]	[0.02, 0.05]	[0.00, 0.01]
RU5	[0.00, 0.01]	[0.02, 0.04]	[0.03, 0.05]	.....	[0.01, 0.02]	[0.02, 0.05]	[0.00, 0.01]
RU6	[0.01, 0.04]	[0.04, 0.07]	[0.04, 0.06]	.....	[0.01, 0.02]	[0.03, 0.05]	[0.00, 0.01]

RU	RU1	RU2	RU3	.....	RU23	RU24	RU25
RU7	[0.00, 0.01]	[0.01, 0.02]	[0.01, 0.02]	.....	[0.04, 0.07]	[0.01, 0.02]	[0.02, 0.04]
RU8	[0.00, 0.01]	[0.00, 0.01]	[0.00, 0.01]	.....	[0.03, 0.06]	[0.01, 0.02]	[0.00, 0.01]
RU9	[0.00, 0.01]	[0.01, 0.02]	[0.01, 0.02]	.....	[0.04, 0.07]	[0.01, 0.02]	[0.02, 0.04]
RU10	[0.00, 0.01]	[0.01, 0.02]	[0.00, 0.02]	.....	[0.04, 0.08]	[0.01, 0.03]	[0.04, 0.07]
RU11	[0.00, 0.01]	[0.00, 0.01]	[0.00, 0.01]	.....	[0.01, 0.02]	[0.00, 0.01]	[0.00, 0.01]
RU12	[0.00, 0.01]	[0.01, 0.02]	[0.00, 0.01]	.....	[0.02, 0.04]	[0.03, 0.06]	[0.01, 0.02]
RU13	[0.01, 0.01]	[0.00, 0.01]	[0.00, 0.01]	.....	[0.01, 0.03]	[0.00, 0.01]	[0.00, 0.01]
RU14	[0.00, 0.01]	[0.00, 0.01]	[0.00, 0.01]	.....	[0.01, 0.02]	[0.00, 0.01]	[0.00, 0.00]
RU15	[0.00, 0.01]	[0.01, 0.02]	[0.00, 0.01]	.....	[0.01, 0.02]	[0.00, 0.01]	[0.00, 0.01]
RU16	[0.01, 0.02]	[0.01, 0.01]	[0.00, 0.01]	.....	[0.01, 0.02]	[0.00, 0.01]	[0.00, 0.01]
RU17	[0.00, 0.01]	[0.01, 0.02]	[0.01, 0.02]	.....	[0.03, 0.07]	[0.01, 0.03]	[0.03, 0.06]
RU18	[0.00, 0.00]	[0.00, 0.01]	[0.00, 0.01]	.....	[0.01, 0.02]	[0.01, 0.02]	[0.00, 0.01]
RU19	[0.00, 0.01]	[0.01, 0.03]	[0.03, 0.06]	.....	[0.01, 0.02]	[0.01, 0.02]	[0.00, 0.01]
RU20	[0.00, 0.01]	[0.01, 0.02]	[0.00, 0.02]	.....	[0.03, 0.06]	[0.00, 0.02]	[0.01, 0.02]
RU21	[0.00, 0.01]	[0.01, 0.02]	[0.01, 0.02]	.....	[0.01, 0.02]	[0.00, 0.02]	[0.00, 0.01]
RU22	[0.02, 0.05]	[0.02, 0.07]	[0.02, 0.06]	.....	[0.05, 0.00]	[0.03, 0.07]	[0.01, 0.03]
RU23	[0.02, 0.05]	[0.02, 0.06]	[0.02, 0.06]	.....	[0.01, 0.04]	[0.02, 0.06]	[0.01, 0.03]
RU24	[0.00, 0.01]	[0.01, 0.02]	[0.00, 0.01]	.....	[0.03, 0.01]	[0.00, 0.01]	[0.01, 0.04]
RU25	[0.00, 0.00]	[0.00, 0.01]	[0.00, 0.00]	.....	[0.00, 0.02]	[0.00, 0.01]	[0.00, 0.01]

The total relation matrix was used to estimate the causal parameters. The summation of the columns of the total relation matrix (using Equation (6)) is represented by ⊗Ci, while the summation of the rows (using Equation (1)) is denoted as ⊗Ri. Using Equations (9) and (10), the prominence (⊗Pi) and net effect (⊗Ei) were calculated. Table 6 presents the prominence (⊗Pi) and net effect (⊗Ei) scores along with their crisp values. Based on the net effect (⊗Ei) scores, the OSH risk factors were classified into cause and effect categories.

Table 6
Prominence and net effect score of OSH risk factors in the textile industry

RU	⊗R	⊗C	⊗Pi	Crisp	⊗Ei	Crisp	**Cause/Effect**
RU1	[0.078, 0.228]	[0.105, 0.316]	[0.183, 0.543]	0.363	[-0.317, 0.289]	-0.057	effect
RU2	[0.213, 0.464]	[0.275, 0.645]	[0.488, 1.108]	0.798	[-0.336, 0.26]	-0.122	effect
RU3	[0.235 , 0.519]	[0.230, 0.552]	[0.465, 1.071]	0.768	[-0.379, 0.193]	-0.014	effect
RU4	[0.217 , 0.487]	[0.227, 0.553]	[0.444, 1.04]	0.742	[-0.339, 0.355]	-0.038	effect
RU5	[0.168 , 0.41]	[0.218, 0.547]	[0.386, 0.957]	0.671	[-0.525, 0.349]	-0.093	effect
RU6	[0.266 , 0.605]	[0.250, 0.605]	[0.516, 1.21]	0.863	[-0.501, 0.303]	0.008	cause
RU7	[0.313 , 0.704]	[0.355, 0.838]	[0.669, 1.542]	1.105	[-0.514, 0.35]	-0.088	effect
RU8	[0.208 , 0.562]	[0.259, 0.709]	[0.466, 1.271]	0.869	[-0.595, 0.318]	-0.099	effect
RU9	[0.275 , 0.667]	[0.317, 0.789]	[0.592, 1.456]	1.024	[-0.832, -0.134]	-0.082	effect
RU10	[0.36 , 0.771]	[0.452, 0.955]	[0.812, 1.725]	1.269	[-0.211, 0.465]	-0.138	effect
RU11	[0.085 , 0.243]	[0.376, 0.918]	[0.462, 1.16]	0.811	[-0.249, 0.196]	-0.483	effect

RU	⊗R	⊗C	⊗Pi	Crisp	⊗Ei	Crisp	**Cause/Effect**
RU12	[0.262 , 0.654]	[0.189, 0.473]	[0.451, 1.127]	0.789	[-0.325, 0.099]	0.127	cause
RU13	[0.159 , 0.359]	[0.163, 0.409]	[0.322, 0.768]	0.545	[-0.151, 0.242]	-0.027	effect
RU14	[0.136 , 0.308]	[0.209, 0.461]	[0.345, 0.769]	0.557	[-0.286, 0.167]	-0.113	effect
RU15	[0.14 , 0.35]	[0.108, 0.291]	[0.248, 0.641]	0.444	[-0.118, 0.611]	0.045	cause
RU16	[0.186 , 0.379]	[0.212, 0.472]	[0.398, 0.852]	0.625	[-0.283, 0.15]	-0.060	effect
RU17	[0.368 , 0.831]	[0.220, 0.486]	[0.588, 1.317]	0.953	[-0.195, 0.352]	0.246	cause
RU18	[0.13 , 0.315]	[0.165, 0.413]	[0.295, 0.728]	0.512	[-0.196, 0.45]	-0.066	effect
RU19	[0.246 , 0.537]	[0.185, 0.441]	[0.431, 0.978]	0.705	[-0.234, 0.28]	0.078	cause
RU20	[0.269 , 0.65]	[0.200, 0.465]	[0.469, 1.116]	0.793	[-0.024, 1.242]	0.127	cause
RU21	[0.221 , 0.492]	[0.212, 0.455]	[0.433, 0.947]	0.690	[-0.363, 1.07]	0.023	cause
RU22	[0.634 , 1.575]	[0.333, 0.658]	[0.967, 2.233]	1.600	[-0.333, 0.507]	0.609	cause
RU23	[0.614 , 1.52]	[0.450, 0.977]	[1.063, 2.497]	1.780	[-0.439, -0.009]	0.354	cause
RU24	[0.36 , 0.806]	[0.299, 0.693]	[0.659, 1.499]	1.079	[-0.317, 0.289]	0.087	cause
RU25	[0.057 , 0.179]	[0.189, 0.495]	[0.245, 0.675]	0.460	[-0.336, 0.26]	-0.224	effect

⊗Ri represents the net effect of the OSH risk "*i*" on the OSH risk *j*, while ⊗Ci indicates that the OSH risk "*j*" is influenced by other OSH risks. Furthermore, the prominence score (⊗Pi) of each OSH risk can be used to assess its importance in controlling risk factors within the textile industry. Furthermore, the causal diagram is constructed by mapping the values of Pi and ⊗Ei, as illustrated in Figures 2 and 3.

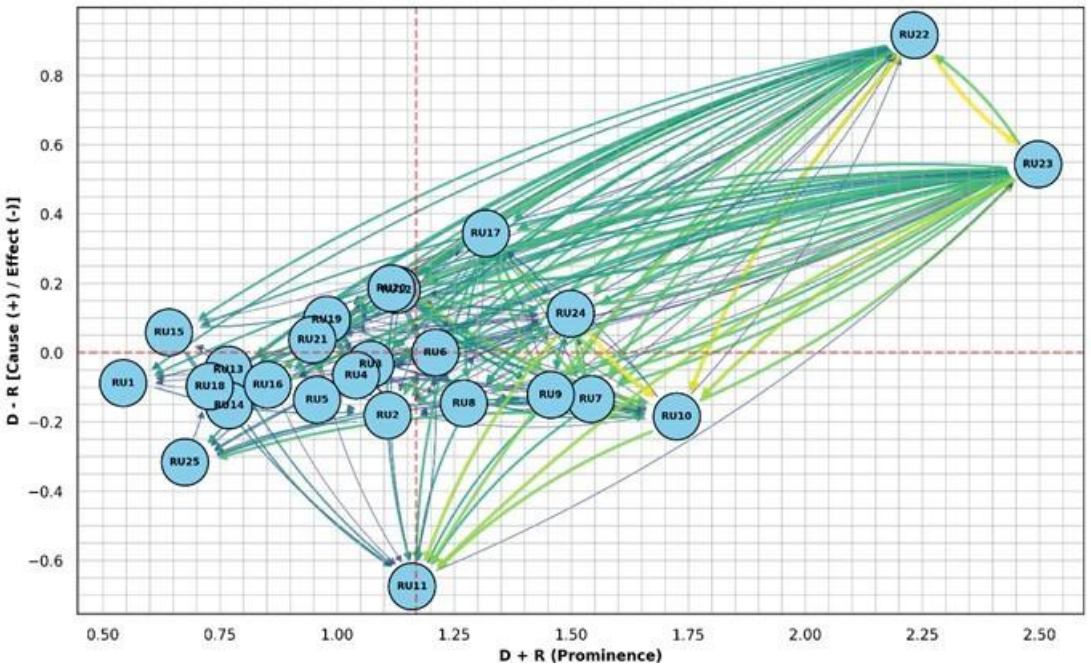


Fig. 2. Causal relationship among the occupational health and safety hazard risks in the textile industry

4. Discussion

4.1 Causal Structure and Engineering Significance of Safety Risks in Textile Manufacturing

The Grey DEMATEL analysis delineates a well-defined cause–and–effect structure of occupational safety risks within textile manufacturing systems. Of the twenty-five risk factors examined, a subset was identified as dominant causal drivers based on their high prominence scores and positive net influence values. These factors, specifically RU6, RU12, RU15, RU17, RU19, RU20, RU21, RU22, RU23, and RU24, constitute upstream system vulnerabilities that play an active role in transmitting and amplifying risk throughout the production process.

From an engineering standpoint, the identified causal drivers reflect fundamental issues related to equipment environment incompatibility, deficiencies in process control mechanisms, and gaps in system integration, rather than isolated operational lapses. For instance, the operation of electrical equipment in wet environments (RU6) and the use of non-compliant electrical devices (RU19) indicate misalignment between equipment design specifications and actual operating conditions. Likewise, insufficient fire detection and suppression systems (RU20) point to the lack of integrated safety architectures within the production system. Collectively, these findings indicate that risk emergence in textile manufacturing is predominantly rooted in engineering and system design decisions rather than in individual worker behavior.

4.2 Effect Factors as Indicators of System Performance Degradation

Conversely, factors classified within the effect group, such as excessive machinery noise, chemical exposure, inhalation of cotton dust, deterioration of electrical components, and ergonomic strain, demonstrate negative net influence values, indicating that they primarily function as outcomes of upstream system inadequacies. These risks arise as downstream manifestations when engineering-based preventive controls at the source are either insufficient or not implemented.

For example, uncontrolled chemical reactions (RU10) should not be interpreted as isolated incidents but rather as direct consequences of inaccuracies in chemical dosing systems (RU24) and weaknesses in overall process control and system integrity (RU12). Similarly, elevated noise levels (RU1) and dust exposure (RU11) reflect deficiencies in machine enclosure design as well as the absence of effective ventilation and dust extraction systems. This system-oriented interpretation is consistent with system-theoretic safety frameworks, including STAMP-informed DEMATEL approaches, which hold that occupational accidents and hazards arise from complex interactions among system components rather than from isolated single-point failures.

4.3 Integration of Technical and Organizational Factors within a Socio-Technical System

By contrast, factors categorized within the effect group, such as excessive machinery noise, exposure to hazardous chemicals, inhalation of cotton dust, deterioration of electrical components, and ergonomic-related strain, are characterized by negative net effect values, indicating that they represent consequences of upstream system deficiencies rather than primary sources of risk. These hazards materialize as downstream outcomes when engineering-based preventive measures at the causal level are inadequate or absent.

For example, uncontrolled chemical reactions (RU10) do not occur in isolation but are closely associated with inaccuracies in chemical dosing systems (RU24) and shortcomings in process control reliability (RU12). Likewise, elevated noise levels (RU1) and dust exposure (RU11) can be attributed to inadequate machine enclosures and ineffective ventilation or dust extraction systems. This perspective is consistent with system-theoretic safety frameworks, including STAMP-informed

DEMATEL models, which posit that occupational accidents and hazards arise from dynamic interactions among system elements rather than from isolated component failures.

4.4 Comparison with Global Textile Industry Studies from an Engineering Perspective

The causal configuration identified in this study aligns with evidence reported in textile manufacturing sectors across other developing industrial regions. Empirical studies from Bangladesh and South Asia consistently indicate that machinery-related hazards, insufficient fire protection infrastructure, and improper chemical handling practices constitute major contributors to occupational accidents. These findings correspond closely with the dominant causal factors identified in this research, particularly RU19, RU20, and RU17.

While downstream occupational health issues such as exposure to cotton dust (RU11) and extended working hours (RU16) have been extensively documented in previous studies, the present analysis advances existing knowledge by revealing their underlying systemic origins. Specifically, the results demonstrate that these hazards are largely driven by upstream engineering deficiencies and process design decisions, rather than arising as isolated operational or behavioral issues.

4.5 Theoretical Contribution to Engineering-Oriented Safety Analysis

This study contributes to engineering-oriented safety analysis by reframing Grey DEMATEL from a descriptive risk identification method into a decision-support tool for system-level engineering intervention and safety-by-design optimization. Recent research highlights that occupational risks in complex manufacturing systems arise primarily from interactions among system components, control structures, and design decisions, rather than isolated technical or human failures [4]. Studies published between 2022 and 2025 further demonstrate that fuzzy and grey DEMATEL approaches are effective in prioritizing engineering controls, process redesign, and equipment modification under uncertainty [10]. By quantifying causal dominance through prominence and net effect measures, this study extends these theories to textile manufacturing, reinforcing the view that sustainable occupational safety should be addressed as a socio-technical engineering problem driven by structural system optimization rather than compliance-based controls.

Theoretically, this study affirms that Grey DEMATEL is an effective tool for mapping cause–and–effect relationships in complex and uncertain risk systems, particularly in contexts where quantitative accident data is limited. Compared to previous research in the construction or mining sectors, this study offers an original contribution by highlighting the textile sector, which has relatively rarely employed a systemic approach based on grey systems [10] on the application of Grey DEMATEL in the apparel industry.

5. Engineering Implications

5.1 Engineering Implications and System-Level Interventions

The outcomes of the Grey DEMATEL analysis provide practical, evidence-based insights for engineering-driven safety mitigation and system optimization in textile manufacturing settings. In contrast to conventional occupational safety research, which largely focuses on administrative or behavioral approaches, this study demonstrates that analyzing causal interdependencies among risk factors can be systematically translated into engineering control strategies. These strategies are specifically designed to address the fundamental sources of risk propagation within the production system.

5.2 Engineering Control Prioritization Based on Causal Factors

The identification of dominant causal factors defined by elevated prominence and positive net influence values highlights critical leverage points for targeted engineering interventions. For example, the operation of electrical equipment in wet environments (RU6) indicates a misalignment between equipment specifications and process conditions. This risk can be effectively reduced through engineering-oriented solutions such as the adoption of ingress-protected (IP-rated) electrical enclosures, physical separation of wet and dry operational zones, enhanced drainage infrastructure, and the incorporation of ground-fault protection systems. These interventions address the hazard at a structural level, thereby reducing reliance on procedural adherence.

In a similar context, the lack of adequate fire detection and suppression systems (RU20) represents a fundamental deficiency in system engineering. Appropriate engineering responses include the deployment of automated fire detection systems, zoned sprinkler installations, smoke and heat sensors integrated with programmable logic controllers (PLCs), and emergency shutdown interlock mechanisms. Such measures improve overall system robustness by enabling rapid and automated responses to abnormal or hazardous conditions.

5.3 Process Redesign and Equipment Modification

Several causal risk factors identified in this study underscore the necessity for process redesign and equipment modification. Manual handling of heavy materials without mechanical assistance (RU15) indicates shortcomings in the material-handling system design. Engineering solutions such as conveyor-based transport systems, mechanical lifting devices, automated guided vehicles (AGVs), and ergonomically optimized workstation configurations can substantially reduce physical strain on workers while concurrently enhancing process efficiency.

Chemical-related risks, including cross-contamination between hazardous substances and finished products (RU12) and improper dosing that may trigger hazardous reactions (RU24), reveal limitations in existing process control and instrumentation systems. These risks can be mitigated through the implementation of closed-loop dosing mechanisms, automated mixing systems equipped with safety interlocks, physically segregated piping networks, and sensor-based concentration monitoring. From an engineering standpoint, these modifications reduce dependence on manual decision-making and limit process variability.

5.4 System-Level Engineering Optimization

At the system level, the causal structure derived from the Grey DEMATEL analysis reflects the characteristics of a socio-technical system, in which technical components, organizational structures, and human factors interact dynamically. Consequently, isolated corrective measures are insufficient to achieve long-term risk mitigation. Comprehensive system-level engineering solutions are therefore required, including integrating safety principles into production system design, adopting real-time monitoring technologies, and applying predictive maintenance strategies.

The findings indicate that Grey DEMATEL can function as an effective decision-support mechanism for safety-oriented system engineering by facilitating the prioritization of interventions with the greatest systemic influence. By emphasizing engineering controls rather than administrative measures, textile manufacturing organizations can simultaneously improve occupational safety performance and enhance operational reliability.

5.5 Engineering Mapping of DEMATEL Results

To translate the Grey DEMATEL causal structure into actionable engineering insights, Table 7 maps dominant causal factors to corresponding engineering controls and system-level interventions.

Table 7
Mapping of grey DEMATEL causal factors to engineering-based interventions

Causal Risk Factor (RU)	DEMATEL Interpretation (Engineering Perspective)	Engineering Control / Intervention	System-Level Impact
RU6 Use of electrical equipment in wet areas	Incompatibility between equipment design and operating environment	IP-rated electrical enclosures, wet–dry zoning, improved drainage, ground-fault protection	Reduced electrical shock risk and improved system reliability
RU12 Cross-contamination between hazardous chemicals and products	Inadequate process segregation and control	Physical separation of process lines, closed-loop material transfer, automated isolation valves	Prevention of chemical contamination and process instability
RU15 Manual lifting without assistive devices	Inefficient material handling system design	Conveyors, mechanical lifting aids, AGVs, ergonomic workstation redesign	Reduced musculoskeletal risk and improved production efficiency
RU17 Improper storage of flammable chemicals	Lack of engineered safety barriers in storage systems	Explosion-proof storage cabinets, ventilation systems, and fire-rated compartments	Mitigation of fire and explosion propagation
RU19 Non-compliant electrical equipment	Equipment selection and specification failure	Standard-compliant equipment replacement, electrical system upgrading	Improved electrical safety and operational continuity
RU20 Lack of fire detection and suppression systems	Absence of an integrated safety system architecture	Automated fire detection, sprinkler zoning, PLC-linked emergency shutdowns	Enhanced system resilience and rapid hazard containment
RU21 Untrained emergency evacuation procedures	Over-reliance on human response in emergency design	Engineered evacuation routes, automated alarms, and fail-safe guidance systems	Reduced evacuation time and improved emergency response effectiveness
RU22 Lack of SOP understanding	High dependence on human compliance	Automation, interlocks, poka-yoke mechanisms, digital work instructions	Reduced human error and process variability
RU23 Improper or non-use of PPE	Engineering controls insufficient, PPE used as last barrier	Machine guarding, enclosure design, local exhaust ventilation	Shift from behavioral to source-based risk control
RU24 Incorrect chemical measurement	Absence of precision instrumentation and feedback control	Automated dosing systems, sensor-based monitoring, interlocked mixing units	Prevention of hazardous reactions and improved process stability

6. Conclusion

This study reveals that the occupational safety and health (OSH) risks in the textile industry are complex, interrelated, and influenced by a combination of technical, organizational, and worker behavioral factors. Using the Grey Decision-Making Trial and Evaluation Laboratory (Grey DEMATEL) approach, several key causal factors were identified, including the use of electrical equipment in wet areas, cross-contamination of chemicals, manual lifting of heavy loads without assistance, improper storage of flammable materials, limited fire detection systems, and non compliance with standard operating procedures (SOPs) and personal protective equipment (PPE) usage. These factors were

found to trigger secondary risks affecting the work environment, including excessive noise, exposure to cotton dust, slippery floors, long working hours, and mold growth in textile materials. The findings suggest that mitigation efforts should focus on upstream factors to break the causal chain and prevent cascading effects. Theoretically, this study strengthens the application of Grey DEMATEL in OSH risk analysis within the textile industry. In practice, it provides management with an analytical foundation for designing systematic, sustainability-oriented safety strategies. Future research is recommended to integrate Grey DEMATEL with other multi-criteria methods to deepen risk prioritization analysis and support OSH policy development in labor-intensive sectors.

Conflict of interest: The authors declare that they have no conflict of interest.

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