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A Sustainable Approach to Risk Assessment in Automotive Paint Shops

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Abstract

Automotive paint shops are critical areas in the automotive industry where a range of risks can pose serious threats to workers, the environment, and the quality of the final product. As sustainability becomes an increasingly important concern, it is essential for these facilities to manage risks effectively and adopt practices that prioritize environmental protection. Multi-Criteria Decision Making (MCDM) approaches have shown promise in improving risk management in various industries. Specifically, we aim to fill the research gap of prioritizing critical factors and identifying the most significant risks in the context of automotive paint shops. To such an aim, we propose a case study for a real company operating in this sector, where we will utilize an MCDM-based approach to optimize the risk assessment procedure. Our approach can help managers develop more effective risk management strategies, allocate resources more efficiently, and ultimately create a safer and more sustainable work environment.

Keywords: Automotive Paint Shop; Sustainability; Risk Management; Decision-Making; Fuzzy Logic

1. Introduction

The automotive industry has a pivotal role in shaping the future of sustainability by designing, manufacturing, and distributing eco-friendly and energy-efficient vehicles (Atkinson, 2020). To meet the growing pressure to reduce its carbon footprint and promote sustainable materials, the industry is adopting new technologies that reduce emissions and improve fuel efficiency, fueling the demand for electric and hybrid vehicles. Sustainability in the automotive sector protects the environment and drives innovation, competitiveness, and contributes to the economic growth of involved countries. Automotive paint shops play a vital part in the automotive industry (Güven et al., 2017) by giving vehicles their final appearance and protection.

These shops use specialized equipment and materials to paint cars, not only enhancing their aesthetics but also protecting them from weather and wear and tear. Their contribution to vehicle quality and durability towards a more sustainable value chain (Zahler and Iglauer, 2012) makes them important. Due to the growing production and sales of vehicles, the demand for automotive paint shops is constantly increasing. Sustainable risk assessment is a necessity in automotive environments as it prioritizes the safety of workers and workplaces (Abotbol et al., 2022). A comprehensive assessment can detect potential hazards and implement preventive measures, reducing the risk of accidents, incidents, and environmental damage. This approach also enhances reputation and brand image while improving profitability.

By focusing on sustainability, automotive paint shops can secure long-term success and stability while embracing a responsible business approach. Many risks in automotive paint shops are intertwined, making it imperative for thorough risk assessments to consider their interplay (Mwai et al., 2023). For instance, inadequate training or protocol violations can amplify the risks posed by the use of specific chemicals and materials in the painting process to both workers and the environment. Poor ventilation or protective equipment can harm workers' health and safety while increasing the likelihood of environmental contamination. Other factors such as equipment maintenance, emergency response planning, and waste management also impact the paint shop's overall risk profile. A holistic approach to addressing these interconnected risks is critical for ensuring sustainable and responsible operations in the automotive paint industry.

To effectively tackle the interrelated risks in automotive paint shops, we will employ the Fuzzy DEMATEL (DEcision MAking Trial and Evaluation Laboratory) method, which analyzes the causal relationships between various factors or variables. We aim to fill the following research gaps in the context of automotive paint shops:

- consider the interconnections between various risks such as worker safety, environmental contamination, equipment maintenance, and waste management;
- identify the most influential risks and determine the best approach for mitigating or reducing their impact;
- achieve a comprehensive approach to addressing the interconnected risks in the automotive paint industry, leading to sustainable and responsible operations.

The structure of the paper includes: a literature review in section 2, where we discuss existing studies and theories related to sustainable risk assessment in automotive paint shops; method description in section 3, where we provide an in-depth explanation of the Fuzzy DEMATEL method and its application in the context of automotive paint shops; a case study in section 4, where we demonstrate the application of the Fuzzy DEMATEL method through a real-life example in the automotive paint industry; conclusions and future lines in section 5, where we summarize the main findings, draw conclusions, and suggest future directions for research in the field of sustainable risk assessment in automotive paint shops.

2. Literature Review

The automotive industry is striving to reduce its environmental impact, and automotive paint shops are an important area of focus in this effort. As their processes require a substantial amount of energy and materials, it is necessary to explore ways to minimize the environmental impact to enhance sustainability in this area (Carpitella et al., 2022).

As highlighted by Sanz et al. (2021), smart and automatic solutions using Artificial Intelligence should be integrated into automotive paint shops to improve maintenance processes. The authors propose a holistic approach implementing Industry 4.0 principles to improve the efficiency of an automotive paint shop process, which involves complex processes such as painting, drying, and curing. The maintenance process can be optimized by improving data collection, analysis, and decision-making.

Another possible solution is to use sustainable materials. Howarth (2013) focused on improving the filtration system in automotive paint shops to reduce paint contamination and improve the quality of the paint finish. This topic is connected to the importance of sustainable materials as the authors discussed how the filtration system can be improved by using higher-quality filters that can capture smaller particles and reduce the need for frequent filter replacements. The use of high-quality filters can improve the quality of the paint finish as well as lead to more sustainable practices by reducing the amount of waste generated by filter replacements.

Energy efficiency is another critical area in which automotive paint shops can become more sustainable. Giampieri et al. (2020) provided a comprehensive review of the current automotive manufacturing practices in terms of energy consumption and efficiency. The authors discussed the importance of reducing energy consumption in the automotive industry due to the significant environmental impact and high energy costs. They analyzed various manufacturing processes, including stamping, welding, painting, and assembly, by evaluating the impact of manufacturing technology, material choice, and production planning on energy consumption.

The process of paint application can also be optimized to enhance sustainability. Fan et al. (2022) highlighted the importance of sustainable process control and optimization in improving the quality of painted automotive parts, which is a relevant topic in the context of robotic paint systems. Additionally, the disposal of paint waste is a significant environmental concern in automotive paint shops. Salihoglu and Salihoglu (2016) focused on the generation, characteristics, and management of paint sludge, a type of hazardous waste generated during the automotive painting process. The authors pointed out the need for continued research and development of more sustainable and environmentally friendly methods for managing this hazardous waste stream.

Automotive paint shops are intricate and high-risk environments that require effective risk management to ensure the safety of workers, protect the environment, and maintain the quality of the final product. Several risks are associated with the paint shop process, including exposure to hazardous chemicals, the potential for accidents, and interconnected risks that can affect worker safety and product quality. The use of robotic systems in the painting process can pose safety risks if not adequately maintained and monitored, presenting a potential accident risk. As highlighted by Andronas et al. (2023), safety risks associated with robotic systems can be minimized through proper training, maintenance, and safety monitoring. Risks in automotive paint shops can also be interconnected with each other, resulting in potential safety and quality control issues. Fan et al. (2022) dealt with the quality control issues that can arise if the painting process is not appropriately monitored and maintained, leading to product defects and rework. Specifically, the authors investigated the First Time Quality (FTQ) feature in an automotive paint shop as a measure of the percentage of vehicles that are painted correctly on the first attempt, without requiring any rework or touch-up. They proposed several recommendations for improving FTQ, including optimizing the paint application process, increasing training for paint shop personnel, and implementing better quality control procedures. Rework can indeed impact production schedules, leading to potential safety risks if workers are rushed to complete tasks. A comprehensive risk management approach in the automotive paint shop is then of paramount importance due to the complexity and interconnectedness of risks.

MCDM (Multi-Criteria Decision Making) is a widely used approach for risk evaluation across various industries (Ahmed et al., 2021; Benítez et al., 2018; Brentan et al., 2022; Benítez et al., 2019). This approach enables decision-makers to consider multiple criteria and weigh them based on their significance in the decision-making process. Fuzzy DEMATEL, in particular, has recently gained significant attention as an MCDM method. Fuzzy DEMATEL utilizes fuzzy logic to address the uncertainty and imprecision inherent in decision-making. By analyzing the interrelationships among different criteria, decision-makers can identify the most significant factors affecting the overall evaluation process. This enables managers to allocate resources more effectively and develop better risk management strategies. The use of the fuzzy DEMATEL method can enhance the transparency and objectivity of the decision-making process, leading to more informed and effective risk management decisions. By prioritizing the most critical factors and analyzing the interrelationships among different criteria, decision-makers can develop more effective risk management strategies. Ultimately, this can result in a safer and more productive work environment.

Given the usefulness of fuzzy DEMATEL in the context of research, we propose its application to a practical case study for a real automotive paint shop. This company is seeking to optimize its risk assessment procedure as well as its risk management strategies to ensure a safer and more productive work environment. By utilizing the fuzzy DEMATEL method, we aim to identify and prioritize the critical risk factors within the company's automotive paint shop and provide a comprehensive risk assessment framework. This will also help decision-makers to allocate resources more efficiently.

In the next section, we delve into the specifics of the fuzzy DEMATEL approach employed in the case study, outlining the step-by-step methodology and providing guidance on how to interpret the final results.

3. Method Description

A step-by-step description of the Fuzzy DEMATEL method is provided in the following. Our objective is to enable other automotive paint shops to implement similar structured approaches in their own operations by offering a comprehensive breakdown of the technique.

1. **Identify the decision-making factors**. The first step is to identify the n decision-making factors relevant to the system under study. These factors are usually referred to as criteria or decision-making elements. This step also involves determining the single decision-maker or the group of K experts to be involved in the evaluation process.
2. **Collect pairwise comparison matrices from the experts**. In this step, each expert provides a relationship between each pair of decision-making factors. This relationship is typically represented using a pairwise comparison matrix, where the elements of the matrix are the relative importance of each pair of factors. To estimate the interaction between factors, triangular fuzzy numbers (TFN), $\tilde{z} = (l, m, u), l \leq m \leq u \in [0, 1]$, can be used. For example, the triplet $(0, 0, 0.25)$ indicates no interaction (NO); $(0, 0.25, 0.5)$ indicates very low interaction (VL); $(0.25, 0.5, 0.75)$ indicates low interaction (L); $(0.5, 0.75, 1)$ indicates high interaction (H); and $(0.75, 1, 1)$ indicates very high interaction (VH).
3. **Convert these pairwise comparison matrices into fuzzy direct-relation (FDR) matrices and aggregate them**. The pairwise comparison matrices elicited by the experts are then converted into fuzzy direct-relation matrices, whose elements are the TFN assigned to each factor according to the previously defined scale. The generic fuzzy matrix $\tilde{Z}^{(k)}$, representing the input FDR matrix elicited by k^{th} expert, is:

$$\tilde{Z}^{(k)} = \begin{bmatrix} (0,0,0) & \tilde{z}_{12}^{(k)} & \dots & \tilde{z}_{1n}^{(k)} \\ \tilde{z}_{21}^{(k)} & (0,0,0) & \dots & \tilde{z}_{2n}^{(k)} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{z}_{n1}^{(k)} & \tilde{z}_{n2}^{(k)} & \dots & (0,0,0) \end{bmatrix}, k = 1, 2, \dots, K; \quad (1)$$

being $\tilde{z}_{ij}^{(k)} = (l_{ij}^{(k)}, m_{ij}^{(k)}, u_{ij}^{(k)})$, K the total number of experts involved, and setting $\tilde{z}_{ii}^{(k)} = (0, 0, 0)$ for $(i = 1, 2, \dots, n)$. These matrices are now aggregated using some (possibly weighted) aggregation method. In this contribution, we use the arithmetic mean (with no expert weighting). Let's call this FDR matrix $\tilde{Z}$.
4. **Normalize the fuzzy direct-relation matrix**. Now the elements of $\tilde{Z}$ are normalized:

$$\tilde{x}_{ij} = \frac{\tilde{z}_{ij}}{r} = \left(\frac{l_{ij}}{r}, \frac{m_{ij}}{r}, \frac{u_{ij}}{r}\right), \quad (2)$$

where

$$r = \max_{ij}\left\{\max_i \sum_{j=1}^{n} u_{ij}, \max_j \sum_{i=1}^{n} u_{ij}\right\}, 1 \leq i, j \leq n. \quad (3)$$

Let's call this normalized FDR matrix $\tilde{X}$.

5. **Calculate the fuzzy total-relation matrix.** In crisp DEMATEL, given a direct-relation matrix X, its associated total-relation matrix T is obtained by

$$T = \lim_{w \to \infty} (X + X^2 + \ldots + X^w) = X(I - X)^{-1}, \quad (4)$$

where I denotes the identity matrix. The convergence of this series is guaranteed by the performed normalization. In fuzzy DEMATEL, this operation is made element-wise with respect to the components of the TFNs in the FDR matrix; using the binary operator $\oplus$:

$$\tilde{T} = \lim_{w \to \infty} (\tilde{X} \oplus \tilde{X}^2 \oplus \ldots \oplus \tilde{X}^w) \quad (5)$$

The convergence of the 3 series involved is guaranteed by the normalization (2).
Calling X_l, X_m, and X_u, respectively, to the matrices of the first (lower), second (medium), and third (upper) components of the TFNs in X, the elements of matrix $\tilde{T}$ are $\tilde{t}_{ij} = (l^*_{ij}, m^*_{ij}, u^*_{ij})$, where

$$[l^*_{ij}] = X_l(I - X_l)^{-1}; \quad (6)$$

$$[m^*_{ij}] = X_m(I - X_m)^{-1}; \quad (7)$$

$$[u^*_{ij}] = X_u(I - X_u)^{-1}. \quad (8)$$

6. **Obtain the crisp total-relation matrix**. Finally, the fuzzy values in $\tilde{T}$ are converted into crisp values. This can be done using one of the defuzzification methods available in the literature, such as the Converting Fuzzy Data into Crisp Scores (CFSC) algorithm proposed in (Opricovic and Tzeng, 2003). This algorithm is used to obtain a crisp total-relation matrix, which we note as T.
A suitable threshold should be set now to avoid taking into account negligible relations. This threshold is usually set as the average of all the values in matrix T.
7. **Draw the causal relationship diagram**. The causal relationship diagram is obtained from matrix T (ignoring the values that are lower than the previously mentioned threshold) by summing its rows (D) and its columns (R). The values of $(D + R)$ and $(D - R)$ respectively indicate the overall importance of element i in the system and its net impact as a result of component i. the causal relationship diagram is formed by plotting $(D + R)$ on the horizontal axis and $(D - R)$ on the vertical axis. This coordinate system locates each factor and shows its interaction within the space defined by $(D + R, D - R)$.

4. Case Study

This case study pertains to an automotive paint shop that performs the task of auto-painting. The activity takes place inside an industrial-type facility along with an adjacent outdoor area. The company's primary objective is to complete the auto-painting work cycle, which encompasses all the phases from the acceptance phase to the delivery of the vehicle. The various work cycle phases have been distinguished into the following categories: acceptance; preparation; cabin painting; finishing; and delivery.

Within the phases of the work cycle, various activities can be identified that are associated with specific tasks such as preparation, painting, and finishing. The preparation phase includes tasks such as cleaning, sanding, and masking to ensure a smooth and even surface for painting. The painting phase involves the application of suitable paint products using various techniques with spray guns or automated systems. The finishing phase involves the final touches to the painted surface mainly through the activity of polishing, to achieve the desired appearance and texture. Each of these tasks requires specific skills, equipment, and materials, and involve multiple workers with specialized training. Proper coordination and communication among the workers are essential to ensure that the work is carried out efficiently and effectively.

The work equipment (marked CE) in the auto-painting facility includes a painting booth, which is a monoblock room specifically designed for painting vehicles. The painting booth is equipped with proper ventilation and aspiration systems to ensure that the paint fumes and overspray are effectively removed from the working area, providing a clean and safe environment for the workers. The room is constructed with specific materials that can withstand the high temperatures generated by the drying process of the paint, as well as the chemical properties of the paints and coatings used in the auto-painting process. The painting booth is installed in compliance with the manual of use and maintenance, which provides guidelines for the correct operation and maintenance of the booth to ensure optimal performance and longevity. Regular maintenance and cleaning of the booth are essential to prevent any malfunctions or accidents that could compromise the quality and safety of the auto-painting process. Proper use and maintenance of the painting booth guarantee that the auto-painting facility operates smoothly and efficiently, delivering high-quality results. Table 1 synthesizes and describes the potential risks that could be present in the painting booth.

We now apply fuzzy DEMATEL by first establishing interdependence relations among these risks in order to characterize those set of risks whose occurrence may likely trigger the occurrence of all the other risks. Data needed for the practical application was collected during several brainstorming sessions with the safety and security system administrator (K=1). The expert's linguistic evaluations provided in Table 2 were then translated into TFN using the previously defined scale (section 3, step 2). Tables 3, 4 respectively provide the crisp total-relation matrix and the crisp total-relation matrix taking into account a threshold value (section 3, step 6). In this study, the threshold value is equal to 0.126. This means that all the values in the crisp total-relation matrix which are smaller than 0.126 are set to zero so that the related causal relation is not considered. Table 5 shows the final output of the fuzzy DEMATEL procedure, while the causal relationship diagram is given in Figure 1. Results have been eventually double-checked via the OnlineOutput software.

Table 1. Risks connected to the activity performed in the cabin booth

Risk	Description
R_1: Inhalation of toxic substances	The painting process generates harmful chemicals and fumes, which can cause respiratory problems and other health issues if inhaled in determined amounts.
R_2: Fire and explosion	The high temperatures generated during the painting and drying process, combined with the flammable nature of the paint and solvents, can create a risk of fire or explosion if the equipment or the facility is not properly maintained or operated.
R_3: Slips, trips, and falls	The presence of paint and other liquids on the floor, combined with the use of heavy equipment, can create a risk of slips, trips, and falls for the workers.
R_4: Exposure to hazardous substances	Workers may come into contact with hazardous substances beyond paints and solvents, such as cleaning agents and substances for maintenance, which can cause skin irritation, chemical burns, or other health problems.
R_5: Electrocution	The use of electrical equipment in the painting booth, combined with the presence of flammable materials, can create a risk of electrocution hazards.
R_6: Inadequate ventilation	Inadequate ventilation in the painting booth can cause an increase in pollutants, leading to respiratory problems and other health issues for the workers.
R_7: Noise pollution	The use of equipment in the painting booth can create high levels of noise, which can cause hearing damage.
R_8: Eye and face injuries	The use of spray guns and other equipment in the painting process can create a risk of eye and face injuries from paint overspray or particles.
R_9: Skin exposure to paint and solvents	Workers may come into contact with paint, stuccos and solvents, which can cause skin irritation, allergic reactions, or chemical burns.
R_{10}: Electrical malfunctions	The use of electrical equipment in the painting booth can cause accidents or injuries to workers, in the case of malfunctions or breakdowns.
R_{11}: Ergonomic hazards	Workers may be required to perform repetitive motions or work in awkward positions, which can cause musculoskeletal disorders over time.
R_{12}: Suspected polluted area	The painting booth is confined space and suspected polluted area, which can create a risk of asphyxiation or inhalation of toxic substances if the ventilation system malfunctions or if workers are not properly trained in related procedures.
R_{13}: Chemical spills and leaks	The use of paint and solvents in the painting booth can create a risk of spills or leaks, which can lead to slips, falls, or chemical exposure.
R_{14}: Equipment malfunction	The use of equipment and tools in the painting booth can create a risk of malfunctions or breakdowns, which can cause accidents or injuries to workers.
R_{15}: Manual handling	Workers may be required to manually handle heavy parts or equipment, which can create a risk of strains, sprains, or other injuries.
R_{16}: Physical agents	The use of ultraviolet (UV) light in the curing process of some paints may expose workers to UV radiation, which can cause skin damage, eye damage, or even skin cancer.
R_{17}: Improper disposal of hazardous waste	The painting process generates hazardous waste such as used paint and solvent containers, rags, and filters. Improper disposal of this waste can cause environmental pollution and health hazards to workers and the general public.

According to the fuzzy DEMATEL analysis, risks R_{12}, R_{14}, R_8, R_9, R_{13}, and R_{10} are the most prominent risks associated with the painting process. Risk R_{12}, suspected polluted area, is the most significant risk also to manage emergencies, followed by risk R_{14}, equipment malfunction, risk R_8, eye and face injuries, risk R_9, skin exposure to paints and solvents, risk R_{13}, chemical spills and leaks, and risk R_{10}, electrical malfunctions, respectively.

From a practical point of view, these findings suggest that managers should prioritize addressing risks related to suspected polluted area and equipment malfunction. This involves providing adequate training and education for workers on specific procedures in the booth, ensuring periodical controls so that ventilation and aspiration systems are functioning correctly, and regularly inspecting and maintaining equipment to prevent malfunctions. Additionally, providing appropriate Personal Protective Equipment (PPE), such as face protection and protective clothing, can help reduce the risk of eye and face injuries and skin exposure to paint and solvents. With this regards, the company is complying with the indications outlined in legislative decree in force in Italy "Testo Unico sulla Salute e Sicurezza sul Lavoro" (Legislative Decree No. 81 (2008)) to ensure the safety and protection of its employees. As part of this commitment, the company implemented the management of suitable PPE, including third category PPE, i.e., specific equipment designed to safeguard workers against a wide category of hazards. Examples of third category PPE include respiratory protection devices, protective clothing with high levels of protection, personal fall protection equipment, chemical protective clothing, and protective gloves and boots that guard against high temperatures or sharp objects. These types of PPE are essential in protecting workers against hazardous substances, equipment, and working conditions, and are crucial in creating a safe work environment while reducing the risk of occupational injuries and illnesses. By utilizing PPE of third category with a proper training the company demonstrates its commitment to employee safety and creates a safer workplace.

Efforts should also be made to prevent chemical spills and leaks by implementing proper storage and handling procedures and providing specific training on emergency management, also through periodic simulations. Addressing the risk of electrical malfunctions involves ensuring that electrical systems are properly grounded and protected. The company regularly performs maintenance activities on the painting booth in compliance with the user and maintenance manual. This ensures that the booth is functioning properly and efficiently, respecting the fire safety prescriptions. Regular maintenance also helps to extend the lifespan of the booth, reducing the need for costly repairs or replacement. By carefully following the instructions laid out in the maintenance manual, the company demonstrates a clear indication of its dedication to guaranteeing a safe working environment for its workers, while also striving to minimize the likelihood of occupational injuries and illnesses.

Table 2. Linguistic evaluations provided by the interviewed expert

	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9	R_{10}	R_{11}	R_{12}	R_{13}	R_{14}	R_{15}	R_{16}	R_{17}
R_1	NO	H	H	VL	VH	VL	VL	H	H	VL	L	L	VL	VL	NO	VL	L
R_2	H	NO	H	H	H	H	NO	NO	VL	L	NO	L	H	L	NO	VL	VL
R_3	L	L	NO	H	NO	H	L	L	L	NO	L	VL	VL	NO	VL	NO	VL
R_4	VH	H	H	NO	L	L	L	VH	VH	NO	L	L	VL	VL	L	H	H
R_5	L	VH	L	H	NO	VL	L	L	L	VH	NO	H	H	VH	L	L	L
R_6	VH	H	L	VH	L	NO	VL	L	L	L	L	H	VL	VL	VL	H	L
R_7	VL	NO	L	L	L	VL	NO	NO	NO	L	L	H	NO	H	L	NO	NO
R_8	H	L	VH	H	H	H	NO	NO	VH	VH	H	H	H	VH	VH	VH	H
R_9	H	L	VH	H	VL	H	NO	VH	NO	H	H	H	VH	VH	VH	VH	H
R_{10}	VH	VH	L	VH	VH	VH	H	VH	VH	NO	L	H	H	VH	H	VH	H
R_{11}	H	L	VH	H	H	L	VL	VH	VH	L	NO	VH	H	H	VH	H	H
R_{12}	VH	VH	VH	VH	VH	VH	H	H	H	H	VH	NO	VH	H	VH	VH	H
R_{13}	VH	VH	H	VH	VH	L	L	VH	VH	H	L	VH	NO	VH	VH	L	VH
R_{14}	H	H	H	VH	VH	H	VH	H	H	VH	H	VH	H	NO	VH	H	H
R_{15}	L	L	H	L	L	L	NO	H	H	H	VH	VH	H	H	NO	L	H
R_{16}	NO	NO	L	H	NO	L	NO	H	H	L	VH	H	VL	H	H	NO	L
R_{17}	VH	VH	L	VH	VH	H	VL	L	L	L	L	H	VH	VH	H	H	NO

Table 3. Crisp total-relation matrix using the CFSC algorithm

	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9	R_{10}	R_{11}	R_{12}	R_{13}	R_{14}	R_{15}	R_{16}	R_{17}
R_1	0.078	0.119	0.124	0.1	0.127	0.087	0.058	0.118	0.119	0.083	0.094	0.109	0.086	0.09	0.072	0.085	0.099
R_2	0.119	0.071	0.118	0.123	0.112	0.11	0.045	0.073	0.088	0.09	0.06	0.103	0.107	0.097	0.063	0.08	0.081
R_3	0.095	0.089	0.064	0.111	0.06	0.101	0.064	0.09	0.091	0.054	0.083	0.079	0.069	0.06	0.07	0.058	0.072
R_4	0.148	0.131	0.14	0.1	0.114	0.114	0.078	0.143	0.145	0.082	0.109	0.124	0.098	0.104	0.112	0.126	0.126
R_5	0.128	0.147	0.128	0.148	0.091	0.105	0.085	0.122	0.124	0.137	0.085	0.142	0.128	0.146	0.116	0.116	0.116
R_6	0.145	0.128	0.121	0.15	0.112	0.081	0.064	0.116	0.118	0.104	0.105	0.133	0.093	0.099	0.094	0.123	0.109
R_7	0.074	0.057	0.089	0.092	0.084	0.068	0.033	0.054	0.055	0.079	0.079	0.103	0.049	0.098	0.081	0.05	0.05
R_8	0.163	0.143	0.175	0.171	0.151	0.151	0.066	0.118	0.171	0.154	0.144	0.164	0.147	0.165	0.16	0.16	0.15
R_9	0.159	0.139	0.172	0.167	0.122	0.148	0.064	0.166	0.116	0.139	0.142	0.16	0.154	0.162	0.157	0.157	0.147
R_{10}	0.178	0.17	0.156	0.186	0.167	0.164	0.109	0.171	0.174	0.106	0.134	0.169	0.15	0.17	0.152	0.163	0.152
R_{11}	0.159	0.139	0.172	0.167	0.148	0.134	0.078	0.165	0.167	0.127	0.1	0.171	0.144	0.152	0.157	0.146	0.146
R_{12}	0.181	0.174	0.183	0.19	0.17	0.168	0.111	0.165	0.167	0.149	0.16	0.132	0.163	0.162	0.166	0.165	0.155
R_{13}	0.177	0.17	0.168	0.185	0.167	0.14	0.096	0.171	0.173	0.146	0.132	0.178	0.11	0.169	0.162	0.138	0.162
R_{14}	0.167	0.16	0.169	0.186	0.167	0.154	0.121	0.161	0.163	0.158	0.147	0.18	0.15	0.119	0.163	0.152	0.152
R_{15}	0.138	0.131	0.152	0.144	0.128	0.127	0.059	0.146	0.148	0.133	0.144	0.162	0.137	0.143	0.097	0.125	0.139
R_{16}	0.093	0.086	0.121	0.138	0.083	0.111	0.048	0.13	0.132	0.104	0.132	0.134	0.094	0.126	0.125	0.081	0.11
R_{17}	0.167	0.161	0.143	0.174	0.157	0.143	0.077	0.137	0.139	0.124	0.123	0.157	0.151	0.158	0.141	0.141	0.101

Table 4. Crisp total-relation matrix considering the threshold value

	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9	R_{10}	R_{11}	R_{12}	R_{13}	R_{14}	R_{15}	R_{16}	R_{17}
R_1	0.000	0.000	0.000	0.000	0.127	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R_2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R_4	0.148	0.131	0.140	0.000	0.000	0.000	0.000	0.143	0.145	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.126
R_5	0.128	0.147	0.128	0.148	0.000	0.000	0.000	0.000	0.000	0.137	0.000	0.142	0.128	0.146	0.000	0.000	0.000
R_6	0.145	0.128	0.000	0.150	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.133	0.000	0.000	0.000	0.000	0.000
R_7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R_8	0.163	0.143	0.175	0.171	0.151	0.151	0.000	0.000	0.171	0.154	0.144	0.164	0.147	0.165	0.160	0.160	0.150
R_9	0.159	0.139	0.172	0.167	0.000	0.148	0.000	0.166	0.000	0.139	0.142	0.160	0.154	0.162	0.157	0.157	0.147
R_{10}	0.178	0.170	0.156	0.186	0.167	0.164	0.000	0.171	0.174	0.000	0.134	0.169	0.150	0.170	0.152	0.163	0.152
R_{11}	0.159	0.139	0.172	0.167	0.148	0.134	0.000	0.165	0.167	0.127	0.000	0.171	0.144	0.152	0.157	0.146	0.146
R_{12}	0.181	0.174	0.183	0.190	0.170	0.168	0.000	0.165	0.167	0.149	0.160	0.132	0.163	0.162	0.166	0.165	0.155
R_{13}	0.177	0.170	0.168	0.185	0.167	0.140	0.000	0.171	0.173	0.146	0.132	0.178	0.000	0.169	0.162	0.138	0.162
R_{14}	0.167	0.160	0.169	0.186	0.167	0.154	0.000	0.161	0.163	0.158	0.147	0.180	0.150	0.000	0.163	0.152	0.152
R_{15}	0.138	0.131	0.152	0.144	0.128	0.127	0.000	0.146	0.148	0.133	0.144	0.162	0.137	0.143	0.000	0.000	0.139
R_{16}	0.000	0.000	0.000	0.138	0.000	0.000	0.000	0.130	0.132	0.000	0.132	0.134	0.000	0.126	0.000	0.000	0.000
R_{17}	0.167	0.161	0.143	0.174	0.157	0.143	0.000	0.137	0.139	0.000	0.000	0.157	0.151	0.158	0.141	0.141	0.000

Table 5. Fuzzy DEMATEL output

	R	D	D+R	D-R
R_1	2.369	1.652	4.021	-0.718
R_2	2.214	1.540	3.754	-0.674
R_3	2.394	1.308	3.702	-1.086
R_4	2.531	1.995	4.526	-0.536
R_5	2.160	2.064	4.224	-0.095
R_6	2.107	1.896	4.002	-0.211
R_7	1.259	1.195	2.453	-0.064
R_8	2.247	2.550	4.796	0.303
R_9	2.290	2.471	4.761	0.181
R_{10}	1.968	2.672	4.640	0.703
R_{11}	1.973	2.473	4.446	0.500
R_{12}	2.401	2.762	5.163	0.360
R_{13}	2.031	2.645	4.675	0.614
R_{14}	2.221	2.670	4.890	0.449
R_{15}	2.087	2.253	4.341	0.166
R_{16}	2.065	1.848	3.913	-0.217
R_{17}	2.070	2.394	4.464	0.324

Lastly, proper disposal of hazardous waste is critical to reducing the risk of environmental pollution and health hazards to workers and the general public. Managers should optimize appropriate waste management procedures to address this risk. Overall, prioritizing and addressing these prominent risks can help minimize the potential health and safety hazards associated with the painting process, promote a safe working environment for workers, and reduce the risk of environmental pollution. The company actively engages in minimizing the most prominent risks associated with the painting process, according to the fuzzy DEMATEL analysis.

5. Conclusions and Future Lines

In this study, we applied an MCDM approach coupled with fuzzy logic to classify the risks associated with a booth in a real automotive paint shop. The analysis identified several prominent risks related to the painting process, such as suspected polluted area, equipment malfunction, eye and face injuries, skin exposure to paint and solvents, chemical spills and leaks, and electrical equipment malfunctions. Based on the findings, we recommend that managers prioritize addressing the risks related to suspected polluted area and equipment malfunction, and continue to provide adequate training, education, and equipment to mitigate these risks.

A limitation of this study is to not cover the actual implementation of suitable prevention and/or mitigation strategies, by only offering insights about it. Future research could explore the effectiveness of different strategies in managing the identified risks. This could involve evaluating the implementation of engineering controls, administrative controls, and personal protective equipment in the workplace. By examining the role of human factors in safety, potential safety hazards can be identified to develop effective training and education programs, improve safety practices and reduce the risk of workplace injuries and illnesses. Future studies could also investigate the use of emerging technologies, such as artificial intelligence and machine learning, in improving risk assessment and management in the automotive paint shop context. By exploring new and innovative approaches to risk management, we can continue to enhance safety practices and create a safer and healthier workplace for employees.

Also, in recognition of the importance of seeking input from a diverse range of experts in the evaluation of workplace safety, we aim to involve experts with varying fields of experience to gain a more comprehensive and global perspective on safety issues. By involving experts with different backgrounds, we can identify potential safety hazards and risks that may have been overlooked previously and develop effective safety solutions that are tailored to the specific needs of the workplace. This approach also provides an opportunity for employees to learn from experts who have specialized knowledge in safety and can share their expertise with the workforce. Involving more experts in safety evaluations will enhance safety practices and contribute to creating a safer and healthier workplace.

Another potential area of research could be to explore the effectiveness of different types of safety equipment and protective gear in reducing the risk of occupational injuries and illnesses in the automotive paint shop context. This could involve testing and evaluating various types of equipment, such as respirators, gloves, and safety glasses, to determine which provide the greatest level of protection for workers. Additionally, researchers could investigate the factors that influence worker compliance with safety procedures and the use of protective equipment, in order to develop more effective strategies for promoting and enforcing safe work practices in the industry.

Through this case study, we hope to not only provide valuable insights and recommendations for the company but also contribute to the growing body of knowledge in the field of risk assessment in the automotive paint shop context. The results of this study can be of interest to both academics and industrial practitioners and can help advance the current understanding of the most effective approaches to risk management in this complex and high-risk environment. By continuing to study and improve risk management strategies in the automotive paint shop context, we can help ensure a safe working environment for workers and reduce the risk of environmental pollution.

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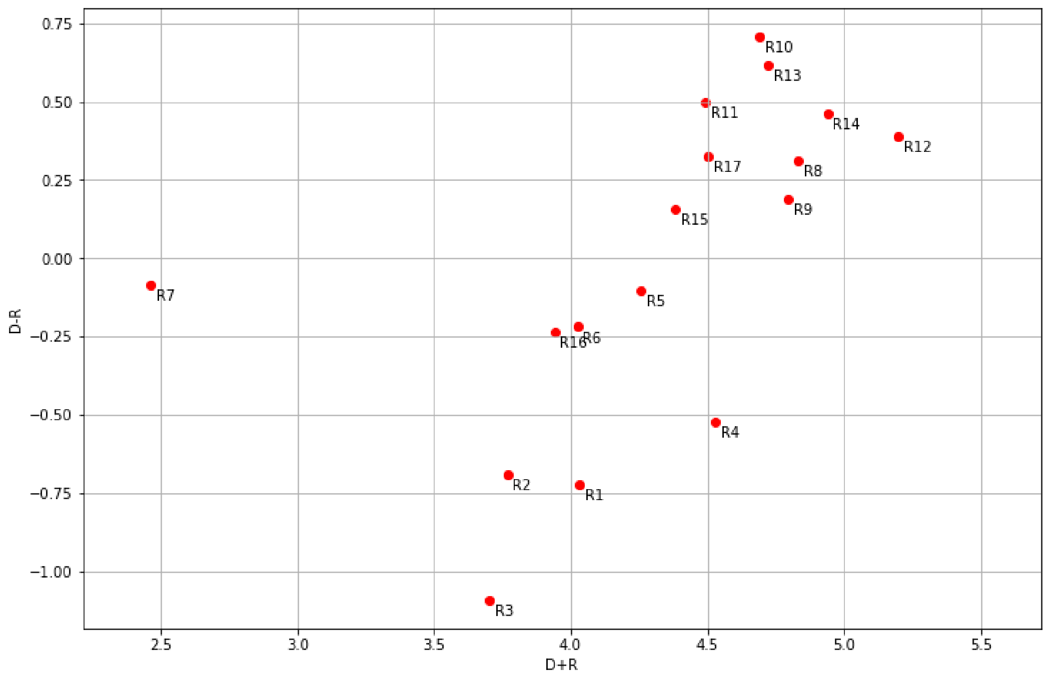

Figure 1. Causal relationship diagram

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