Prioritization of Fire Risk Remedial Actions in the Ready-Made Garment Industry of Bangladesh: A Hybrid MCDM Approach

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Abstract

The ready-made garment (RMG) sector of Bangladesh is one of the largest garment manufacturing sectors in the world. Fire incidents in RMG factories are always a highly discussed issue among local and international policymakers and stakeholders. An efficient prioritization of the remedial actions for fire risks can aid the decision-makers to mitigate the fire hazards and associated damages. This study, thereby, proposes a hybrid Multi-criteria Decision-making (MCDM) framework, combining Stepwise Weight Assessment Ratio Analysis (SWARA) and Weighted Aggregated Sum Product Assessment (WASPAS) method, to prioritize the remedial actions for fire risks in RMG factories. At first, the 16 most important remedial actions have been identified by a panel of experts. For the evaluation of the identified actions, four evaluation criteria- initial cost, maintenance cost, feasibility, and risk reductant- have been selected from both the literature review and expert feedback. By using the SWARA method, the study finds 'initial cost' and 'risk reductant' to be the two criteria with the highest weights. Later, using the obtained criteria weights, the WASPAS method finds that 'proper electrical wiring and connections', 'separating the gas cylinders from the main production building', and 'keeping egress paths and stairs clear of obstruction' are the top three prioritized remedial actions that can be taken to mitigate fire risks in the RMG industries. Results obtained from this research are expected to help the managers of RMG industries to devise an effective fire risk remedial action plan, within their technical constraints and limited resources, to ensure a safe workplace for their workers.

Keywords
Ready-made Garment, Fire Risk Remediation, Stepwise Weight Assessment Ratio Analysis, Weighted Aggregates Sum Product Assessment

1. Introduction
Ready-made garments from Bangladesh are exported to 150 countries of the world and it is an industry aged more than four decades (BGMEA 2021). A safe and sustainable working environment is an important factor for the reputation and stability of such an important industrial sector. However, fire incidents have become a critical issue in recent times, which has created a major hindrance in the way of achieving a safe and sustainable working environment in the RMG sector (Hasan et al. 2017). Several deadly fire incidents in RMG factories have caused the death of hundreds of people in the last few decades. Among those, the fire incident in Tazreen Fashion in 2012 is noteworthy, which caused the death of more than 100 people. The incident drew attention from the national as well as the international community to find an effective and sustainable solution for the fire hazards in the RMG factories (Wiersma 2018).

By conducting continuous fire safety inspections as well as providing remedial suggestions and corrective action plans, it is possible to drive the number of deadly fire incidents to a minimum (Accord 2021; Hasan et al. 2019). Therefore, the remedial suggestions made in the factory inspection reports after analyzing the existing risk factors can carry significant insights into the safety of the RMG industries. Especially, a prioritization of the remedial actions for the existing risk factors can aid the decision-makers to devise an effective hierarchical implementation plan.

There are several studies in recent years on various fire safety issues in the RMG sector. For instance, computer simulation-based studies have been conducted to determine the correlations among fire propagation, spatial layout, occupant movement, and evacuation scenarios in an RMG factory (Khan et al. 2021; Nilufar and Choiti, 2019; Khandoker et al. 2018), fire risk index (FRI) has been calculated to sort out the risky RMG factories (Islam and Roman 2019; Wadud and Huda 2017), the difference between the existing standard and non-compliance issues for fire evacuation in RMG factories has been discussed (Barua et al. 2018), change of fire safety scenario in RMG sector after initiating the inspection activity of the Accord has been analyzed (Wiersma 2018; Accord 2021), burn incidents due to electrical fire has been predicted by probabilistic analysis (Haque et al. 2017), cause-effect relation for deadly accidents in RMG factories have been discussed (Hasan et al. 2017), and so on. There are some other recent studies on various fire safety issues in urban and industrial areas as well (Alkış et al. 2021; Dârmon 2020; Omidvari et al. 2020; Yilmaz et al. 2020). However, no study has yet been conducted to prioritize the remedial actions to mitigate the fire risk factors in the RMG sector of Bangladesh, which presents a clear research gap that is worth exploring.

This research, thereby, aims to determine the priority ranking of the remedial actions for the most significant fire risk factors in the RMG sector by applying a hybrid SWARA-WASPAS method. SWARA is a famous MCDM method for finding subjective criteria weights, which was first proposed by Keršuliene et al. (2010). This technique can find criteria weights with comparatively simple mathematical operations than AHP or other pair-wise comparison-based techniques. The stepwise weight assessment helps the decision-makers to be consistent in their feedback as they do not need to deal with multiple criteria at the same time (Keršuliene et al. 2010). WASPAS is another famous MCDM technique proposed by Zavadskas et al. in 2012, which utilizes the classic weighted sum model (WSM) and weighted product model (WPM) in a combined approach to get a better prioritization score. SWARA-WASPAS can be used combinedly to design an effective decision-making framework in a complex environment (Agarwal et al. 2020; Baç, 2020; Yücenur et al. 2021).

In this study, at first fire safety inspection reports from randomly selected 100 RMG factories have been accumulated from the website of the Accord (https://bangladeshaccord.org). From the selected reports, the 16 most significant remedial actions for the most frequent fire hazards that occur in the RMG sector have been extracted by a panel of 15 industrial experts. Then, four evaluation criteria have been selected from the existing literature and experts' feedback to prioritize the fire risk remedial actions. Later, based on the experts' evaluation, the weights of the evaluation criteria have been determined by the SWARA method. Finally, the WASPAS method has been used to find the final prioritization of the remedial actions, utilizing the criteria weights obtained from the SWARA method. Thereby, in short, this study aims to fulfill the following research objectives:

a) To identify the fire risk remedial actions for the most frequent fire risk factors
b) To identify the evaluation criteria for the remedial actions
c) To determine the weights of the evaluation criteria by applying the SWARA method
d) To determine the priority ranking of the remedial actions by the WASPAS method

The rest of the paper has been arranged as follows: Section 2 reviews the relevant literature. Section 3 discusses the research methodologies and calculations. Section 4 discusses the obtained results from the study. Section 5 discusses the managerial implications of the study and finally, Section 6 concludes the paper and discusses some future research scopes.

2. Literature Review

Industrial fire incidents can be mitigated by implementing proper remedial actions by assessing the fire risk factors observed during regular fire safety inspections (Wiersma 2018; James et al. 2019). Various researchers tried to assess the fire hazards and associated risks in the RMG factories in recent years. For instance, Khandoker et al. (2018) determined the fire propagation pattern on the different floors of a multistoried RMG factory building, Nilufar, and Choiti (2019) determined the relationship between the spatial layout of the exit egress and the movement pattern of the occupants during an evacuation, Khan et al. (2021) tried to find the effects of non-standard practices on safe evacuation. These studies mainly performed some variant of computer simulation-based numerical analysis of the evacuation scenarios in RMG factories while propagating fire or smoke. They attempted to find the correlation between occupants' escape behavior with various unsafe practices like inappropriate fire doors, narrow or obstructed egress, reduced exit numbers, etc. They suggested minimizing these risk factors to create a safe evacuation environment for the occupants at the time of a fire incident. However, they did not prioritize any fire risk remedial actions to aid the decision-makers to reduce the risk factors.

Haque et al. (2017) predicted the number of burn incidents due to electrical faults with empirical statistics. As their calculation variables, they took some of the electrical risk factors which could create electrical short-circuit and fire. Hasan et al. (2019) presented a cost-benefit analysis of the relation between the investment in safety intervention and its long-term financial outcome in the business. The study showed that investment for reducing fire risk factors is outweighed by the achieved benefits. Islam and Roman (2019) assessed by dividing the fire risk factors into hard (structural risks) and soft (managerial risks) parameters, to sort out the vulnerable RMG factories. This work was conducted to show a comparative analysis of the presence of risky RMG factories in two different industrial zones. There are also some recent works focusing on the RMG sector, in which different aspects of fire risk factors, fire safety inspection regulation, historical data, cause-effect analysis of fire incidents, and comparative analysis (James et al. 2019; Barua et al., 2018; Wiersma 2018; Moazzem et al. 2018; Hasan et al., 2017), etc. were discussed. However, none of the studies has introduced any MCDM approach to prioritize the remedial actions to help the managers and other decision-makers in the RMG industries.

Besides studies on the RMG sector, there are some other recent studies, which have analyzed various urban and industrial fire risk factors. For instance, Omidvari et al. (2020) assessed fire risks in a hospital and determined the riskiest zone during a fire incident by applying the failure mode effect analysis (FMEA) combined with MCDM techniques, Dârmon (2020) predicted fire risk-related consequences for industrial buildings by calculating the probability of occurring different risky incidents, Alkış et al. (2021) prioritized the vulnerability of the surrounding structures of a factory during an industrial fire with the Analytical Hierarchy Process (AHP), Wang et al. (2021) used Fuzzy AHP to rank the fire risk factors in the industrial spaces and so on. However, no study has yet been conducted with the intention to prioritize the fire risk remedial actions, which is the prime objective of this present work.

This study is going to utilize two MCDM techniques in a combined manner- SWARA and WASPAS. SWARA has been utilized to find criteria weights in several recent decision-making problems like Majeed and Breesam (2021) solved a land selection problem, Singh and Modgil (2020) presented a supplier selection problem, Ulutaş and Karaköy (2019) did a performance evaluation of the logistics' activities, Agarwal et al. (2020) evaluated the solutions to overcome the barriers of the supply chain, and Valipour et al. (2018) assessed project risks by prioritizing the risk factors by utilizing SWARA method. WASPAS has also been used in several recent MCDM-based studies to prioritize the alternatives. For instance, Bid and Siddique (2019) assessed the risk factors of a river dam, Pathapalli et al. (2020) determined the optimal machining parameters, Jayant et al. (2019) presented a supplier selection problem, Tuş, and Adalı (2019) showed a software selection framework and Mihajlović et al. (2019) presented a location prioritization process by utilizing WASPAS method. However, no work has yet been conducted with a hybrid SWARA-WASPAS method to prioritize any risk remedial actions, which justifies the novelty of this proposed research.

3. Methodology and Calculations

The research methodology used for this study can be explained in 6 steps, as shown below

Step 1. Select a group of industrial experts, who are to be interviewed at different steps of the study.
Step 2. Accumulate fire safety inspection reports for the randomly selected 100 RMG factories from the website of the Accord (https://bangladeshaccord.org).
Step 3. Identify the significant fire risk remedial actions for the most frequent fire risk factors from the selected reports, using expert feedback.
Step 4. Identify the evaluation criteria from the existing literature and experts' feedback.
Step 5. Determine the criteria weights by the SWARA method, utilizing experts' evaluation.
Step 6. Prioritize the identified fire risk remedial actions by the WASPAS method, utilizing the criteria weights determined in Step 5.

A group of 15 industrial experts has been surveyed via Google forms to get their opinion and response at different stages of the study. They have been chosen purposely for this study (Bari et al., 2022). A brief profile of the participating experts in this study can be found in Table 1.

Table 1. Participating experts' profile

Participating Experts (N=15)			
Professional Designations	**Experience**	**N**	**Percentage**
Operation and Maintenance Managers, and Fire Safety Engineers (N=15)	From 5 up to 10 years	7	47.67 %
	From 10 up to 15 years	5	33.33 %
	More than 15 years	3	20%

Fire risk remedial actions from fire safety inspection reports of the randomly selected 100 RMG factories have been gathered from the Accord database. Then the 15 selected experts were requested to identify the most important remedial actions, along with the associated National Fire Protection Association (NFPA) code(s). The identified most important fire risk remedial actions can be found in Table 2.

Table 2. Identified fire risk remedial actions for the most frequent fire risk factors

Code	Remedial Actions	Source
R1	Ensuring inspection, testing, and maintenance (ITM) of fire safety devices	NFPA 10, 2022; NFPA 14, 2019; NFPA 20, 2022; NFPA 25, 2020; NFPA 72, 2022
R2	Arranging regular fire training and drills	NFPA 101, 2015
R3	Providing fire protection system according to occupant load and area	NFPA 1, 2021; NFPA 14, 2019; NFPA 101, 2015
R4	Ensuring proper fire separation by fire rated construction	NFPA 101, 2015
R5	Proper electrical wiring and connections	NFPA 70, 2020; NFPA 70E, 2021
R6	Installing automatic fire/ smoke detection with audible alarm	NFPA 72, 2022
R7	Separating the gas cylinders from the main production building	NFPA 101, 2015
R8	Keeping egress paths and stairs clear of obstruction	NFPA 101, 2015
R9	Ensuring the use of certified fire doors	NFPA 80, 2022; NFPA 101, 2015
R10	Providing illuminated directional signs along the path of travel	NFPA 101, 2015
R11	Maintaining proper length and width of egress aisles	NFPA 101, 2015
R12	Relocating heat-producing utility machines from the work area	NFPA 101, 2015
R13	Removing all nonstandard locking features from egress doors	NFPA 101, 2015
R14	Maintaining occupant load as per regulations	NFPA 101, 2015
R15	Providing additional exits to increase exit capacity	NFPA 101, 2015
R16	Providing adequate illumination throughout the area	NFPA 101, 2015

Based on experts' feedback and reviewing the existing literature, 4 criteria have been selected to prioritize the remedial actions. Those can be found in Table 3.

Table 3. Identified evaluation criteria for the remedial actions

Code	Criteria	Criteria Description	Source
C1	Initial Cost	Initial cost refers to the fixed cost for the preliminary implementation of a risk remedial action. The lower the initial cost for remedial action, the more likely the action is to be implemented. Therefore, this is a **non-beneficial** criterion.	Hasan et al. (2019); Promentilla et al. (2006); Experts' Opinion
C2	Maintenance Cost	Maintenance cost refers to the cost of maintaining a newly implemented practice or a new installation as a part of the remedial plan. The lower the maintenance cost for remedial action, the more likely the action is to be implemented. Therefore, this is a **non-beneficial** criterion.	Hasan et al. (2019); Promentilla et al. (2006); Experts' Opinion
C3	Feasibility	The suitability of implementing a remedial action in real life or industrial culture can be measured by this criterion. As the maximum value for this criterion is desired, this is thereby a **beneficial** criterion.	Liu et al. (2017); Promentilla et al. (2006); Experts' Opinion
C4	Risk Reductant	The risk reduction capability or effectivity of remedial action can be measured by this criterion. This is a **beneficial** criterion, as a higher value for this criterion is desired.	James et al. (2019); Promentilla et al. (2006); Experts' Opinion

3.1 SWARA Method

A simple questionnaire-based survey has been responded to by the 15 experts in Google forms to evaluate the criteria weights by the SWARA method. Experts have opined with a 5-point Likert scale as shown in Table 4.

Table 4. 5-point Likert scale for collecting experts' opinion

Linguistic Variable	Numerical Value
Very Low	1
Low	2
Medium	3
High	4
Very High	5

A sample questionnaire, along with the response from an expert can be found in Appendix A, Table 1A. Experts' feedback on each of the criteria has been aggregated using the geometric mean method (where, "Aggregated values ∈ [1,5]") and then converted to decimal score values (p_j) with a simple linear arithmetical operation (where, "Score values ∈ [0,1]") (see Appendix A, Table 2A). The obtained decimal score values have been utilized in the later steps of the SWARA method. Steps of the SWARA method (Keršuliene et al., 2010; Majeed and Breesam, 2021) can be written as below:

Step 1. Arrange the criteria according to the descending order of the score values or the preferences of the experts.

Step 2. Determine the comparative significance (s_j) of the criteria. This will start from the second preferred criterion. Successive comparative significance is determined by differencing the score values of criterion j and j – 1 following Equation (1).

$$s_{j-1} = p_j - p_{j-1} \tag{1}$$

Step 3. Calculate the comparative coefficient (k_j) by applying Equation (2).

$$k_j = \{1,\ j = 1\ s_j + 1,\ j > 1 \tag{2}$$

Step 4. Find the recalculated weight (q_j), which is defined by using Equation (3)

$$q_j = \{1,\ j = 1\ \frac{k_{j-1}}{k_j},\ j > 1 \tag{3}$$

Step 5. Final weights of the criteria (w_j) are computed by using Equation (4)

$$w_j = \frac{q_j}{\sum_{j=1}^{n} \quad q_j} \tag{4}$$

3.2 WASPAS Method

Experts are needed to evaluate the fire risk remedial actions using a 5-point Likert scale (see Table 4) by responding to a simple questionnaire. Sample responses from an expert can be found in Appendix A, Table 3A. Steps of the WASPAS method (Alinezhad and Khalili, 2019) can be written as below:

Step 1. Form initial decision matrix by the aggregated evaluation score from the experts is organized using Equation (5).

$$X = \left[r_{11} \ \vdots \ r_{i1} \ \cdots \ r_{1j} \ \cdots \ \ddots \vdots \ddots \ \cdots \ r_{ij} \ \ldots \ r_{1n} \ \vdots \ r_{in} \ \vdots \ddots \vdots \ddots \vdots \ r_{m1} \ \cdots \ r_{mj} \ \ldots \ r_{mn} \right] \ ; \ i=1, \ldots, m \quad j=1, \ldots, n \tag{5}$$

Step 2. Normalizing the decision matrix is formed by using Equation (6) (for the beneficial criterion) and Equation (7) (for the non-beneficial criterion).

$$\bar{r}_{ij} = \frac{r_{ij}}{r_{ij}^{max}} \tag{6}$$

$$\bar{r}_{ij} = \frac{r_{ij}^{min}}{r_{ij}} \tag{7}$$

Step 3. Determine additive relative importance (ARI) by using Equation (8) and multiplicative relative importance

(MRI) by using Equation (9).

$$Q_i^{(1)} = \sum_{j=1}^{n} \quad \bar{r}_{ij} W_j \;; \qquad i = 1, \ldots, \mathrm{m} \tag{8}$$

$$Q_i^{(2)} = \prod_{j=1}^{n} \quad \bar{r}_{ij}^{\;(W_j)} \;; \qquad i = 1, \ldots, \mathrm{m} \tag{9}$$

Here, $Q_i^{(1)}$ denotes ARI; $Q_i^{(2)}$ denotes MRI; W_j denotes criteria weights obtained from Equation (4).

Step 4. Final evaluation scores of the fire risk remedial actions can be obtained from Equation (10), Whereas Equation (11) can be used for checking the accuracy of the finalized evaluation score.

$$Q_i = \frac{1}{2}(Q_i^{(1)} + Q_i^{(2)}) \tag{10}$$

$$Q_i = \lambda Q_i^{(1)} + (1 - \lambda) Q_i^{(2)} \tag{11}$$

Here, Q_i is the finalized evaluation score for prioritizing. The value of λ can be changed in a range of 0 to 1 to examine the sensitivity of the result.

3.3 Calculations

Calculated weights of the criteria by the SWARA method can be found in Table 5 and Figure 1.

Table 5. Weights of the criteria

Order of Preference	Criteria	p_j	s_j	k_j	q_j	wj
1	C1	0.814	---	1.000	1.000	**0.265**
2	C4	0.752	0.062	1.062	0.942	**0.250**
3	C2	0.728	0.024	1.024	0.920	**0.244**
4	C3	0.714	0.014	1.014	0.907	**0.241**

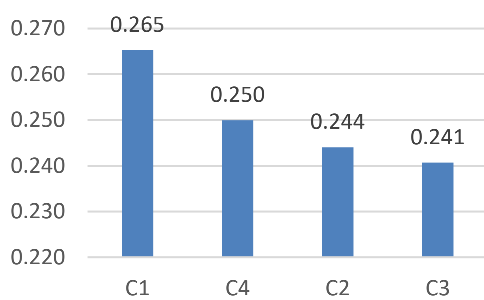

Figure 1. Criteria Weights

The initial decision matrix by aggregating experts' evaluations to apply the WASPAS method is shown in Table 6. A simple geometric mean operation is used to aggregate the evaluation scores from 15 experts. The normalized matrix obtained from the initial decision matrix can be found in Table 7.

Table 6. Initial decision matrix

	C1	C2	C3	C4

Table 7. Normalized matrix

	C1	C2	C3	C4
R1	0.375	0.466	1.000	0.803

R1	2.913	3.889	4.876	3.799
R2	3.128	3.017	3.034	3.814
R3	4.930	4.942	3.099	4.143
R4	4.675	2.457	2.786	4.597
R5	1.092	1.991	3.891	3.996
R6	4.112	3.102	2.987	3.109
R7	4.798	1.811	3.888	4.732
R8	3.123	2.910	4.131	3.945
R9	4.678	3.792	4.777	4.704
R10	4.121	3.884	3.894	2.831
R11	4.678	2.013	3.099	4.195
R12	4.609	4.872	2.139	4.292
R13	3.805	3.007	4.781	3.669
R14	3.809	4.250	1.839	3.710
R15	4.833	2.794	1.800	4.557
R16	3.932	3.664	3.219	4.287

R2	0.349	0.600	0.622	0.806
R3	0.222	0.366	0.636	0.876
R4	0.234	0.737	0.571	0.971
R5	1.000	0.910	0.798	0.844
R6	0.266	0.584	0.613	0.657
R7	0.228	1.000	0.797	1.000
R8	0.350	0.622	0.847	0.834
R9	0.233	0.478	0.980	0.994
R10	0.265	0.466	0.799	0.598
R11	0.233	0.900	0.636	0.887
R12	0.237	0.372	0.439	0.907
R13	0.287	0.602	0.981	0.775
R14	0.287	0.426	0.377	0.784
R15	0.226	0.648	0.369	0.963
R16	0.278	0.494	0.660	0.906

Computed ARI, MRI, combined final evaluation score, and the prioritization of the fire risk remedial actions achieved from the WASPAS method can be found in Table 8. Figure 2 depicts a graphical presentation of the finally obtained prioritization score.

Table 8. ARI, MRI, Combined score, and prioritization

Code	ARI	MRI	Combined score	Prioritization
R1	0.653	0.604	0.629	4
R2	0.589	0.563	0.576	9
R3	0.516	0.452	0.484	14
R4	0.619	0.546	0.583	8
R5	0.891	0.887	0.889	1
R6	0.524	0.493	0.509	11
R7	0.746	0.639	0.692	2
R8	0.656	0.618	0.637	3
R9	0.660	0.561	0.611	7
R10	0.526	0.486	0.506	13
R11	0.655	0.576	0.616	6
R12	0.481	0.426	0.453	15
R13	0.653	0.592	0.622	5
R14	0.463	0.431	0.447	16
R15	0.544	0.470	0.507	12
R16	0.576	0.527	0.552	10

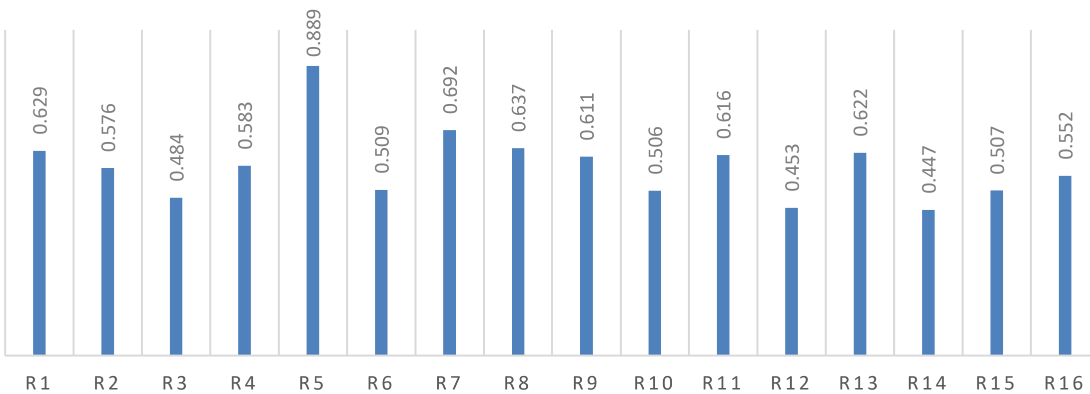

Figure SEQ Figure * ARABIC 2: Prioritization of the fire risk remedial actions

For checking the consistency of the prioritization, a sensitivity analysis has been performed for six different values of λ (0, 0.2, 0.4, 0.6, 0.8, 1.0). Obtained 6 prioritization scores and ranks can be found in Table 9. Figure 3 presents the relative comparison.

Table 9. Comparing the prioritization scores and ranks for different values of λ

	λ = 0.00		λ = 0.20		λ = 0.40		λ = 0.60		λ = 0.80		λ = 1.00	
Code	**Score**	**Rank**	**Score**	**Rank**	**Score**	**Rank**	**Score**	**Rank**	**Score**	**Rank**	**Score**	**Rank**
R1	0.604	4	0.614	4	0.624	4	0.633	4	0.643	4	0.653	6
R2	0.563	7	0.568	8	0.573	9	0.578	9	0.583	9	0.589	9
R3	0.452	14	0.465	14	0.478	14	0.491	14	0.503	14	0.516	14
R4	0.546	9	0.56	9	0.575	8	0.59	8	0.605	8	0.619	8
R5	0.887	1	0.888	1	0.889	1	0.889	1	0.89	1	0.891	1
R6	0.493	11	0.499	11	0.505	11	0.512	12	0.518	12	0.524	13
R7	0.639	2	0.66	2	0.682	2	0.703	2	0.724	2	0.746	2
R8	0.618	3	0.625	3	0.633	3	0.641	3	0.648	3	0.656	4
R9	0.561	8	0.581	7	0.601	7	0.62	7	0.64	6	0.66	3
R10	0.486	12	0.494	12	0.502	12	0.51	13	0.518	13	0.526	12
R11	0.576	6	0.592	6	0.608	6	0.623	6	0.639	7	0.655	5
R12	0.426	16	0.437	16	0.448	15	0.459	15	0.47	15	0.481	15
R13	0.592	5	0.604	5	0.616	5	0.628	5	0.641	5	0.653	7
R14	0.431	15	0.438	15	0.444	16	0.45	16	0.457	16	0.463	16
R15	0.47	13	0.485	13	0.499	13	0.514	11	0.529	11	0.544	11
R16	0.527	10	0.537	10	0.547	10	0.557	10	0.566	10	0.576	10

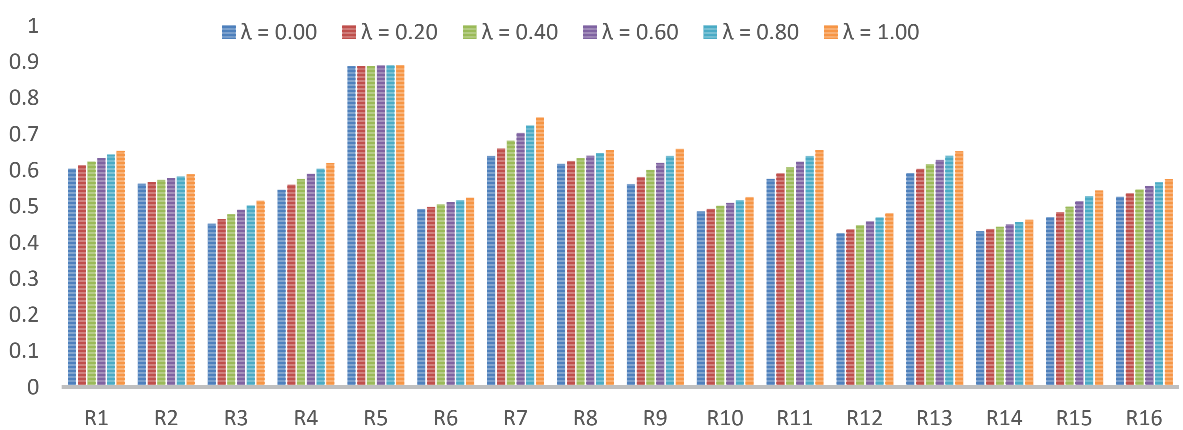

Figure SEQ Figure * ARABIC 3: Comparison of the prioritization scores and ranking for different values of λ

4. Results and Discussions

This study determines the weights of the criteria by SWARA method as Initial Cost (0.265) > Risk Reductant (0.250) > Maintenance Cost (0.244) > Feasibility (0.241) (see Table 5 and Figure 1). The experts evaluated the 'initial cost' as the topmost weighted criterion to prioritize the risk remedial actions. This seems very logical, given the fact that in an emerging economy like Bangladesh, the resource is very limited. 'Risk reductant' has been weighted as the second most prioritized criterion in this study. This is reasonable since it is always important for decision-makers to think of the prospective risk-reducing ability of a remedial action before implementing a new practice or a new installation. Factory owners and factory managers are always conscious about the way they are going to invest their capital. 'Maintenance cost' and 'feasibility' of a remedial action come next to the criteria weighting. Maintenance cost is a lifetime cost for an implemented practice or installation. As this is a permanent cost after initiating a remedial action, this will become a part of the regular budget planning. Therefore, management can be prepared for this cost with proper scheduling and need not be worried about investing a large amount of capital at a time like the initial cost. Similarly, 'feasibility' analysis is important to implement remedial action, to make sure of its practicality. Thereby, the weights obtained from this study align with the socio-economic reality of a developing country like Bangladesh.

This study finds the prioritization of the fire risk remedial actions as R5> R7> R8> R1> R9> ……> R3> R12> R14 (see Table 8 and Figure 2). Proper electrical wiring and connections, separating the gas cylinders from the main production building, keeping egress paths and stairs clear of obstruction, ensuring ITM of fire safety devices, and ensuring the use of certified fire doors are the top 5 prioritized fire risk remedial actions obtained from this research. Previous studies found that electrical fires are the most frequently seen hazardous incident in RMG factories (Hasan et al., 2017; Haque et al., 2017). Fire safety inspections in the factories always have some findings of the negligence of maintaining proper electrical safety. Therefore, implementing proper electrical wiring and connection and electrical safety practice can reduce the fire risk by a significant level. Compressed natural gas (CNG) cylinders are used in the RMG factories mainly as a source of fuel for electricity generation with gas engines, steam generation with boilers for ironing clothes, and running thermal oil heaters in the textile section.

As CNG is highly combustible, releasing gas will intensify and propagate fire during a fire incident, creating an uncontrollable fire hazard that is difficult to extinguish. CNG cylinders are also very explosion-prone when they come into contact with a heat source. Therefore, after ensuring electrical safety, this study prioritizes the separation of CNG cylinders from the main production building as a part of the fire risk remedial action. Previous studies showed that evacuation situations of the RMG factories are not very well planned, which can cause a lot of death in case of a serious fire incident (Nilufar and Choiti, 2019; Khandoker et al., 2018). The production floor, storage, and egress paths of RMG factories are very congested due to space constraints. Therefore, after implementing the remedial actions related to the cause of the fire (electrical) and fire propagation (gas cylinder), ensuring safe evacuation comes as the priority for fire risk remediation. Proper inspection, testing, and maintenance (ITM) of the fire safety devices and installing fire doors are part of sustainable development and standardized best practice in the field of fire safety in any industry. Proper ITM can activate the fire detection and protection devices smoothly when a fire incident takes place. Besides this, fire doors are necessary for creating fire separation. Fire safety specialists always emphasize fire separation for obstructing the fire propagation from the source and properly manufactured fire doors can act as an ideal fire separation. Therefore, implementing ITM and installing fire doors come up in the top prioritized fire risk remedial actions.

The sensitivity analysis performed in this study shows that the sequence of the top prioritized remedial actions is almost constant for different values of λ (see Table 9 and Figure 2). There is a little variation for some places in the prioritization list. However, after implementing the top prioritized remedial actions, the developed culture and situation will assist in the spontaneous implementation of the remaining actions. Therefore, this sensitivity analysis indicates the consistency of the result.

5. Managerial Implications

The results obtained from this study have been shared and discussed with some of the most experienced industrial safety experts in the RMG sector, to acquire an extended overview of the managerial implications of this study. Workplace safety and reputation are important for upholding sustainable success in this sector. However, the prime concern of the managers of the RMG sector is to obtain high productivity utilizing their limited resources. Remediating all the fire risk factors at the same time can be very expensive for these factories. Industrial managers of the RMG sector can utilize the framework developed in this study to implement fire risk remediation strategies hierarchically. This can allow them to implement the fire remedial actions gradually, one by one, without straining their available resources. This way this research is expected to help the managers of other similar industries as well to devise and implement their customized fire risk remedial plans.

6. Conclusion

This study has utilized a hybrid MCDM method-based framework to rank the fire risk remedial actions for the RMG industries of Bangladesh. The SWARA method has been applied for determining the criteria weights and the WASPAS method has been applied for finding the final prioritization of the actions in this framework. Initial cost and risk reductant ability of remedial action has been found to be the topmost weighted criteria in this study. This can be an interesting insight that can divert the attention of national and international policymakers in the right direction. While making fire risk remedial policy for a developing country like Bangladesh, they need to be more thoughtful about the initial implementing cost of remedial action, since the owners and the management of the RMG factories are always highly sensitive about the initial cost. Moreover, for initiating a safety program in a risk-prone but profitable industry like the RMG sector, policymakers should go for the most practical and risk-reductant remedial actions to inspire decision-makers.

From the results of the WASPAS method, proper electrical wiring, and connections, separating the gas cylinders from the main production building, keeping egress paths and stairs clear of obstruction, ensuring ITM of fire safety devices, and ensuring the use of certified fire doors, turned out to be the top-ranked fire risk remedial actions. The pattern of this result may seem interesting and insightful to the decision-makers of the RMG sector. At first, they should mitigate the prime cause of the fire (electrical fire), then they should reduce the cause of fire propagation (highly combustible materials), and later they should create an environment for proper evacuation (unobstructed egress). After implementing these three, they should go for the practices related to the sustainability of the implemented remedial actions (ITM practice and fire separation door). This pattern can help them to realize the true implications of this study and take effective decisions to ensure a safe work environment.

Future research can be conducted with some other combination of decision-making tools to perform a comparative study. More decision-makers can be involved in the decision-making procedure and decision-makers can be weighted based on their experience in the related field. More new evaluation criteria can be explored and incorporated in the future study criteria used in this study. Finding the correlation among the remediation actions can also be a good future research scope.

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Appendix A

Table 1A. Sample Questionnaire for SWARA (with Response from an Expert)

Question	Very Low	Low	Medium	High	Very High
How important is the criterion 'Initial Cost' to prioritize fire risk remedial actions for RMG factories?	☐	☐	☐	☐	☒
How important is the criterion 'Maintenance Cost' to prioritize fire risk remedial actions for RMG factories?	☐	☐	☒	☐	☐
How important is the criterion 'Feasibility' to prioritize fire risk remedial actions for RMG factories?	☐	☐	☒	☐	☐
How important is the criterion 'Risk Reductant' to prioritize fire risk remedial actions for RMG factories?	☐	☐	☐	☒	☐

Table 2A: Aggregated feedback and decimal scores of the experts' evaluation

	C1	C2	C3	C4
Expert 1	4	3	3	3
Expert 2	5	4	3	3
Expert 3	4	4	3	4
Expert 4	4	3	3	3
Expert 5	5	4	3	4
Expert 6	4	4	3	4
Expert 7	5	3	2	3
Expert 8	3	3	2	4
Expert 9	4	2	3	4
Expert 10	4	3	3	4
Expert 11	3	3	4	4
Expert 12	5	2	4	4
Expert 13	4	3	3	4
Expert 14	3	3	4	5
Expert 15	5	3	3	4
Aggregated Score	**4.068**	**3.069**	**3.010**	**3.760**
Decimal Score (p_j)	**0.814**	**0.614**	**0.602**	**0.752**

Table 3A: Sample evaluation from an expert to prioritize the fire risk remedial actions

Remedial Actions	C1	C2	C3	C4
R1	3	4	5	4
R2	3	3	3	4
R3	5	5	3	4
R4	5	3	3	5
R5	1	2	4	4
R6	4	3	3	3
R7	5	2	4	5
R8	3	3	4	4
R9	5	4	5	5
R10	4	4	4	3
R11	5	2	3	4
R12	5	5	2	4
R13	4	3	5	4
R14	4	4	2	4
R15	5	3	2	5
R16	4	4	4	4