Prioritization of the Electrical Risk Factors in the Ready-Made Garment Industries of Bangladesh: A Hybrid MCDM Approach

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Abstract

Electrical accidents wound and kill a lot of people in the ready-made garment (RMG) industries of Bangladesh every year. Regular electrical safety inspections and prioritization of the identified significant risk factors can effectively minimize the occurrence of these electrical accidents. This study proposes a Multi-Criteria Decision-Making (MCDM) based framework to prioritize the frequently observed significant electrical risk factors in the RMG industries of Bangladesh to aid the decision-makers to ensure a safe and sustainable workplace. In this study, 26 most significant electrical risk factors have been identified from the opinions of 12 experts who have analyzed the electrical safety inspection reports accumulated from 100 different RMG industries. After that, the Best Worst Method (BWM) has been applied to find the weights of the three evaluation criteria- Consequence, Likelihood, and Manageability, based on the expert feedback. Then, a Weighted Aggregated Sum Product Assessment (WASPAS) method has been utilized to get the final ranking of the risk factors. The existence of hot spots detected by thermal imaging, improper support and protection for hanging cables, and heat source adjacent to electrical installations have been determined as the most prioritized electrical risk factors for the RMG industries. The findings of this research are expected to help the managers and other decision-makers of RMG industries to devise effective mitigation strategies to minimize the electrical safety risks efficiently and hierarchically.

Keywords
Ready-made Garment, Electrical Risk Factors, Best Worst Method, Weighted Aggregated and Sum Product Assessment

1. Introduction

RMG sector of Bangladesh is one of the largest manufacturing sectors in the world, consisting of around 4.4 million people working in more than 4500 industries (Fathi, 2021; Statista, 2021). This is also one of the accident-prone industries which have faced many injurious and fatal accidents in the last three decades. Fatality from the electrical and chemical fire incidents is the highest, compared to other workplace hazards, in this sector (Hasan et al., 2017). Such a noteworthy accident is the fire incident in the Tazreen Fashions Ltd. in 2012 due to an electrical fault, which was one of the deadliest accidents in the country's history causing more than 100 deaths and more than 300 injuries (Wiersma, 2018). Studies show that most of the fire incidents in

RMG industries are caused by electrical faults, and more than 50% of the safety risks found during safety inspections by inspecting authorities are electrical issues (Islam et al., 2019; Moazzem et al., 2018; Haque et al., 2017). Local and international policymakers and researchers are continuously working to establish a safe and sustainable working environment in the RMG sector by minimizing fire and other hazards due to electrical faults. Since 2013, the establishment of the 'Accord' on fire and building safety in Bangladesh as a safety inspecting regulatory organization for around 1700 RMG industries has reduced such accidents significantly, compared to the previous years (Wiersma, 2018; Accord, 2021). However, there are still many industries that are still not under this agreement. A methodological study on the electrical risk factors can be helpful for the overall RMG sector to minimize electrical and fire-related hazards, especially given that no other researchers addressed this issue previously.

Though each of the electrical risk factors can cause severe damage to life and property, it is not always possible for the decision-makers to mitigate all the risk factors at the same time, due to the constrained resource and various managerial obstacles. Therefore, prioritization of the electrical risk factors can be beneficial for the decision-makers, as it allows them to devise an efficient hierarchical mitigation approach, which is more practical and less expensive than trying to mitigate all the risk factors at the same time.

Previous studies have discussed various electrical safety concerns with different qualitative and quantitative approaches. There are several studies, which have discussed different electrical safety concerns regarding RMG industries as well. For example, the approach to conducting an electrical safety inspection in an RMG industry has been discussed descriptively in a theoretical study (Hossain and Salam, 2015; Moazzem et al., 2018; Bhuiyan et al., 2018), the relation between temperature rise and load in electrical installations of RMG industries has been analyzed with thermographic test (Islam et al., 2017), cause-effect relations of the deadly incidents of RMG industry have been analyzed with a statistical presentation of historical data (Hasan et al., 2017), burn incidents because of electrical faults have been predicted applying probabilistic method (Haque et al., 2017), electrical risk index for the RMG industries has been developed based on the electrical inspection findings (Islam et al., 2019). Various aspects of electrical inspection and electrical safety in different industries and appliances other than RMG industries have also been explored in some other recent studies (Anderson et al., 2021; Charoenchit and Thongchaisuratkrul, 2021; Reddy, 2019; Araneo et al., 2019; Neitzel, 2018). However, none has yet tried to prioritize the electrical risk factors of RMG industries through any MCDM approach, which presents a clear research gap that is worthy of exploration. Considering this gap in the literature, this research aims to determine the weights of the risk evaluation criteria by BWM based on experts' opinions, then use the WASPAS method to prioritize the electrical risk factors.

BWM is relatively a modern MCDM technique to determine criteria weights by the subjective evaluation of the decision-makers (Gani et al., 2021; Ma et al., 2021). This method is less complex to be utilized compared to most other pairwise comparison-based MCDM techniques, to calculate the weights of the evaluation criteria (Rezaei, 2015). WASPAS is another modern MCDM technique, which is a combination of the Weighted Sum Model (WSM) and Weighted Product Model (WPM) and can be more effective than solely using classic WSM or WPM (Jayant et al., 2019; Mihajlović et al., 2019).

This study aims to utilize both BWM and WASPAS in a combined approach. At first, electrical inspection reports from randomly selected 100 RMG industries were accumulated from the website of Accord (https://bangladeshaccord.org/industries), which were then sent to 12 industrial electrical safety experts. Next, 26 most significant electrical risk factors have been extracted from the selected reports based on the experts' feedback. Then, based on the subjective evaluation of the experts, the weights of the risk evaluation criteria have been determined by BWM. Later, WASPAS has been used to get the final ranking of the risk factors, which utilizes the evaluation criteria weights obtained from the BWM method. Thereby, in short, this study intends to achieve the following research objectives:

a) To identify the risk evaluation criteria and the significant electrical risk factors of RMG industries from the expert feedback.
b) To find evaluation criteria weights by using the BWM method, using the expert feedback.
c) To rank the electrical risk factors by WASPAS method, utilizing the criteria weights obtained from the BWM method

The rest of the paper is divided into the following sections: Section 2 discusses the literature review. Section 3 depicts the research methodologies, and calculations. Section 4 discusses the obtained results. Section 5 describes the managerial implications of the study. Finally, Section 6 is for discussing the conclusion and some future research directions.

2. Literature Review

Electrical safety inspections are conducted in a structured way, to minimize the risk of electrical hazards and improve the productivity of the industry by reducing unwanted accidents, breakdowns, and property damage (Hossain and Salam, 2015). Electrical and other safety inspection scopes and findings in RMG industries by different regulatory organizations have been explored with different qualitative and descriptive statistical methods in some the recent studies (Rose, 2021; James et al., 2019; Hasan et al., 2019; Moazzem et al., 2018; Bhuiyan et al., 2018; Hasan et al., 2017). However, none attempted to prioritize the electrical risk factors using any MCDM methods.

Islam et al. (2019) presented an electrical risk indexing (ERI) method, following the existing fire risk indexing method, to evaluate some randomly selected RMG industries. The main drawback of that method was there was no methodological approach to get the weights of the risk factors, rather the inspection findings were weighted randomly. Moreover, the electrical risk factors were not prioritized in a hierarchical order. Haque et al. (2017) only emphasized the faulty electrical connections to predict burn incidents with a statistical approach. Their study utilized an empirical probability method to describe a prediction framework but did not try to prioritize the electrical risk factors.

Besides research on electrical hazards in the RMG sector, there are some other works in recent literature on electrical hazards, inspection, and safety. For instance - Islam et al. (2017) emphasized thermal imaging test results to find the correlation between temperature rise and electrical load. Neitzel (2018) highlighted the importance and different aspects of electrical safety training for all the personnel of the industry in a theoretical study. Araneo et al. (2019) described some probable hazardous situations in academic or research laboratories with preventive action plans. Reddy (2019) discussed some causes of electrical accidents with mitigation techniques.

Some works applied a descriptive statistical approach, such as Charoenchit and Thongchaisuratkrul (2021) presented electrical safety inspection findings from two paper-manufacturing industries and two animal food-manufacturing industries; Anderson et al., (2021) presented globally electrical accidents data from engineering, procurement, and construction industry occurred in last 10 years, and so on. However, none of those works came up with the idea of prioritizing electrical risk factors, which is the main aim of this study.

This ongoing study has utilized two MCDM techniques- BWM and WASPAS. BWM has been used in various recent decision-making-related studies, where experts' feedback has been used to find criteria weights. For instance - Ali and Rashid (2021) utilized BWM for industrial robot selection, Gani et al. (2021) used BWM to identify, rank, and prioritize the indicators behind environmental sustainability, Mostafaeipour et al. (2021) applied BWM to prioritize the barriers for solar energy development, Ecer (2021) used BWM to access sustainability of some wind power plants, Ma et al. (2021) ranked the risks for water-saving management contract by BWM, and so on. WASPAS has also been used in many recent decision-making problems, Bid and Siddique (2019) assessed human risk factors of a river dam by the WASPAS method, Pathapalli et al. (2020) used WASPAS to find the optimized machining parameters for a composite material, Jayant et al. (2019) utilized WASPAS to solve a supplier selection problem for the battery manufacturing industry, Mihajlović et al. (2019) selected the best location for logistic distribution center by WASPAS method, and Tuş and Adalı (2019) applied WASPAS method in a software selection problem. However, no previous research utilized a combined BWM-WASPAS method so far to prioritize electrical risk factors of RMG industries, which justifies the novelty of the proposed study.

3. Research Methodology and Calculations

This study proposes a methodological approach to prioritize the most significant electrical risk factors in the RMG industries. The methodology of this study is explained below in 6 steps:

Step 1. Select a group of experts to get feedback at different stages of the study.

Step 2. Accumulate electrical inspection reports of randomly selected 100 RMG industries from the website of Accord (https://bangladeshaccord.org/industries) and provide them to the selected experts.
Step 3. Select risk evaluation criteria based on the experts' opinions, and existing literature.
Step 4. Sort out the most significant risk factors from the experts' feedback.
Step 5. Determine the subjective weight of the criteria by BWM based on the experts' evaluation.
Step 6. Utilize the weights from BWM in WASPAS to obtain the final ranking of the electrical risk factors.

A group of 12 industrial experts has been surveyed via Google forms to get their opinion and response at different steps of the study. A brief profile of the participating experts in this study can be found in Table 1.

Table 1. Participating experts' profile

Participating Experts (N=12)			
Professional Designations	**Experience**	**N**	**Percentage**
Electrical Engineers, Maintenance Managers, and Electrical Safety Engineers (N=12)	From 5 up to 10 years	6	50.00 %
	From 10 up to 15 years	4	33.33 %
	More than 15 years	2	16.67 %

3.1 Data Collection

Selected risk evaluation criteria to rank the electrical risk factors for this study are shown in Table 2.

Table 2. Evaluation criteria for prioritizing the electrical risk factors

Criteria	**Description**	**Source**
Consequence	The severity of a risk factor to create a potential hazard by burning or electrocuting a person can be measured by this criterion. The higher the consequence of a risk factor is, the more critical the factor. Therefore, this is a **direct or positive criterion** for this study.	Islam et al., 2019; Hasan et al., 2019; Mikulak et al., 2017
Likelihood	Frequency of observing a risky incident and the probability of occurring that event can be measured by this criterion. The higher the likelihood of a risk factor is, the more critical the factor. Therefore, this is a **direct or positive criterion** for this study.	Rose, 2021; Mikulak et al., 2017
Manageability	How much effort is needed to mitigate a risk factor can be measured by this criterion. Less effort means highly manageable or vice versa. Therefore, this is an **indirect or negative criterion** for this study.	Charkhakan and Heravi, 2018; Roberts, 2015

Most significant 26 electrical risk factors have been identified and enlisted by the experts by analyzing the electrical inspection reports from randomly selected 100 RMG industries in Bangladesh. Those reports were generated by Accord after conducting field inspections by the electrical safety engineers at more than 1700 industries. The list of the identified electrical risk factors can be seen in Table 3.

Table 3: List of identified electrical risk factors

Factor Code	**Risk Factors**
RF1	Overloaded cable tray with excessive cables
RF2	Fluffs and dust-filled cable channels
RF3	Improper support and protection for hanging cables
RF4	Inadequate maintenance clearance
RF5	Irregular or no resistance test of earth pit
RF6	Existence of hot spots detected by thermal imaging
RF7	Irregular or no thermographic survey
RF8	Irregular or no resistance test on the cable insulations
RF9	Congested bus bars touching power cables of another phase

RF10	Improper Personal Protective Equipment (PPE) and electrical tools for maintenance personnel
RF11	No Lightning Protection System (LPS) for high-risk indexed structure
RF12	Absence of electrical safety training program
RF13	The discrepancy between field information and the existing Single Line Diagram (SLD)
RF14	Buried power cable in the concrete floor
RF15	Absence of arcing horn in the transformer
RF16	Heat source adjacent to electrical installations
RF17	Low oil level in transformer conservator tank
RF18	Merged LPS earthing with main electrical system earthing
RF19	Non-segregated earth connections for different electrical installations
RF20	Inadequate number of earth pits
RF21	Improper earthing connection for electric machines
RF22	No Lock-Out-Tag-Out (LOTO) policy during maintenance work
RF23	The unterminated live wire inside the electrical panel
RF24	Distribution circuit board adjacent to a water source
RF25	The discrepancy between installed circuit breakers (CB) capacity and load demand
RF26	Connected cables to busbar and circuit breaker terminals without cable lug

3.2 BWM

A questionnaire-based survey needs to be responded to by the experts to apply BWM to determine the weights of the evaluation criteria. Detailed methods (Rezaei, 2015) of BWM are as follows:

Step 1. The best (most important electrical risk factor prioritizing criterion) and the worst (least important electrical risk factor prioritizing criterion)) are nominated by all the experts separately.

Step 2. The severity of the best criterion over other criteria is decided on a scale of 1 to 9 rated by all the experts separately. Here, 1 is for 'equal' and 9 is for 'extreme'. The mathematical expression of the 'Best to Others' relation for the Mth expert is shown in Equation (1).

$$X_B^M = \left(x_{b1}^m, x_{b2}^m, \ldots, x_{bj}^m\right) \quad (1)$$

where, x_{bj}^m shows the importance of the best criterion compared to other criteria.

Step 3. Following Step 2, the 'Others to Worst' relation is decided where the importance of all other criteria over the least important criterion is figured out. Mathematically, for the Mth expert, this relation is as shown in Equation (2).

$$X_W^M = \left(x_{1w}^m, x_{2w}^m, \ldots, x_{jw}^m\right) \quad (2)$$

where, x_{jw}^m shows the importance of any other criterion compared to the worst criterion.

Step 4. Optimal weights of the criteria are computed by solving a linear programming problem as below-

$$Min\ \xi^L$$

Subject to,

$$\left|W_B^M - x_{bj}^m W_J^M\right| \leq \xi^L \quad \text{for all } j \quad (3)$$

$$\left|W_J^M - x_{jw}^m W_W^M\right| \leq \xi^L \quad \text{for all } j \quad (4)$$

$$\sum_j W_J^M = 1 \quad (5)$$

$$W_J^M \geq 0 \text{ for all } j \quad (6)$$

Here, according to the Mth expert, W_B^M is the weight of the best criterion, W_W^M is the weight of the worst criterion, and W_J^M is the weight of any other criterion. Weights $\left(W_1^M, W_2^M, \ldots, W_J^M\right)$ are calculated by solving equations (3) to (6), minimizing the value of ξ^L. The closer the value of ξ^{L*} (Ksi*) is to 0, the more consistent the weights are.

Step 5. Weights of the criteria obtained from all the experts are aggregated by using the geometric mean

(GM) shown in Equation (7).

$$\text{GM} = \bar{W_j} = \sqrt[M]{W_J^{\ 1} W_J^{\ 2} \cdots W_J^{\ M}} \qquad (7)$$

Step 6. Normalization of the aggregated weights for each criterion is done using Equation (8)

$$\text{W}_c = \frac{\bar{W_j}}{\Sigma_{J=1}^{J} \bar{W_j}} \qquad (8)$$

3.3 WASPAS

Experts are needed to respond to a questionnaire where a 5-point Likert scale (see Table 4) can be used for the evaluation of the identified risk factors.

Table 4: 5-point Likert scale for the evaluation of the electrical risk factors

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

Details method of WASPAS (Alinezhad and Khalili, 2019) are as follows:

Step 1. Decision-matrix is formed by the aggregated evaluation score from the experts as shown in Equation (9).

$$X = \begin{bmatrix} r_{11} & \cdots & r_{1j} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ r_{i1} & \cdots & r_{ij} & \cdots & r_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mj} & \cdots & r_{mn} \end{bmatrix}; \qquad i=1, \ldots, \text{m} \qquad j=1, \ldots, \text{n} \qquad (9)$$

Step 2. Normalization of the decision-matrix is done by using Equation (10) for positive or direct criteria and Equation (11) has been used for calculating the negative or indirect criterion.

$$\bar{r}_{ij} = \frac{r_{ij}}{r_{ij}^{\max}} \qquad (10)$$

$$\bar{r}_{ij} = \frac{r_{ij}^{\min}}{r_{ij}} \qquad (11)$$

Step 3. Additive relative importance (ARI) is determined using Equation (12) and multiplicative relative importance (MRI) is determined with Equation (13) from the obtained normalized decision-matrix in step 2.

$$Q_i^{(1)} = \sum_{j=1}^{n} \bar{r}_{ij} W_c\,; \qquad i = 1, \ldots, \text{m} \qquad (12)$$

$$Q_i^{(2)} = \prod_{j=1}^{n} \bar{r}_{ij}{}^{(W_C)}\,; \qquad i = 1, \ldots, \text{m} \qquad (13)$$

Here, $Q_i^{(1)}$ denotes additive relative importance; $Q_i^{(2)}$ denotes multiplicative relative importance; W_c denotes criteria weights obtained from Equation (8).

Step 4. A combined evaluation score can be obtained from Equation (14), Whereas Equation (15) can be used for increasing the accuracy of the finalized evaluation score.

$$Q_i = \frac{1}{2}(Q_i^{(1)} + Q_i^{(2)}) \qquad (14)$$

$$Q_i = \lambda Q_i^{(1)} + (1 - \lambda) Q_i^{(2)} \qquad (15)$$

Here, Q_i is the finalized evaluation score for prioritizing the electrical risk factors. The value of λ can be changed in a range of 0 to 1 to check the accuracy of the obtained score.

3.4 Calculations

A sample of the survey questionnaire for applying BWM and a response from an expert can be found in Table 1A in Appendix A. Calculated weights of the criteria using the feedback from 12 experts can be found in Table 5 and Figure 1.

Table 5: Weights of the evaluation criteria determined by BWM

	Consequence	Likelihood	Manageability	Ksi*
Expert-1	0.500	0.200	0.300	0.100
Expert-2	0.542	0.167	0.292	0.042
Expert-3	0.550	0.200	0.250	0.050
Expert-4	0.400	0.400	0.200	0.000
Expert-5	0.292	0.167	0.542	0.042
Expert-6	0.292	0.167	0.542	0.042
Expert-7	0.292	0.542	0.167	0.042
Expert-8	0.542	0.167	0.292	0.042
Expert-9	0.286	0.143	0.571	0.000
Expert-10	0.292	0.167	0.542	0.042
Expert-11	0.229	0.143	0.629	0.057
Expert-12	0.385	0.462	0.154	0.077
Weights	**0.366**	**0.216**	**0.333**	
Normalized Weights	**0.400**	**0.236**	**0.364**	

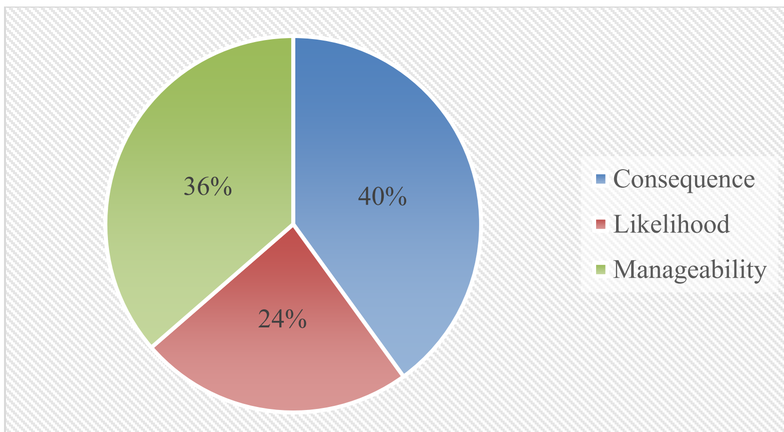

Figure 1. Percentage weights of the evaluation criteria determined by BWM

For applying WASPAS, a Sample response for the evaluation of the electrical risk factors from an expert using the Likert scale (see Table 4) can be found in Table 2A in Appendix A. The initial decision matrix can be found in Table 6 which has been formed by aggregating the evaluation scores of 12 experts.

Table 6. Initial decision matrix by aggregated evaluation scores of 12 experts

	Consequence	Likelihood	Manageability
RF1	4.08	4.08	3.08
RF2	3.92	3.08	4.92
RF3	4.92	2.92	1.75
RF4	3.83	2.92	1.83
RF5	3.08	3.08	4.92
RF6	4.92	4.92	1.75
RF7	3.75	3.08	4.08
RF8	4.08	2.92	3.92
RF9	4.92	4.08	3.92
RF10	4.08	1.92	4.08
RF11	4.17	1.75	3.75
RF12	4.08	3.17	3.75
RF13	2.83	4.17	4.75

	Consequence	Likelihood	Manageability
RF14	4.92	4.08	3.08
RF15	3.83	1.08	4.83
RF16	4.92	4.92	2.92
RF17	3.92	1.83	4.83
RF18	4.83	1.17	4.75
RF19	4.08	2.08	3.75
RF20	2.75	1.92	3.83
RF21	4.08	3.08	3.83
RF22	4.92	4.08	2.92
RF23	4.92	4.17	4.92
RF24	3.92	2.83	3.08
RF25	3.75	3.92	4.92
RF26	3.08	3.75	3.83

For aggregation, simple arithmetic mean has been utilized. The normalized decision matrix which has been computed from the initial decision matrix can be found in Table 7.

Table 7. Normalized decision-matrix

	Consequence	Likelihood	Manageability
RF1	0.829	0.829	0.568
RF2	0.797	0.626	0.356
RF3	1.000	0.593	1.000
RF4	0.778	0.593	0.956
RF5	0.626	0.626	0.356
RF6	1.000	1.000	1.000
RF7	0.762	0.626	0.429
RF8	0.829	0.593	0.446
RF9	1.000	0.829	0.446
RF10	0.829	0.390	0.429
RF11	0.848	0.356	0.467
RF12	0.829	0.644	0.467
RF13	0.575	0.848	0.368

	Consequence	Likelihood	Manageability
RF14	1.000	0.829	0.568
RF15	0.778	0.220	0.362
RF16	1.000	1.000	0.599
RF17	0.797	0.372	0.362
RF18	0.982	0.238	0.368
RF19	0.829	0.423	0.467
RF20	0.559	0.390	0.457
RF21	0.829	0.626	0.457
RF22	1.000	0.829	0.599
RF23	1.000	0.848	0.356
RF24	0.797	0.575	0.568
RF25	0.762	0.797	0.356
RF26	0.626	0.762	0.457

Calculated additive relative importance, multiplicative relative importance, and the combined evaluation score by applying WASPAS from the normalized decision matrix can be found in Table 8.

Table 8. ARI, MRI, and Combined evaluation score

	ARI	MRI	Combined Score	Prioritization
RF1	0.734	0.723	0.729	8
RF2	0.596	0.561	0.579	18
RF3	0.904	0.884	0.894	2
RF4	0.799	0.787	0.793	5
RF5	0.528	0.510	0.519	24
RF6	1.000	1.000	1.000	1
RF7	0.609	0.590	0.600	15
RF8	0.634	0.612	0.623	13
RF9	0.758	0.714	0.736	7
RF10	0.580	0.546	0.563	20
RF11	0.593	0.556	0.574	19
RF12	0.654	0.634	0.644	11
RF13	0.564	0.536	0.550	21

	ARI	MRI	Combined Score	Prioritization
RF14	0.803	0.779	0.791	6
RF15	0.495	0.437	0.466	26
RF16	0.854	0.830	0.842	3
RF17	0.538	0.500	0.519	23
RF18	0.583	0.492	0.537	22
RF19	0.601	0.574	0.588	17
RF20	0.482	0.477	0.480	25
RF21	0.646	0.625	0.635	12
RF22	0.814	0.794	0.804	4
RF23	0.730	0.660	0.695	9
RF24	0.661	0.652	0.657	10
RF25	0.623	0.584	0.603	14
RF26	0.597	0.585	0.591	16

For checking the accuracy of the prioritization following step 4 of WASPAS (see equations (14) and (15)), a sensitivity analysis has been performed for six different values of λ (0, 0.2, 0.4, 0.6, 0.8, 1.0), which are calculated by using Equation (15). This way, 6 different rankings are obtained, which are shown in Table 9.

Table 9. Comparing risk factor prioritizations for 6 different values of λ

	λ= 0.0	λ= 0.2	λ= 0.4	λ= 0.6	λ= 0.8	λ= 1.0
RF1	7	7	8	8	8	8
RF2	18	18	18	18	18	18
RF3	2	2	2	2	2	2
RF4	5	5	5	5	6	6
RF5	22	22	23	24	24	24
RF6	1	1	1	1	1	1
RF7	14	14	15	15	15	15
RF8	13	13	13	13	13	13
RF9	8	8	7	7	7	7

	λ= 0.0	λ= 0.2	λ= 0.4	λ= 0.6	λ= 0.8	λ= 1.0
RF14	6	6	6	6	5	5
RF15	26	26	26	26	25	25
RF16	3	3	3	3	3	3
RF17	23	24	24	23	23	23
RF18	24	23	22	22	21	20
RF19	17	17	17	17	16	16
RF20	25	25	25	25	26	26
RF21	12	12	12	12	12	12
RF22	4	4	4	4	4	4

RF10	20	20	20	20	20	21	RF23	9	9	9	9	9	9
RF11	19	19	19	19	19	19	RF24	10	10	10	10	10	10
RF12	11	11	11	11	11	11	RF25	16	15	14	14	14	14
RF13	21	21	21	21	22	22	RF26	15	16	16	16	17	17

4. Results and Discussions

This study determines the weights of the evaluation criteria for electrical risk factors prioritization by BWM as (see Table 5 and Figure 1) Consequence (0.400)> Manageability (0.364)> Likelihood (0.236). As the consequence of not addressing an electrical risk factor can be extremely severe, most experts have evaluated 'consequence' as the most important criterion of all. 'Manageability' criterion is related to the amount of effort needed for remediation of a risk factor and 'likelihood' is related to occurrence frequency. If the manageability of a risk factor improves, the likelihood decreases spontaneously. Thereby, most of the experts have emphasized manageability over likelihood.

For this study, subjective judgment has been made by the practical experience of the experts. Based on the experts' feedback, WASPAS determines a prioritization order of the risk factors as RF6> RF3> RF16> RF22> RF4>……> RF17> RF5> RF20> RF15 (see Table 8). According to the obtained results from Table 8, the existence of hot spots detected by thermal imaging (RF6), improper support and protection for hanging cables (RF3), heat source adjacent to electrical installations (RF16), no Lock-Out-Tag-Out (LOTO) policy during maintenance work (RF22), inadequate maintenance clearance (RF4) are the top five prioritized electrical risk factors for RMG industries.

If overheated zones are observed during the testing of electrical installations by thermal imaging, it can be the most safety issue for the industry. Hot spots are not identifiable visually, but thermal images can identify the hot spots since it uses infrared technology. Hot spots are mainly observed if the electrical load exceeds the capacity limit of the conductive wire. This can be dangerous, as it can trigger electrical fire at any time. Improper support and protection for the hanging cables is another the most significant electrical risk factor in the RMG industries of Bangladesh. Sometimes, there is a lack of awareness in the management, which can lead to overlooking this issue. But this can be very dangerous, since tearing a live wire can create a short-circuit, which consequently causes a fire hazard. Adjacent heat sources like boilers, pumps, compressors, steam lines for ironing clothes, etc. near electrical installations can also cause severe fire incidents. So, the top three prioritized findings according to this study are related to an electrical fire. The remaining two risk factors of the top five positions of the prioritized list are related to electrocution hazards as well as severe damage to the machinery. The absence of a LOTO policy can create devastating situations by causing a communication gap between the operation and maintenance personnel. In an under-maintenance or disconnected machine, sudden restoration of electrical energy without checking the condition of the wirings is an outcome of not having a LOTO policy. Inadequate maintenance clearance around electrical installations makes the maintenance job risky and tiresome. Again, wrong electrical connections and incomplete repair by fatigued persons can also create dangerous electrical accidents.

The accuracy checking calculation for this study (see Table 9) shows that the obtained prioritized scores in Table 8 (which is basically the ranking obtained for λ= 0.50) are almost similar to the obtained prioritized scores for different values of λ. This is an important indicator of the consistency of the obtained result from this study. The prioritized risk factors of this study were also identified as the most severe electrical safety issues by different previous research works reviewed earlier in this paper, which can be considered as a validation of the obtained result before implementing it in an industrial setting.

5. Managerial Implications

Obtained results in this study have been discussed with several electrical maintenance managers and safety personnel to get a better understanding of the implications of this study. Industrial managers have various limitations and challenges, working within time and budget constraints, obtaining maximum productivity from man and machines, maintaining constant mobility and continuity of the production line, and so on. In these circumstances, mitigating all the electrical risk factors at the same time is very difficult. Managers need to be calculative and strategic to mitigate the risk factors one after another. In such situations, they can follow the ranking of the risk factors derived from this study to overcome the safety issues productively. The result shows that risk factors that are directly related to electric fire and electrocution need to be mitigated at first. From the results, it is quite evident that the willingness and awareness of the management can reduce the electrical risk factors of RMG industries to a significant extent. Industrial managers can utilize this study to generate hierarchical mitigation plans for other industrial safety issues in a systematic way, rather than going with their intuition or gut feeling, when it comes to taking important decisions related to worker safety.

6. Conclusion

This study implements a combined BWM-WASPAS approach to find the criteria weights and prioritize the electrical risk factors in the RMG sector. Most risk assessment studies deal with the two criteria- severity and likelihood, whereas this study considers three criteria. The criterion 'consequence' is almost similar to the criterion 'severity'. The main difference is that 'severity' deals with injuries or life risks whereas the 'consequence' criterion in this study deals with both life-threatening issues and other causatives of electrical hazards. Another interesting insight obtained from this study is that decision-makers have emphasized 'manageability' over 'likelihood' here, which was not considered as an evaluation criterion in other relevant studies on risk or hazard analysis. Therefore, 'manageability' should be considered an important criterion for different risk or hazard assessment studies from now on.

This study indicates that the management of RMG industries should be more aware of documentation, testing, and periodic maintenance to mitigate some of the top prioritized electrical risk factors like, hot spot detection in thermographic testing, implementing LOTO policy, and so on. Proper documentation can help in the development of a responsible workforce, which can minimize electrical risk factors, thus increasing the reputation of the industry. A common stereotype about electrical safety studies is that electrical shock or electrocution is the riskiest hazard caused by electricity. But the interesting finding from this study is that decision-makers prioritize the electrical risk factors most of which can initiate electrical fire. Future researchers can pick this finding as an important insight from this study. In a developing country like Bangladesh, managers need to be careful to utilize their limited resources. The study can assist them by showing a practical solution to mitigate the critical electrical risk factors in a step-by-step manner.

This study, however, has some limitations, which can be addressed in future research attempts. For instance, other MCDM techniques can also be applied here, and results can be compared for the same electrical risk factors to get a comparative overview. This study has considered only three evaluation criteria for the ranking of the risk factors. Other prospective evaluation criteria like probability, detectability, time frame, extent, cost, etc. can be included in future work. Showing the interrelations among the risk factors and their mitigation approach can also be considered to further extend this study in the future.

References

Accord., *The Bangladesh Accord on Fire and Building Safety.* Retrieved from https://bangladeshaccord.org/factories, 2021.

Alinezhad, A., and Khalili, J., New methods and applications in multiple attribute decision making (MADM) (Vol. 277). Cham: Springer, 2019.

Ali, A., and Rashid, T., Best–worst method for robot selection. *Soft Computing*, *25*(1), 563–583, 2021.

Anderson, R., McGaw, S., and Parra, G., Electrical safety in industrial construction: An analysis of 10 years of incidents in the global engineering, procurement, and construction industry. *IEEE Industry Applications Magazine*, *27*(3), 31–41, 2021.

Araneo, R., Dehghanian, P., and Mitolo, M., On electrical safety in academic laboratories. *IEEE Transactions on Industry Applications*, *55*(6), 5613–5620, 2019.

Bhuiyan, M., Majumder, S., Arafat, Y., Rahman, S., and Islam, M., On the guidelines for electrical safety audits in RMG industry of Bangladesh. *Safety in Garment Industry*, 26., 2018.

Bid, S., and Siddique, G., Human risk assessment of Panchet dam in India using TOPSIS and WASPAS multi-criteria decision-making (MCDM) methods. Heliyon, 5(6), e01956., 2019.

Charkhakan, M. H., and Heravi, G., Risk manageability assessment to improve risk response plan: case study of construction projects in Iran. Journal of Construction Engineering and Management, 144(11), 05018012., 2018.

Charoenchit, S., and Thongchaisuratkrul, C., Safety inspection of electrical systems case study in paper and animal food factories. *GMSARN International Journal 15,* 331–339, 2021.

Ecer, F., Sustainability assessment of existing onshore wind plants in the context of triple bottom line: a best-worst method (BWM) based MCDM framework. *Environmental Science and Pollution Research*, *28* (16), 19677–19693, 2021.

Fathi, N., *Safety First: Bangladesh Garment Industry Rebounds.* Retrieved from https://www.ifc.org/wps/wcm/connect/news_ext_content/ifc_external_corporate_site/news+and+events/news/insights/bangladesh-garment-industry, 2021.

Gani, A., Asjad, M., Talib, F., Khan, Z. A., and Siddiquee, A. N., Identification, ranking, and prioritisation of vital environmental sustainability indicators in manufacturing sector using Pareto analysis cum best-worst method. *International Journal of Sustainable Engineering*, *14* (3), 226–244, 2021.

Haque, F., Marma, H.-U.-M., and Chowdhury, A., Prediction of burn incidents due to faulty installations in RMG factories in Bangladesh. In *2017 international conference on electrical, computer and communication engineering (ecce)* (pp. 733–737)., 2017.

Hasan, M. M., Mahmud, A., and Islam, M. S., Deadly incidents in Bangladeshi apparel industry and illustrating the causes and effects of these incidents. *Journal of Finance and Accounting*, *5* (5), 193–199, 2017.

Hasan, S. M. T., Kaium, A., Ahmed, S., Mehmood, S., Kristensen, A., and Ahsan, D., Risk assessment and cost benefit analysis of occupational safety intervention for readymade garment factories: A case study of Bangladesh. In *Safety and reliability-safe societies in a changing world: Proceedings of European safety and reliability conference (ESREL), 2019* (pp. 3917–3925)., 2019.

Hossain, M. S., and Salam, K., Basic approach of an electrical safety assessment in RMG industries: Development of electrical hazards. *Journal of Modern Science and Technology*, *3* (1), 40–46, 2015.

Islam, M. M., Ashraf, M. N., and Bhuiyan, M. I. H., A new electrical risk index for electrical safety assessment of RMG industries in Bangladesh. In *Proceedings on international conference on disaster risk management.,* 2019.

Islam, S. R., Huque, M. M., Khan, L. A., and Hossain, M. I., An experimental thermographic safety audit focusing on temperature rise vs load in electrical installations in a Bangladesh garments factory. In *2017 4th international conference on advances in electrical engineering (ICAEE)* (pp. 561–564)., 2017.

James, P., Miles, L., Croucher, R., and Houssart, M., Regulating factory safety in the Bangladeshi garment industry. *Regulation and Governance*, *13* (3), 431–444, 2019.

Jayant, A., Chandan, A. K., and Singh, S., Sustainable supplier selection for battery manufacturing industry: A MOORA and WASPAS Based Approach. In Journal of Physics: Conference Series (Vol. 1240, No. 1, p. 012015). IOP Publishing., 2019.

Ma, W., Li, X., and Wang, X., Water saving management contract, identification and ranking of risks based on life cycle and best-worst method. *Journal of Cleaner Production*, *306,* 127153., 2021.

Mihajlović, J., Rajković, P., Petrović, G., and Ćirić, D., The selection of the logistics distribution center location based on MCDM methodology in southern and eastern region in Serbia. Operational Research in Engineering Sciences: Theory and Applications, 2(2), 72-85, 2019.

Mikulak, R. J., McDermott, R., and Beauregard, M., The basics of FMEA. CRC Press., 2017.

Moazzem, K. G., Halim, S. F. B., and Shafayat, M., Can a sustainable inspection system be developed? the case of RMG sector in Bangladesh. *Centre for Policy Dialogue*., 2018.

Mostafaeipour, A., Alvandimanesh, M., Najafi, F., and Issakhov, A., Identifying challenges and barriers for development of solar energy by using fuzzy best-worst method: A case study. *Energy*, *226,* 120355., 2021.

Neitzel, D. K., Electrical safety training requirements for all personnel. In *2018 IEEE IAS pulp, paper and forest industries conference (PPFIC)* (pp. 1–5), 2018.

Pathapalli, V. R., Basam, V. R., Gudimetta, S. K., and Koppula, M. R., Optimization of machining parameters using WASPAS and MOORA. World Journal of Engineering., 2020.

Reddy, B. K., Safety in use of electrical appliances. *International Journal for Research and Development*, *7*., 2019.

Rezaei, J., Best-worst multi-criteria decision-making method. *Omega*, *53,* 49–57, 2015.

Roberts, D., Risk management and electrical safety: Implementation of an occupational health and safety management system. IEEE Industry Applications Magazine, 21(3), 67-74, 2015.

Rose, J., The accord and the alliance of Bangladesh: An analysis of factory safety data and insights into their inspection systems., 2021.

Statista., *Number of garment factories Bangladesh 2010-2019.* Retrieved from https://www.statista.com/statistics/987697/bangladesh-number-garment-factories/, 2021.

Tuş, A., and Aytaç Adalı, E., The new combination with CRITIC and WASPAS methods for the time and attendance software selection problem. Opsearch, 56(2), 528-538, 2019.

Wiersma, J., Fire safety in the ready-made garment industry in Bangladesh, five years after Ranaplaza. *Safety in Garment Industry*, 16., 2018.

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Appendix A

Table 1A: Sample Questionnaire for BWM (with Response from an Expert)

Question	Criterion									
What is the 'Most Important' criterion to prioritize electrical risk factors of RMG factories?	☒ Consequence ☐ Likelihood ☐ Manageability									
How many times are your 'Most Important' criterion comparatively important over other criteria? (1 for equal and 9 for extreme)	Consequence	1☒	2☐	3☐	4☐	5☐	6☐	7☐	8☐	9☐
	Likelihood	1☐	2☐	3☒	4☐	5☐	6☐	7☐	8☐	9☐
	Manageability	1☐	2☒	3☐	4☐	5☐	6☐	7☐	8☐	9☐
What is the 'Least Important' criterion to prioritize electrical risk factors of RMG factories?	☐ Consequence ☒ Likelihood ☐ Manageability									
How many times are other criteria comparatively important over your 'Least Important' criterion? (1 for equal and 9 for extreme)	Consequence	1☐	2☐	3☒	4☐	5☐	6☐	7☐	8☐	9☐
	Likelihood	1☒	2☐	3☐	4☐	5☐	6☐	7☐	8☐	9☐
	Manageability	1☐	2☒	3☐	4☐	5☐	6☐	7☐	8☐	9☐

Table 2A: Sample Response from an Expert with Evaluation Score of the Electrical Risk Factors

	Consequence	Likelihood	Manageability
RF1	4	4	3
RF2	4	3	5
RF3	5	3	2
RF4	4	3	2
RF5	3	3	5

	Consequence	Likelihood	Manageability
RF14	5	4	3
RF15	4	1	5
RF16	5	5	3
RF17	4	2	5
RF18	5	1	5

RF6	5	5	2
RF7	4	3	4
RF8	4	3	4
RF9	5	4	4
RF10	4	2	4
RF11	4	1	4
RF12	4	3	4
RF13	3	4	5

RF19	4	2	4
RF20	3	2	4
RF21	4	3	4
RF22	5	4	3
RF23	5	4	5
RF24	4	3	3
RF25	4	4	5
RF26	3	4	4