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RESEARCH PAPER

Integrating FMEA and BWM Methods to Evaluate and Prioritize Risks with Greater Differentiation (A Case Study of Operational Risks of Electricity Distribution Network)

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Abstract

One of the most important factors of socio-economic development in any country is the quality of electricity sources. Considering the sensitivity of electronic devices and the dependence of most activities on electricity, providing sustainable energy in the urban system is very important. Therefore, a comprehensive view of the factors causing disturbances in the electricity distribution network is very valuable in order to prevent any electricity losses. The goal of the current research is to identify, evaluate and prioritize operational risks in the aerial electricity distribution network. Any operational risk is a potential cause of the incident that leads to an unplanned outage. In this study, by reviewing the research literature, incidents recorded in the electricity distribution network incident registration system (known as the 121 system), and conducting interviews, 21 operational risk cases have been listed and approved by experts. On the other hand, to solve the limitations of the FMEA method, by combining the BWM method and using the knowledge of experts (completion of the questionnaire), evaluation and prioritization were done with more differentiation. The results showed that from the point of view of experts, the intensity index is critical (0.475). Also, three operational risks with high priority in the electricity distribution network of Yazd province include; Failure in concrete foundations, the impact of foreign objects, and failure in transformers. Statistics emphasize that high-priority risks are responsible for 27% of unplanned outages in the last ten years. Operators and managers of electricity distribution companies can consider high-priority risks and provide solutions to reduce, eliminate or transfer risks. In this case, in addition to minimizing unplanned outages in the network and selling more electricity, customer satisfaction is achieved.

Keywords:
Risk Assessment and Prioritization;
Operational risk;
Power Distribution Network;
FMEA;
BWM.

Introduction

The power system or the power generation, transmission, and distribution network is a crucial supply chain that is a combination of processes, from the supply of primary fuel sources to the consumption of electricity. One of the most important factors of socioeconomic development in any country is the quality of electricity sources [1]. The electric power industry has experienced fundamental changes worldwide over the past two decades [2]. Consumers of electric energy demand electricity supply at a very high level of safety from producers. Considering the sensitivity of electronic devices and the dependence of most activities on

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electricity, providing sustainable energy in the urban system is very important. Unscheduled blackouts are the main cause of disruption in the continuity of electricity supply, reducing the quality of power delivered to electricity customers, which causes public dissatisfaction and the occurrence of adverse social consequences [3]. Therefore, a comprehensive approach and perspective towards the power distribution network are precious to prevent any power loss in all processes. The exhaustibility of the primary sources of electricity, the vital need to use them, and the high price of their products are among the most critical factors that have doubled the importance of paying attention to the occurrence of disruptions in the electricity supply chain. The occurrence of disturbances from an economic point of view can lead to losses and loss of economic resources and reduce the competitive power in this area [4]. Disruption in the electricity distribution network can be caused by factors such as the threat of natural disasters (Storms, floods, earthquakes, etc.), special economic and political conditions, incidents, and terrorist attacks, and exposes the network to all kinds of risks and disruptions. Based on this, due to the extraordinary importance of the electricity sector in the economy of countries and various government policies, a risk-resistant electricity distribution network can be of great help in saving and reducing costs in the electricity industry. During the ups and downs of its life, the world's electricity industry has been involved with crises that, in order to be resilient, risks must be carefully identified, evaluated and prioritized depending on the political, economic, and social conditions of each region. When there are some big storms or incidents cause severe damage to the electricity supply network; Responding quickly to risks or reducing them reduces all types of damage [5]. This brings the importance of the issue that the correct management with the slightest error is one of the day's needs for the sustainable supply of electricity. In the current research, the operational risks of the electricity distribution network are considered in the maintenance and operation system section.

The purpose of this study is to identify, evaluate and finally prioritize operational risks affecting the unplanned outage index of the electricity distribution network of Yazd City, with a new approach of FMEA. Various methods for risk assessment have been presented by researchers, one of the most important of which is the FMEA method (Failure Mode and Effects Analysis) [6]. In this method, the risk priority number (RPN) is the product of three indicators of severity (S), probability of occurrence (O), and detection (D), which is an important criterion for determining risk priority [7]. Failure and Effect Analysis (FMEA) methods are one of the most widely used methods in risk assessment. However, the common disadvantages of FMEA, such as using the Risk Priority Number (RPN) to prioritize risks, make this method ineffective in industries [8]. One of the limitations of this method is considering the same importance for the three indicators of severity, probability of occurrence, and detectability. In this research, using the BWM method and expert knowledge, the risk assessment indicators are weighted, then a distinct priority number (RPN) is obtained. While considering the same importance for the evaluation indicators, an equal priority number may be obtained, and the prioritization will be problematic.

Next, the review of the literature, the background of the research, and various risk assessment methods in the electricity distribution network are presented in the second part. In the third part, the research method is described, and the numerical results, which include the list of operational risks and their priority number, are presented in the fourth part, and the results of the proposed approach are compared with the traditional FMEA. Conclusions and future suggestions are described in the fifth section.

Literature Review

Many pieces of research in the field of risk and its management have been widely presented. Also, various methods for ranking risks have been investigated by researchers**.** The current research evaluates the operational risks of the electricity distribution network; Therefore, researches are categorized and presented around the types of risk and their assessment methods and unplanned blackouts in the electricity distribution network.

Types of risk and its evaluation methods

A risk is an event or potential event, both predictable and unpredictable, that can hurt achieving the company's vision and mission [9]. There are many differences of opinion about the most important risks and how to pay attention to them. Indeed, identifying the most important risks and dealing with them is time-consuming and costly [10]. Operational risk arises from day-to-day operations. Failure to identify operational risk, in a relatively short period of time, has been highlighted as a factor in the collapse of companies [11]. So far, a disproportionate set of supply chain risks have been classified as operational risks, including internal and external quality problems, delivery delays at any point in the supply chain, service failures due to poor management, problems related to poor forecasting, etc., which are operational performance failures. It has been mentioned [12]. The management of operational risks along with financial risks has been investigated by studies in banks [13] and transportation (shipping [14] and containers [15]).

As an active risk analysis technique, failure mode and effect analysis (FMEA) has been widely used for reliability and safety in various fields. In the research by Wang et al., they developed a hybrid FMEA framework that integrates the TODIM (Portuguese acronym for interactive and multi-criteria decision-making) approach and the Choquet integral method. This method was able to simulate the psychological behavior of FMEA team members and model the interrelationships between risk indicators [16]. Cao and Deng presented a new geometric mean FMEA method based on information quality [7]. In research by Guimarães and Lapa, to solve a nuclear reliability engineering problem, the Risk Priority Number (RPN) (usually the traditional Failure Mode and Effects Analysis - FMEA) was calculated and compared with the Fuzzy Risk Priority Number (FRPN) [17]. Vahdani et al presented a new FMEA model combining the technique for priority order based on similarity to the ideal solution (TOPSIS) and belief structure to overcome the shortcomings of the traditional FMEA index [6]. Yousefi et al presented a robust data envelopment analysis (RDEA)-FMEA approach to evaluate and prioritize HSE risks in various industries and cover the disadvantages of the traditional RPN scoring system in the FMEA method [8].

Power distribution network

Electric energy, as a clean and flexible energy, is the main factor of economic growth and social welfare of human societies. In the three main sectors of power systems (i.e., generation), transmission, and distribution, the distribution sector of electric energy has more complex technical issues related to the design and operation of generation and transmission systems. One of the most essential parts of a large interconnected power system is the electrical energy distribution system; This group is responsible for the final and direct electricity supply to consumers. Although it does not deal with high voltage levels, its complexity and scope are much greater than other parts of the power system. This issue has made research and study on this system more complicated, and its protection and maintenance much more sensitive [18].

Disruption in infrastructure networks (electricity, water, communication and information networks and public transportation systems) can have more consequences [19]. Quiroga et al. (2011) discovered the main causes of accidents and breakdowns in electricity distribution networks based on the monitoring data of an electricity distribution company located in Spain between 2004 and 2009. Then, using principal component analysis (PCA), they investigated the trend of the number of failures and their rate in the air and ground distribution network [20]. Taherabadi and his colleagues analyzed the blackout data recorded in the event registration software of the Big Tehran Electric Power Distribution Company from 2015 to 2015 using data mining techniques. They also prioritized the causes of errors that lead to blackouts based on the impact of blackouts [21]. In research by Adel Azar et al., by collecting the opinions of 23 experts (managers and experienced employees in the electricity industry) and using the fuzzy method, the current situation of the electricity industry in the three areas of production, transmission, and distribution during the one year period of 2016-2017 was investigated and analyzed [22]. Network equipment information is very essential in asset management decisions. These data should be provided to power company decision-makers as input to asset management decision-making processes. By extracting and preparing the required information, analysis and evaluation will be possible [23]. Many electric utilities in developing countries are investing in installing and renewing electric distribution systems (EDS) components, such as overhead lines, cables, and switching devices, to improve EDS reliability and cope with rapidly increasing load demand. In reference [24], a comprehensive model for predicting the reliability of the power distribution system is presented, which is made of two separate parts of power distribution system failure models and planned outages. The statistical study conducted on the failure events of the transmission and super distribution substations of Khorasan regional electricity for sixteen years (2001-2017) has been helpful in comprehensive planning in the repair and maintenance of substation equipment [25]. In a research conducted by the Intelligent Systems and Control Engineering Group of Girona, Spain, using the multilayer principal component analysis method, they presented a strategy to identify abnormal operating conditions on weak pressure system data [26]. Due to the low voltage level and as a result of the high current, the distribution networks have very high losses and high voltage drop, which has always accounted for the largest share in losses and reduced the reliability of the electricity distribution network [27]. The results of investigations show that blackouts in the field of electricity distribution are divided into two categories: unplanned blackouts (accidental) and planned blackouts, the first category of which occurs as a result of technical and non-technical events in the electricity distribution networks, and without the will of the company and its employees, the electricity is cut off, and many It is critical [28]. In Mohammad Firouzfar's study, unplanned blackouts with titles registered in the 121 system of Hamedan province are presented [3]. In this research, the operational risk in the electricity distribution network is defined as unexpected events and incidents that occur in the network during an unplanned power outage. In this situation, the operation without a hot line should be done so that the power distribution network returns to its original state. In this research, the distribution of electricity at the Yazd city level is considered (receiving electricity with high voltage, reducing voltage, and delivering it to subscribers).

Research gaps

Many pieces of research have been done in the field of risk management with different methods. In Table 1, the methods of risk management in different industries and the implemented methods are reviewed. As it is known, many methods have been used for risk management, but the integration of FMEA and BWM methods has not been done. On the other hand, using the FMEA method alone has limitations. That when evaluating based on three indicators of severity, probability of occurrence, and detection capability; The importance of these indicators is considered the same and does not have superiority over each other, while in the real world and according to experts, the importance of these indicators is not the same. This leads to the production of the same priority number (RPN index) for some risks, which cannot determine the superiority of one risk over another in the final decision. In this research, this limitation is solved by using the BWM method and weighting the risk assessment indicators.

Table 1. Conducted researches

Row	Resource	Method / approach	Application / implementation
1	B. Vahdani, M. Salimi 2015. [6]	FMEA & TOPSIS	Numerical case study on failure cause preference of steel production process
2	M. J. Rezaee, S. Yousefi,M.Babaei,2016. [29]	Development of cognitive map and PFMEA using machine learning algorithms	Automobile parts company
3	S.Yousefi, A. Alizadeh, J. Hayati, M. Baghery,2018. [8]	Robust Data Envelopment Analysis (RDEA)-FMEA	Safety risk in a company active in the production of spare parts
4	M. Jahangoshai Rezaee, S. Yousefi, M. Valipour M. M. Dehdar,2018. [30]	Fuzzy Cognitive Map (FCM) and PFMEA	Food industry
5	X.Cao, Y. Deng,2019. [7]	The new FMEA geometric mean method	Numerical case study
6	W. Wang, X. Liu, X. Chen,2019. [16]	FMEA and TODIM, and Choquet integral method	Numerical case study
7	D.Lintang Trenggonowati, M. Ulfah, F. Arina,C. Lutfiah,2020. [16]	Fuzzy FMEA and FAHP	The supply chain of a company active in the steel industry
8	M. Abdel-Basset, R. Mohamed,2020. [31]	TOPSIS-CRTIC	Telecommunication equipment company in China
9	M. Tavana, A. Shaabani, S. Mansouri Mohammadabadi, N. Varzgani,2020. [32]	FAHP & MULTIMOORA	Manufacturer of consumer electronic goods in the city of New Jersey, USA
10	J. C. Osorio Gómez و K. T. España,2020, [33]	QFD + Ontology	A pharmaceutical company in Colombia
11	G. C. Dias, C. T. Hernandez,U. R. de Oliveira,2020, [34]	AHP	Automotive in Brazil
12	R. Rathore, J. J. Thakkar, J. K. Jha,2020, [35]	Fuzzy VIKOR and Fuzzy FMEA	Halal food of India
13	J. El Baz, S. Ruel,2021, [36]	Structural equation	French companies
14	S. Khan, A. Haleem, M. I. Khan,2021, [37]	FBWM	Halal food chain
15	S. Khan, A. Haleem, M. I. Khan,2021, [38]	Fuzzy Delphi and DEMATEL	Halal supply chain (HSCM)
16	This research	FMEA and BWM	Yazd electricity distribution network

Research Method

The current research is practical regarding the type of research based on the purpose. Also, considering that quantitative and qualitative data and related tools were used simultaneously, the type of research method is a combined quantitative and qualitative method. First, the operational risks of electricity distribution networks have been identified and listed by field and library studies and then evaluated. FMEA is a powerful and popular technique that is used to achieve some suggestions, such as identifying defects and failures in systems, evaluating their effects on system performance, and determining ways that can reduce the chance of their occurrence and consequences [30, 39]. To overcome the limitation of the FMEA method (as mentioned in the previous section; considering the equal importance of risk assessment indicators (SOD)), The integration of BWM and FMEA methods is used. Based on this, a proposed hybrid approach is presented in Fig. 1. In terms of its purpose, this research is a part of applied developmental research.

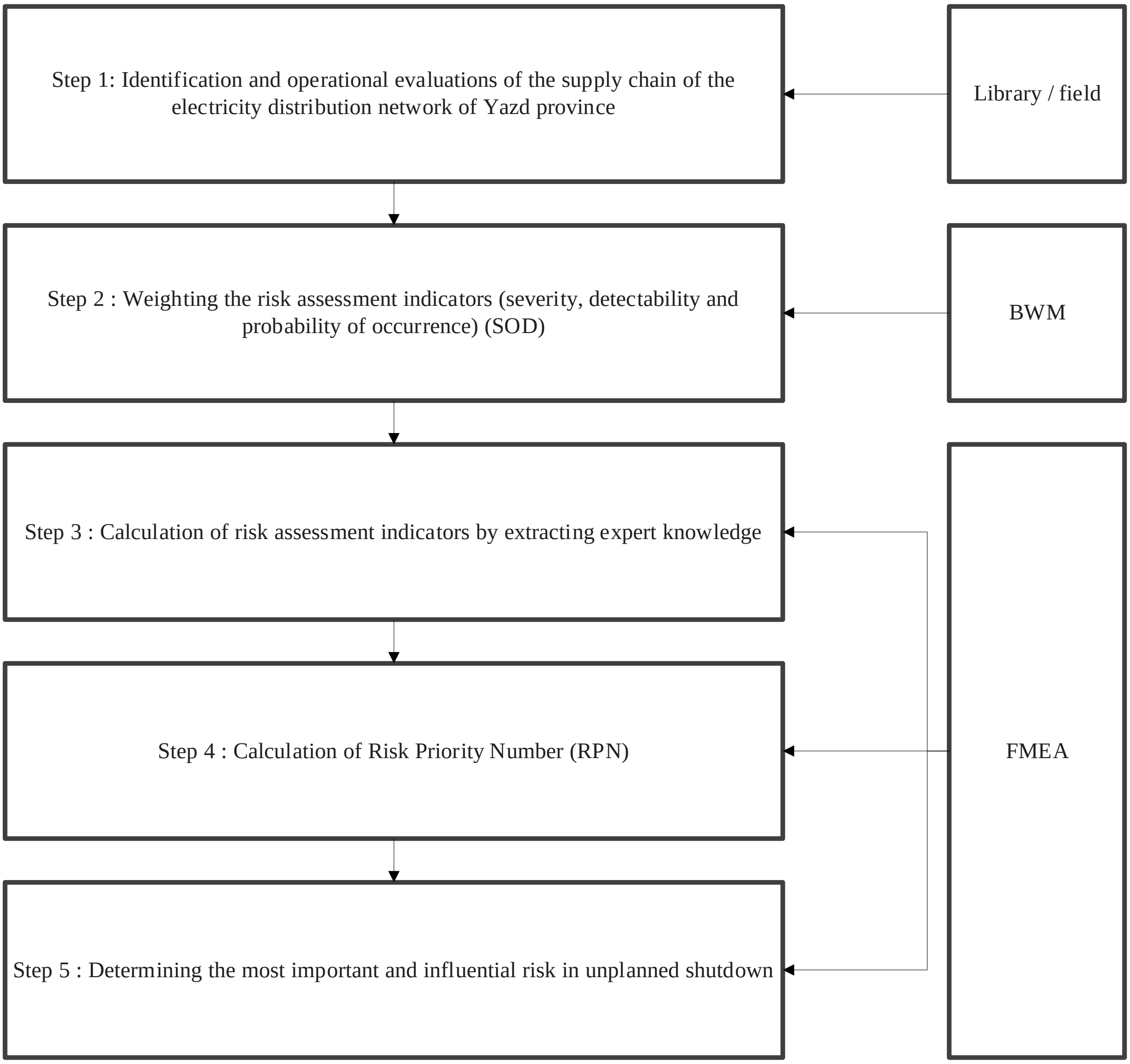

Fig. 1. The flow diagram of the proposed integrated BWM and FMEA approach

The distinguishing feature of this method, in addition to preparing a list of operational risks of the electricity distribution network, is the development of a more differentiated classification of these risks. So in the FMEA method, all evaluation indicators have the same weight. This results in generating the same priority number for two or more risks. Therefore, in this method, we evaluated the risks for prioritization with more differentiation. One of the limitations of this method is the possibility of inconsistency when implementing the BWM method. Also, this research has been done based on the knowledge of experts and field studies on the electricity distribution network of Yazd province, so the time and space limitations are for this research.

Problem Definition

One of the main reasons for customers' power outages is the blackouts in the distribution field, which are affected by technical and non-technical events in the electricity distribution networks.

According to the characteristics of electricity distribution airlines in Iran, distribution networks are dominant in the form of airlines. Categorization of aerial electricity distribution networks in the form of; The network is medium pressure, weak pressure and lighting. Various equipment are placed together in the power distribution network to distribute and flow electrical energy. According to the type of network arrangement, the equipment is different. The overhead power distribution network is exposed to many types of accidents that lead to power outages. Any operational risk is a potential cause of the incident that leads to an unplanned outage. Prioritizing these risks by considering the importance of indicators of the probability of occurrence, severity of detection probability, helps managers to recognize high importance risks. Then fix, reduce or transfer these risks. In this case, while improving the stability of the system, the satisfaction of the subscribers is provided and finally, the efficiency of the system is improved. The distinction of this research in the prioritization of risks is considering different weights for risk assessment indicators, the results of which are presented in the next parts of the article.

Numerical Results

According to the steps presented, Numerical results are presented in the research method. The list of operationalized risks resulting from the research is presented in Section 4.1. The risk assessment indicators are weighted by the BWM method in Section 2.4, and the prioritization results are presented.

Identification and selection of operational risks of the electricity distribution network supply chain

Blackouts can be examined from different perspectives. For this purpose, using library and field methods, disturbances and incidents that cause unplanned power outages in the aerial power distribution network of Yazd City were extracted. According to the output from the system of 121 electricity distribution companies in Yazd province, a total of 28 risk titles were extracted. By summarizing the opinions of experts and defining each risk, 21 cases were approved for analysis and evaluation. The definition of each operational risk can be seen in Table 2.

Table 2. Definition of operational risks of the electricity distribution network in Yazd city

Row	Risk	Define
1	Transitory defect	The network has suffered a fault that can be fixed by itself, and after a concise period, time, the flow will be restored again.
2	The collision of foreign objects (such as the collision of cars, construction equipment, trees, etc.)	The electricity distribution network is an open system that is directly connected with urban and non-urban environments. Therefore, the collision of foreign objects is undeniable. Of course, because there are a large amount of distribution networks next to the traffic arteries, the collision of vehicles is more important.
3	Failure in network foundations (concrete, wooden, and metal)	The foundations (poles) in the electricity distribution network are the support of wires and network equipment. Breaking or falling of the bases leads to the breaking of the wires and interruption of the electricity flow.
4	Failure in cut-out fuse	One of the devices that is used to quickly isolate the faulted parts from other parts of the system is the cut-out fuse. Distribution transformers are often connected to primary lines through a fuse cutout. Failure and fault in this part lead to interruption of electricity flow to the transformer and along the network.
5	Network conductors hitting each other or the fuselage	Medium-pressure network conductors are without insulation. If a short circuit occurs due to an accident, the network will be disrupted.

6	Failure in circuit breakers (recloser, sectionalizer, etc.)	In overhead distribution systems, it is used to identify and interrupt transient faults. Since many short circuits are tripped on overhead lines, circuit breakers such as reclosers improve the continuity of service by automatically restoring power to the line after a transient fault. In case of failure in this part of the network, there will be many more outages.
7	Human error (wrong maneuver or power cut during hot line operation)	In human-made systems, the possibility of error is non-zero. It is possible for any person who maintains and operates the system to make an error.
8	Birds collision	The presence of birds around the power distribution network equipment leads to accidents such as short circuits and failure of power transformers. This disorder occurs more in the year's seasons when birds are migrating.
9	Adverse weather conditions	The occurrence of natural disasters such as floods, earthquakes, or storms can damage the equipment of the electricity distribution network as well as other urban infrastructures.
10	Failure in the Lightning arrester	A lightning arrester is a protective device that limits and directs overvoltages that destroy distribution network equipment to the ground. Compared to other protection devices, it provides the best protection and maximum removal of transient waves. Therefore, the failure of this device leads to more accidents in the system.
11	Failure in the internal network of subscribers	A group of subscribers who have formed a new network together may have experienced a power outage. This disorder is from within the subscribers' network
12	failure in the electrical jumper	It is an interface that is used in overhead lines and tension double beams. Moreover, if it fails, it will result in a power cut.
13	Failure in pin insulator	It is an electrical insulator that connects electric cables with transmission, and electricity bases and isolates the conductors under voltage from the bases. If there is a fault in the pin insulators, the connection with the bases will occur and in addition to the interruption of the current, electrical energy will be wasted.
14	Rupture wire	The rupture of conductors is one of the obvious things that result in the interruption of the electric current circuit.
15	Self-maintained cable breakage	These cables have good advantages, but due to the non-observance of technical issues and principles in the operation of these cables, has caused many problems in the electricity industry.
16	Theft of network equipment	One of the issues faced by distribution networks, especially in places where the network has just been installed, is the theft of tools and equipment.
17	Failure in the transformer	The distribution transformer performs the final voltage conversion (reducing the medium pressure voltage and converting it to the voltage required by the customer) in the electricity distribution network. A fault in this part of the network disrupts a large part.
18	Failure in fittings	The fittings used in the distribution are: 1. Crossarm or console 2. Rock, failure in any of these cases will lead to disruption in the network.
19	Failure in electrical substations	An electrical substation is a substation that changes the voltage to higher or lower values through a set of equipment. Disturbance in this part leads to the power outage in the network.
20	Electrocution	Electrocution along the network (collision of living beings, both human and non-human) leads to disruption in the electricity distribution network.
21	Failure in the above distribution equipment	The supplier of the electricity distribution network is the above distribution or electricity transmission network; in case of failure in that part, the electricity is not well supplied in the electricity distribution network.

In the 121 system, which belongs to the registration of unexpected electrical incidents. The above disturbances were recorded in this system, and the blackout time caused by these disturbances was received in the electricity distribution network of Yazd City between October 2010 and October 2022. In this period, the Total unscheduled blackout is 171,635 minutes (Table 3).

Table 3. Unplanned blackout times of the electricity distribution network of Yazd city (October 2010 to October 2021)

Row	type of unplanned outage time	Time (minute)
1	Total blackout time at specified time efficiency	171635
2	Air network blackout time	141069
3	Ground network blackout time	30566

In this system, the events that occurred in the network, along with the duration of the power outage, are recorded. The breakdown of unplanned shutdown times of the air network is shown in Table 4.

Table 4. Unplanned shutdown time of operational risks of electricity distribution network

Row	Risk	Time (minute)
1	Transitory defect	5031
2	The collision of foreign objects (such as the collision of cars, construction equipment, trees, etc.)	13843
3	Failure in network foundations (concrete, wooden, and metal)	24337
4	Failure in cut-out fuse	24450
5	Network conductors hitting each other or the fuselage	1503
6	Failure in circuit breakers (recloser, sectionalizer, etc.)	1315
7	Human error (wrong maneuver or power cut during hot line operation)	3558
8	Birds' collision	4414
9	Adverse weather conditions	10562
10	failure in the Lightning arrester	2679
11	Failure in the internal network of subscribers	7243
12	failure in the electrical jumper	7748
13	Failure in pin insulator	4954
14	Rupture wire	14684
15	Self-maintained cable breakage	1467
16	Theft of network equipment	17
17	Failure in the transformer	841
18	Failure in fittings	860
19	Failure in electrical substations	426
20	Electrocution	244
21	Failure in the above distribution equipment	692

Identified risks (Table 2), according to the place of occurrence in the network and the nature of their origin, were presented step by step according to Fig. 2.

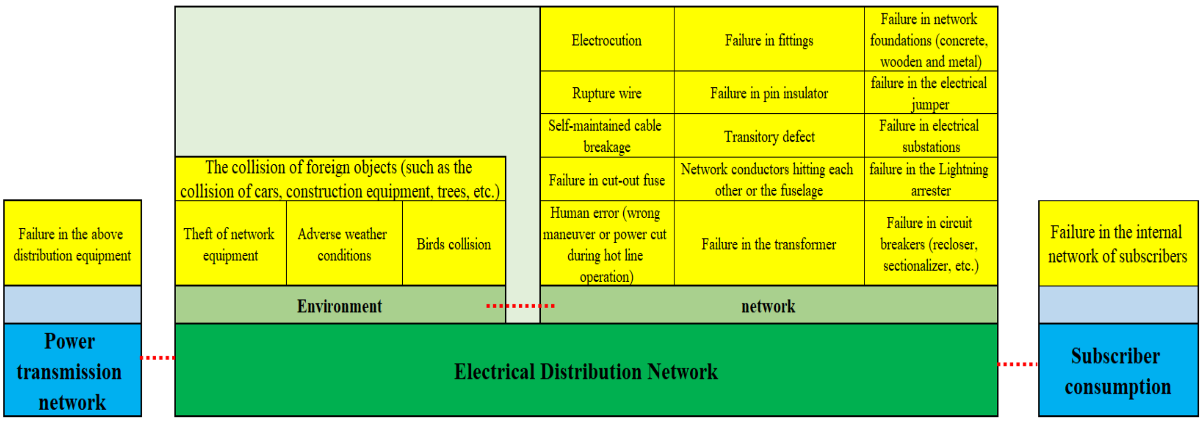

Fig. 2. Classification of electricity distribution network risks

The electricity distribution network of Yazd city consists of three sections titles; part one, part two and, part three have been formed. The total time of unplanned outages of the air power distribution network of Yazd province for each business and the entire city is shown in the following diagram.

As you can see in Fig. 3, the duration of unplanned outages of each part has been different in the last ten years, but the trend of the whole province has increased sharply in the last two years. Therefore, finding operational risk with high priority and managing it helps to improve the efficiency of the distribution network.

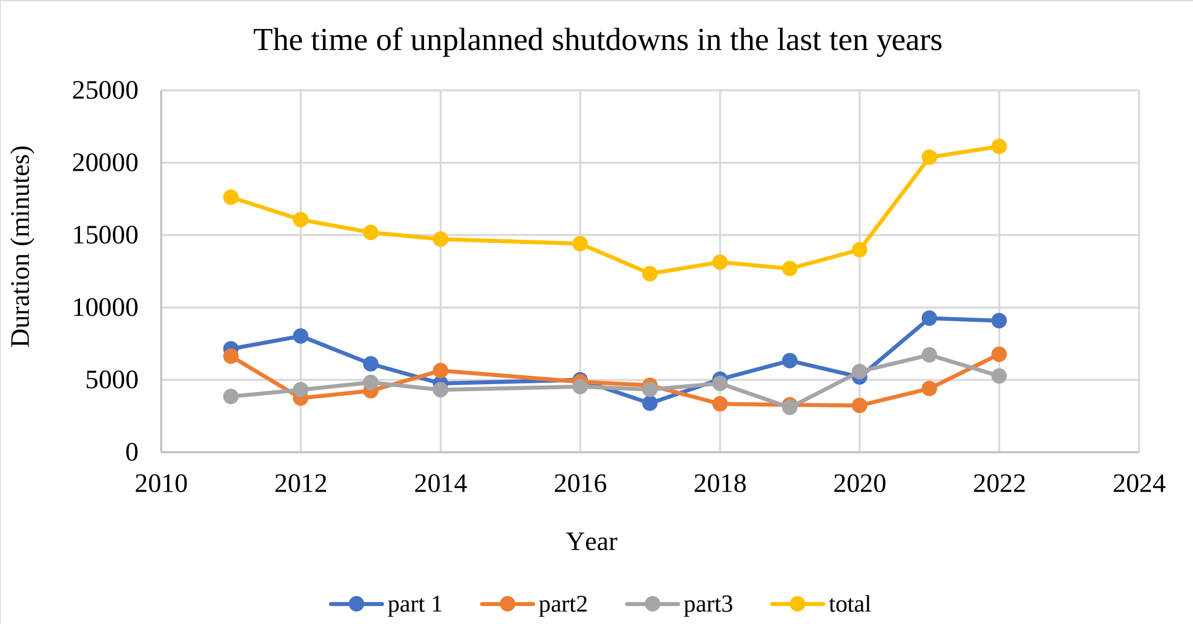

Fig. 3. Time series of unplanned outages

Evaluating and prioritizing the operational risks of the electricity distribution network

As explained in the research stages, after identifying the risks, weighting is done to three effective indicators in calculating the RPN number (probability of occurrence, severity, and consequence) in the FMEA method. In this way, by using the BWM method and the knowledge of experts, the comparison vectors have been formed, and by using the Solver option in the Excel software, the linear mathematical model of the BWM method has been solved (equation (4-1) to (4-5)) [39]. After implementing the BWM method, the final weight of the indicators of severity, probability of occurrence, and detection capability is calculated (Table 5). Because the BWM method has fewer comparisons, it has been used to weigh these indicators.
Figure 3: Time series of unplanned outages

$$z = MIN\ \varepsilon \tag{1}$$

$$\left|W_B - a_{Bj}W_j\right| \leq \varepsilon^* \qquad \forall\ j \tag{2}$$

$$\left|W_j - a_{jw}W_w\right| \leq \varepsilon^* \qquad \forall\ j \tag{3}$$

$$\textstyle\sum_j W_j = 1 \tag{4}$$

$$W_j \geq 0 \qquad \forall\ j \tag{5}$$

As it is known, Eqs. 2 and 3 are not linear, and the above mathematical model for BWM implementation is not a linear model. Therefore, Eqs. 6 to 9 have been used to linearize the model.

$$W_B - a_{Bj}W_j \leq \varepsilon^* \qquad \forall\, j \tag{6}$$

$$-W_B + a_{Bj}W_j \leq \varepsilon^* \qquad \forall\, j \tag{7}$$

$$W_j - a_{jw}W_w \leq \varepsilon^* \qquad \forall\, j \tag{8}$$

$$-W_j + a_{jw}W_w \leq \varepsilon^* \qquad \forall\, j \tag{9}$$

The calculation of the compatibility rate in the BWM method has been checked using the table presented in reference [40]. When the ratio of the best to the worst a_Bw is equal to the value of 9, the maximum value of inconsistency can be 23.5. In all calculations, this value has been considered and checked (Table 5).

Table 5. Inconsistency rate in the implementation of the BWM method

Row	Incompatibility Rate	Row	Incompatibility Rate
1	0.132	6	0.104
2	0.104	7	0.132
3	0.131	8	0.106
4	0.132	9	0.170
5	0.105	10	0.150

As it is clear from Table 5, the incompatibility rate for each expert is less than 5.23.

Table 6. The weight of effective indicators in calculating the RPN number

BWM method	Severity	Occurrence	Diagnosis
Weight	0.475	0.117	0.408

Table 6 is the final result of the importance of risk assessment indicators relative to each other. As it is known, the two indicators of severity and detection ability are more important for experts, and the probability of occurrence is less important. During the interview, they reasoned that if an incident has little consequence and has a high detection capability, it will be targeted, and preventive measures will be taken. The five-point Likert scale, according to Table 7, has been used to determine the intensity, probability of occurrence, and detectability indicators.

Table 7. Likert's five-point scale

Intensity		Occurrence		Diagnosis	
5	Very little	1	Very unlikely	1	Very little
4	Low	2	unlikely	2	Low
3	Medium	3	Occasionally	3	Medium
2	Much	4	Likely	4	Much
5	Very much	5	Repeated	5	Very much

Now, considering the weight of each index, the calculation of the improved RPN number has been done according to Eq. 6 (S^w=severity, O^w=probability of occurrence, and D^w=detectability) (Table 8).

$$RPN = S^w * O^w * D^w \tag{10}$$

Table 8. Calculation of the weighted priority number

Row	Risk	Severity S^w	Occurrence O^w	Diagnosis D^w	RPN (FMEA&BWM)	RPN (traditional FMEA)
1	Failure in network foundations	0.556	0.375	1.551	0.308	100
2	The collision of foreign objects	0.463	0.333	1.536	0.237	80
3	Failure in the transformer	0.486	0.352	1.380	0.236	60
4	Transitory defect	0.520	0.394	1.022	0.209	48
5	Rupture wire	0.37	0.259	1.471	0.141	48
6	Failure in pin insulator	0.381	0.339	1.051	0.136	48
7	Self-maintained cable breakage	0.416	0.279	1.138	0.132	36
8	Birds collision	0.356	0.321	1.051	0.120	36
9	Failure in the above distribution equipment	0.409	0.242	1.128	0.112	36
10	Adverse weather conditions	0.267	0.418	0.983	0.110	27
11	Failure in circuit breakers	0.423	0.239	1.046	0.106	27
12	Failure in the electrical jumper	0.345	0.312	0.960	0.103	20
13	Failure in the Lightning arrester	0.344	0.253	1.147	0.100	18
14	Theft of network equipment	0.521	0.159	0.950	0.079	18
15	Failure in cut-out fuse	0.392	0.253	0.791	0.078	18
16	Network conductors hitting each other or the fuselage	0.246	0.239	1.301	0.076	16
17	Failure in fittings	0.310	0.285	0.797	0.070	15
18	Electrocution	0.225	0.186	1.401	0.059	12
19	Human error	0.371	0.198	0.633	0.046	8
20	Failure in electrical substations	0.355	0.351	0.364	0.045	6
21	Failure in the internal network of subscribers	0.253	0.255	0.666	0.043	6

Table 8 shows the results of the priority number (RPN) in the traditional FMEA method and integrated with BWM. Although in the presented method, the distance between the priorities is small, none of them are equal, while in the traditional FMEA method, the priority number for the risks (for example, rows 4 to 6) may be equal. Equal priority number for risks causes errors in managers' decision-making.

Conclusion

One of the most important factors of socio-economic development in any country is the quality of electricity sources. Considering the sensitivity of electronic devices and the dependence of most activities on electricity, providing sustainable energy in the urban system is very important. Therefore, a comprehensive approach towards the factors causing disruption in the electricity distribution network is very valuable in order to prevent any electricity losses. In this research, the factors of unplanned shutdowns were considered as the operational risk of the electricity distribution network. According to the prioritization presented in this research, through the combination of two BWM and FMEA methods, three risks with a very high priority include; Failure in the foundations of the electricity distribution network (breakage or falling due to wear and tear), the impact of foreign objects (effect of the surrounding environment) and failure in transformers. Statistics showed that high-priority risks are responsible for 27% of unplanned outages in the last ten years. Operators and managers of electricity distribution companies can consider high-priority risks and provide solutions to reduce, eliminate or transfer risks. In this case, in addition to minimizing unplanned outages in the network and selling more electricity, customer satisfaction is achieved. In future research, researchers can investigate the factors influencing the failure of foundations and investigate the root causes of this failure. Also, prioritize by considering the relationships between failures. On the other hand, every year, the electricity distribution network is expanding throughout the city of Yazd, and the length of the network is increasing every year. In this research, unplanned outage time data was used for evaluation. To eliminate the effect of network expansion, the ratio of time to network length can be used for analysis in future research. Also, this approach has been prepared using the data and opinions of the experts of the electricity distribution network of Yazd city. Researchers can investigate and research using the data of other networks in other cities.

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