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An Integrated Entropy-Weighted Sum Model Technique for Evaluating the Metrics of Cybersecurity under Uncertainty

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Abstract

Businesses and organizations handle large amounts of data that may be accessed unauthorized by hackers, so we need to protect this data and other resources from malicious users. Here comes the role of cybersecurity. Cybersecurity is a multidisciplinary field touching on the technical sciences as well as the social and behavioral sciences. Cybersecurity is the result of intelligent cyberattacks. Cybersecurity is crucial to protecting sensitive data stored on any device due to the increasing amount of information. So, this study evaluates cybersecurity using neutrosophic multi-criteria decision-making (MCDM) techniques such as entropy to obtain weight and the weighted sum model (WSM), for ranking and obtaining the best digital footprint of modern organization's cybersecurity. The cybersecurity estimation issue illustrates the validity and great performance of the presented method as (1) its capability to deal with uncertainty phenomena (2) its straightforwardness; and (3) its heightened capacity to discern alternatives. The presented case study shows that the best alternative of this study is A3 which refers to (Digital supply chain risk) as the best one of all alternatives.

Keywords: Cybersecurity, Neutrosophic Set, Multi-Criteria Decision-Making, Entropy, Weighted Sum Model.

1 | Introduction

Nowadays, all organizations based on online jobs including government, education, health, finance, and the media, are dependent on computer and internet services. The internet now plays a major part in our daily lives. Networking among businesses is important to increasing productivity and profitability. The Internet offers convenience and many advantages, but it also has significant drawbacks and threats.

Russia and China are in the first global malicious attacks [1]. The India National Crime Records Bureau (NCRB) has recorded 52,000 cases of cybercrimes since 2021[2]. We suffer very much if there is a disruption in the connection. Cybersecurity is meant to protect the technological system in such an environment.

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Because this information is valuable to a person, organization, or nation and we cannot afford to lose it, cybersecurity is crucial.

Unauthorized access to this data may damage the infrastructure or reveal a lot of secrets. Encryption is required for data protection during storage and transmission, so cybersecurity has become a major and important part of our lives [3]. To protect against security attacks in the cyber environment, cybersecurity measures are designed to offer the understanding and maintenance of security properties [3].

The current researches are intimately tied to businesses, so it is important to consider the companies that conduct research on cybersecurity technology like Gartner Company. It is an American worldwide research and advising company [4].

This study requires a lot of alternatives and many different criteria. The trendy technologies for cybersecurity according to Gartner using as alternatives, include Attack surface expansion A1, Identity system defense A2, Digital supply chain risk A3, Vendor consolidation A4, Cybersecurity mesh A5, Distributed decisions A6, and Beyond awareness A7 [5]. These have been identified as information security solutions that are designed to defend against complex attacks. Ranking these technologies and deciding which ones should be taken into consider crucial. It can be challenging to select the best decision from a range of available.

There are several MCDM methods for processing the options, based on the performance matrix and the weights of the criterion. Such as SWM and entropy approaches.

The motivation of this study is to evaluate digital footprint cybersecurity by a neutrosophic multi-criteria decision-making approach for ranking alternatives and handling ambiguity which is usually in reality.

Many researchers have done cybersecurity research. In the literature review, a lot of studies are developed to evaluate criteria. Kim et al. [6] evaluate the skills required for information security and recommend courses for experiential learning opportunities. Hyo Jung et al. [7] develop criteria to evaluate educational institutions for information security. Christoph et al. [8, 9] mention the risks of digital hacking in industry. Other researchers proposed unauthorized access, directed attacks, malevolent patterns, and denial of service [10, 11]. Lopez et al. [12] define an appropriate cybersecurity platform to minimize cyber threats. Jansen [8] presents the weak points in IT systems in which hackers can be compromised.

The remaining parts of our study are provided below. In section 2, a proposed methodology for evaluating cybersecurity is described. In section 3, the managerial implications are presented. This study's conclusions and recommendations for the future are presented in Section 4.

2 | Approach

A multi-criteria decision-making procedure offers a ranking system for determining which quantitative solution among a group is the best. We used the entropy approach in this research study to determine the weight of the attributes. In matrix format, an MCDM problem can be written as Eq. (1). We can choose the m alternatives and n criteria as the decision matrix.

$$X = \begin{Bmatrix} x_{11} \; x_{12} \cdots x_{1j} \; \cdots \cdots x_{1m} \\ x_{21} \; x_{22} \cdots x_{2j} \; \cdots \cdots x_{2m} \\ \cdots \quad \cdots \cdots \cdots \; \cdots \cdots \; \cdots \\ \cdots \quad \cdots \cdots \cdots \; \cdots \cdots \; \cdots \\ x_{n1} \; x_{n2} \cdots x_{nj} \; \cdots \cdots x_{nm} \end{Bmatrix} \tag{1}$$

2.1 | Entropy Method

We will use entropy to determine the weights of the criteria in MCDM problems that will be used to get the rank of the alternatives. This method [13] will be applied in the following steps.

Step 1: We collected data from experts' decisions based on the single-valued neutrosophic scale [14].

Step 2: Converting the linguistic terms into crisp as in Table 1 and normalizing it by Eq. (2):

$$s(Q_{ij}) = \frac{(2+T_r-F1-Id)}{3} \quad (2)$$

Where T_r refers to true, F1 refers to false, and Id refers to indeterminacy.

Table 1. Experts' data.

Expert 1	IT Infrastructure & Operations (ITO)	Digital Marketing (DM)	Data & Analytics (DA)	Risk (R)	Research & Development (RD)
Attack surface expansion A1	0.9	0.10	1	0.1	0.72
Identity system defense A2	0.82	0.18	0.82	0.72	0.18
Digital supply chain risk A3	0.62	0.55	0.62	0.82	0.9
Vendor consolidation A4	0.5	0.18	0.55	0.62	0.18
Cybersecurity mesh A5	0.55	0.62	0.55	0.18	0.82
Distributed decisions A6	0.82	0.18	0.82	0.72	0.18
Beyond awareness A7	0.5	0.10	0.5	0.62	0.18
Expert 2	**ITO**	**DM**	**DA**	**R**	**RD**
A1	0.82	0.50	0.62	0.72	0.18
A2	0.82	0.18	0.9	0.1	0.18
A3	0.72	0.55	1	0.82	0.82
A4	0.5	0.18	0.18	0.18	0.72
A5	0.1	1.00	0.5	0.62	0.9
A6	0.82	0.50	0.82	0.72	0.18
A7	0.72	0.55	1	0.82	0.82
Expert 3	**ITO**	**DM**	**DA**	**R**	**RD**
A1	0.82	0.62	0.52	0.72	0.18
A2	0.72	0.18	0.1	0.9	0.55
A3	0.82	0.10	1	0.62	0.82
A4	0.18	0.50	0.55	0.72	0.18
A5	0.55	1.00	0.5	0.82	0.9
A6	0.5	0.50	0.62	0.72	0.55
A7	0.82	0.62	0.62	0.72	0.18
Expert 4	**ITO**	**DM**	**DA**	**R**	**RD**
A1	0.62	0.82	0.72	0.9	0.18
A2	0.9	0.18	0.1	0.9	0.52
A3	0.82	0.10	0.9	0.62	0.72
A4	0.18	0.50	0.55	0.72	0.18
A5	0.18	0.18	0.5	0.9	0.9
A6	0.18	0.50	0.55	0.72	0.18
A7	0.55	0.18	0.18	0.18	0.62

Step 3: Combine the pairwise comparison matrix to make one matrix that aggregates the expert's opinions as in Table 2.

Table 2. Aggregated matrix.

	ITO	DM	DA	R	RD
A1	0.79	0.51	0.715	0.61	0.315
A2	0.815	0.18	0.48	0.655	0.3575
A3	0.745	0.325	0.88	0.72	0.815
A4	0.34	0.34	0.4575	0.56	0.315
A5	0.345	0.7	0.5125	0.63	0.88
A6	0.58	0.42	0.7025	0.72	0.2725
A7	0.6475	0.3625	0.575	0.585	0.45

Step 4: Compute the feature weight P_{ij} in decision matrix by Eq. (3) as in Table 3:

$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{3}$$

where m number of alternatives, j is a reverse index, x_{ij} is the performance value in each cell.

Table 3. Features weight.

	ITO	DM	DA	R	RD
A1	0.183188	0.179736	0.165414	0.136161	0.092511
A2	0.188986	0.063436	0.111047	0.146205	0.104993
A3	0.172754	0.114537	0.203586	0.160714	0.239354
A4	0.079765	0.119824	0.105842	0.125	0.092511
A5	0.08	0.246696	0.118566	0.140625	0.258443
A6	0.134493	0.148018	0.162522	0.160714	0.080029
A7	0.150145	0.127753	0.133025	0.13058	0.132159

Step 5: Compute the entropy for project outcomes as in Table 4 using the following equation:

$$E_j = \left(-k \sum_{i=1}^{m} P_{ij} \ln P_{ij}\right) \quad (j = 1,2,3, \ldots \ldots, n) \tag{4}$$

$$k = \frac{1}{\ln(m)} \tag{5}$$

Table 4. The output of entropy.

p_{ij}*ln(p_{ij})		ITO	DM	DA	R	RD
	A1	-0.31091	-0.30847	-0.29763	-0.27149	-0.22022
	A2	-0.31487	-0.17494	-0.24406	-0.28112	-0.23664
	A3	-0.30334	-0.24819	-0.32404	-0.29381	-0.34223
	A4	-0.2017	-0.25423	-0.2377	-0.25993	-0.22022
	A5	-0.20206	-0.34528	-0.25282	-0.27586	-0.34969
	A6	-0.26983	-0.28278	-0.29529	-0.29381	-0.2021
	A7	-0.2847	-0.26287	-0.26834	-0.26583	-0.26746
Sum		-1.89644	-1.87676	-1.91988	-1.94184	-1.83856
Ej		-0.912	-0.90253	-0.92327	-0.93383	-0.88416

Step 6: Calculate the variation coefficient as in Table 5 by Eq. (6):

$$d_j = 1 - E_j \tag{6}$$

Table 5. The variation of coefficient.

1-Ej	1.911995	1.90253	1.923267	1.933828	1.884158

Step 7: Compute the weight as in Table 6 by the following formula:

$$w_j = \frac{d_j}{\sum_{i=1}^{m} d_j} \quad (7)$$

Table 6. Weight of the entropy.

W	0.200088	0.199031	0.201201	0.202306	0.197109

2.2 | Weighted Sum Model

Evaluating the several alternatives for rankings using a weighted sum model in terms of several decision criteria [15]. We can apply multi-criteria decision-making (MCDM) techniques such as the weighted sum model (WSM), which can obtain the best results [16].

Step 1: Normalized the aggregated matrix as in Table 7 by the following equation:

$$n_{ij} = \begin{cases} \frac{\min . x_{ij}}{x_{ij}} & if \quad j \in \mathrm{C} \\ \frac{x_{ij}}{\max . x_{ij}} & if \quad j \in \mathrm{B} \end{cases} \quad (8)$$

Table 7. Normalized aggregate matrix.

	ITO	DM	DA	R	RD
Weight	0.200088	0.199031	0.201201	0.202306	0.197109
A1	0.969325	0.728571	0.8125	0.918033	0.357955
A2	1	0.257143	0.545455	0.854962	0.40625
A3	0.91411	0.464286	1	0.777778	0.926136
A4	0.417178	0.485714	0.519886	1	0.357955
A5	0.423313	1	0.582386	0.888889	1
A6	0.711656	0.6	0.798295	0.777778	0.309659
A7	0.794479	0.517857	0.653409	0.957265	0.511364

where n_{ij} is the normalized value of ith alternatives for jth criteria, C is the cost criteria, B is the benefits, $\min . x_{ij}$ and $\max . x_{ij}$ are the minimum and maximum value of the x_{ij}. We apply the benefit equation for ITO, DM, DA, RD, and the cost equation for R.

Step 2: Calculated the weighted normalized matrix as in Table 8 by the following equation:

$$w_{n_{ij}} = w_j \, n_{ij} \quad (9)$$

Table 8. Weighted normalized matrix.

	ITO	DM	DA	R	RD
A1	0.19395	0.145009	0.163476	0.185723	0.070556
A2	0.200088	0.051179	0.109746	0.172964	0.080076
A3	0.182902	0.092407	0.201201	0.157349	0.18255
A4	0.083472	0.096672	0.104602	0.202306	0.070556
A5	0.0847	0.199031	0.117177	0.179827	0.197109
A6	0.142394	0.119419	0.160618	0.157349	0.061037
A7	0.158966	0.10307	0.131466	0.19366	0.100795

Step 3: Ranking of alternatives as in Table 9 by the following equation:

$$S_i^{WSM} = \sum_{i=1}^{n} w_j \, n_{ij} \tag{10}$$

Where S_i^{WSM} is the ranking score of ith alternatives, w_j is the weight of the jth criteria.

Table 9. Ranking of alternatives.

Preference Score		Rank
A1	0.758714	3
A2	0.614052	6
A3	0.81641	1
A4	0.557608	7
A5	0.777844	2
A6	0.640816	5
A7	0.687956	4

Results as appears in Figure 1, show that the best alternatives obtained have the heights value for rank. A3 which refers to (Digital supply chain risk) is the best one of all alternatives.

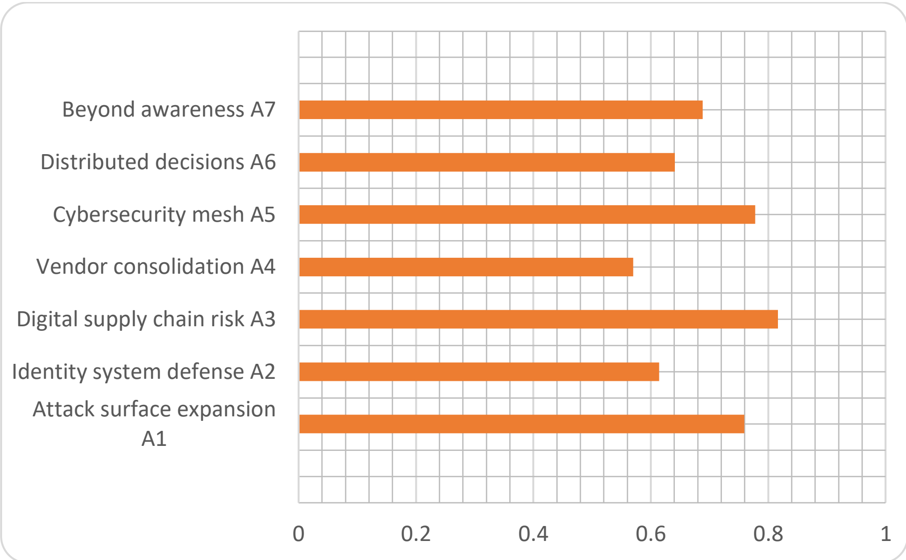

Figure 1. Ranking result.

3 | Managerial Implications

Cybersecurity is crucial for protecting sensitive data stored on any device due to the increasing amount of information. So, this study evaluates cybersecurity using neutrosophic multi-criteria decision-making techniques such as entropy to obtain weight and the weighted sum model, for ranking and obtaining the best digital footprint of modern organization's cybersecurity. The presented model can be a dominant guide for protecting firms, organizations, and governments in medical, social, economic, and environmental domains.

4 | Conclusion

Cybersecurity is a collection of techniques and tools to protect cyber environments from unauthorized access or attacks. This study is proposed to evaluate the metrics of cybersecurity. According to the results of the research, we conduct a study that considers the internet risks to determine the importance of cybersecurity's digital footprint. The way to think about measuring security metrics is the multi-criteria decision-making approach. We apply neutrosophic sets for the experts' data, then apply the entropy approach to get the weight of criteria and to get rank and the priorities for the best alternatives. The weighted sum model selects A3 which refers to (Digital supply chain risk) as the best one of all alternatives.

In the future, we will use the proposed model in various problems like the robot selection process, machine selection, and others. Also, we tend to combine the suggested method with other methods such as AHP, VIKOR, and TOPSIS.

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Author Contribution

All authors contributed equally to this work.

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Data Availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that there is no conflict of interest in the research.

Ethical Approval

This article does not contain any studies with human participants or animals performed by any of the authors.

References

[1] Kethineni, S.J.T.P.H.o.I.C. and Cyberdeviance, Cybercrime in India: Laws, regulations, and enforcement mechanisms. 2020: p. 305-326.

[2] Verma, R., S. Koul, K.J.D.M.A.i.M. Ajaygopal, and Engineering, Evaluation and Selection of a Cybersecurity Platform—Case of the Power Sector in India. 2024. 7(1): p. 209-236.

[3] Von Solms, R., J.J.c. Van Niekerk, and security, From information security to cyber security. 2013. 38: p. 97-102.

[4] gartner, https://www.gartner.com/en/about. 2019.

[5] Cybersecurity, T.T.i., https://www.gartner.com/en/articles/7-top-trends-in-cybersecurity-for-2022 2022.

[6] Kim, T.-Y., S.-K. Park, H.-J. Jun, T.-S.J.I.J.o.S. Kim, and Technology, An Evaluation Model for Private Information Security Education Programs in South Korea. 2016.

[7] Jun, H.-J., T.-S. Kim, and Y.-B.J.T.J.o.t.K.C.A. Kim, Assessment Criteria of Information Security Training Centers for Personnels of Educational Institutions. 2013. 13(12): p. 455-462.

[8] Jansen, C., S.J.A. Jeschke, and Society, Mitigating risks of digitalization through managed industrial security services. 2018. 33: p. 163-173.

[9] Lezzi, M., M. Lazoi, and A.J.C.i.I. Corallo, Cybersecurity for Industry 4.0 in the current literature: A reference framework. 2018. 103: p. 97-110.

[10] Jansen, C.J.I.-P., Stabilizing the industrial system: Managed security services' contribution to cyber-peace. 2017. 50(1): p. 5155-5160.

[11] Corbò, G., C. Foglietta, C. Palazzo, S.J.M.N. Panzieri, and Applications, Smart behavioural filter for industrial internet of things: A security extension for plc. 2018. 23: p. 809-816.

[12] Alba, C.M. Intelligent detection and recovery from cyberattacksfor small and medium-sized enterprises. in Investigación en Ciberseguridad Actas de las VII Jornadas Nacionales (7º. 2022. Bilbao). 2022. Fundación Tecnalia Research and Innovation.
[13] Singh, V., Entropy-based parameter estimation in hydrology. Vol. 30. 1998: Springer Science & Business Media.
[14] Abdel-Basset, M., A. Gamal, N. Moustafa, A. Abdel-Monem, and N.J.I.A. El-Saber, A security-by-design decision-making model for risk management in autonomous vehicles. 2021. 9: p. 107657-107679.
[15] Mesran, M., S. Suginam, S.D. Nasution, and A.P.U.J.J. Siahaan, Penerapan Weighted Sum Model (WSM) Dalam Penentuan Peserta Jaminan Kesehatan Masyarakat. 2017. 2(1): p. 40-47.
[16] Solikhun, S.J.K.-K.J.I.K., Perbandingan metode weighted product dan weighted sum model dalam pemilihan perguruan swasta terbaik jurusan komputer. 2017. 4(1): p. 70-87.