



INTERNATIONAL JOURNAL OF SCIENCE FOR GLOBAL SUSTAINABILITY

Cross-Infection and Risk Prevention in Production Environment: A Multi-criteria Decision-making Approach

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Received on: August, 2023

Revised and Accepted on: September, 2023

Published on: October, 2023

ABSTRACT

Manufacturing relies heavily on the physical presence of human resources, and disease outbreaks that force separation, such as: COVID-19, harm output. As a solution to the problem, this paper proposes a new Hybrid Multi-criteria Decision-making (H-MCDM) model based on the Intuitionistic Fuzzy Weighted Geometric (IFWG) operator, the Intuitionistic Fuzzy Hamacher Interactive Weighting Averaging (IFHIWA) operator, and the Intuitionistic Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (IF-TOPSIS) method for the evaluation, management, and prevention planning. In addition to the role that modeling played in solving the cross-infection problem, the results obtained from putting the model through its implementation show that the use of protective materials during manufacturing operations is the most suitable among the finite alternatives considered, when the safety of the workforce/workplace, cost of implementing risk-mitigating actions, virus transmission level, and ease of implementation are all taken into account. Thus, the proposed model has been validated through a feasibility test, so contributes to maintaining production and reducing cross-infections in workplaces while an epidemic is ongoing.

Keywords: H-MCDM model; IF-TOPSIS; Risk Mitigation Actions; Manufacturing organization; COVID-19.

1.0 INTRODUCTION

COVID-19 has revealed labour market inequities and existing manufacturing practices contribute to inequities. Manufacturing is extremely dependent on the physically present existence of human resources; as a result, production is negatively impacted by disease outbreaks such as COVID-19 if force employees to work from distance. In these cases, the continuity of production is one side of a coin, and protecting people's health is the other.

In fact, the elimination of workplace hazards in the manufacturing sector has remained a major challenge for so many years now. It is particularly worrisome that the injury/death rate as a result of these hazards has increased significantly over the past two years (Liu *et al.*, 2020), mainly due to the recent COVID-19 pandemic. Workers and the products they produce are now at the risk of being exposed to injury, infections, and contaminations due to the pandemic that is ravaging several countries and their manufacturing establishments (Babu, 2020). This has led to so many prominent

occupational safety and health workers that should ordinarily be managing and controlling the workplace hazards, practices, and policies on site, now absenting themselves from work due to fear of contacting the COVID-19 virus. While others, needing special care are made to stay away (working from home) to avoid the possibility of COVID-19 exposure on the manufacturing shop floor or the contamination of the produced products.

Since, stakeholders in the manufacturing industry needs to reduce the risk due to the COVID-19 virus in their respective workplaces and factory, deploying measures to protect the health and safety of workers, visitors, and the produced products within the manufacturing shop floor cannot be over emphasized. COVID-19, which is a public health emergency, is exceptional by any standards and requires everyone to join in the assessment and management of the virus risks especially since it comes with an extreme level and scope of uncertainty (Butler & Rivera, 2020). The

assessment which can be described as a big decision for management, are expected to create efficiencies in production, maintenance, and the safety of the entire workforce and workplace throughout the period of the pandemic and post-pandemic.

Workplaces as we know them can be described as a setting (indoor or outdoor) where a large group of persons shares many hours of their day/night. According to the WHO, these kinds of settings is the main facilitator of the transmission of the COVID-19 disease (Huang *et al.*, 2020). COVID-19 which is transmitted from person to person spreads mostly through respiratory droplets, some of which are through sneezing, coughing, talking (close interactions), or laughing by an infected person (Pearce, 2020; Stadnytskyi *et al.*, 2020). In addressing this issue and preventing the disease spread in the manufacturing environment, there is need for a proper management and control of the workplace practices and policies by (1) providing a methodology for the assessment of likely multi-hazard risks due to the COVID-19 virus. (2) Prioritizing mitigating actions for the prevention of the COVID-19 virus spread in manufacturing, (3) Resilient preparedness and possible responses in the case outbreak, (4) The identification of industries or job types that has the highest potential for the transmission of the COVID-19 disease and finally, (5) A method that is capable of providing a better hazards risk forecast and a prevention technique. In this paper however, the study will be focused on the prioritization of risk mitigating actions, otherwise called the workplace cross-infection control strategy for the prevention of the COVID-19 virus spread in manufacturing industries. The challenges in achieving best practices in the management of mitigating actions for COVID-19 prevention in manufacturing are high (Koonin, 2020), hence, there is a need for a framework/model that could support the evaluation, planning, management, and prioritization of the risk-mitigating actions (Grafakos *et al.*, 2019). And to allow for the identification, of the most feasible and nationally acceptable measures for the mitigation of the COVID-19 risk in the manufacturing sector in Nigeria.

The main objective here is to reduce the risk within the manufacturing environment to the barest reasonably and practicable level, by providing a suitable and optimal workplace cross-infection control strategy (preventive measures). Where this is achieved by prioritizing the mitigation actions and providing a decision support tool, for the manufacturing sector. A novel Hybrid Multi-criteria Decision-making (H-MCDM) model that is based on the Intuitionistic Fuzzy Weighted Geometric (IFWG) operator, the Intuitionistic Fuzzy Hamacher Interactive Weighting Averaging (IFHIWA) operator and the Intuitionistic Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (IFTOPSIS) method have been proposed. For the evaluation, management and prioritization of the different risk-mitigating actions, that have been presented by researchers and the WHO for the prevention of COVID-19 virus spread in manufacturing organizations. The new H-MCDM model which draws both the advantages of the traditional intuitionistic fuzzy TOPSIS model and that of the two aggregation operators, addresses the dependency issues in the traditional TOPSIS model and the data interaction issues by using the IFWG operator in place of the Euclidean distance normally used in the traditional TOPSIS model. And the use of interaction function in the IFHIWA operator between the degree of membership and those of non-membership.

The remaining parts of this paper are organized as follows; in Section 2, the risk mitigating actions for the prevention of the spread of infections in manufacturing environment are reviewed. This is closely followed by the development of the H-MCDM Model in Section 3. The implementation of the model for the prioritization of COVID-19 risk-mitigating actions in Section 4. The discussion of the model results in Section 5 and the presentation of the concluding remarks in Section 6.

2.0 REVIEW OF RISK MITIGATING ACTION FOR THE PREVENTION OF THE SPREAD OF INFECTION IN MANUFACTURING

The outbreak of the COVID-19 virus have adversely affected production and productivity in several manufacturing organizations. This is more so since risks in the workplace now come with an

extreme level and scope of uncertainty (Butler & Rivera, 2020). According to Butler & Rivera, (2020), the key to managing the spread of infectious diseases like the COVID-19 virus is through a proper period of preparation. For the present COVID-19 cases, however, there are not many times for preparations; hence, available information that could lead to the prevention and reduction of the spread must be properly managed by prioritizing such prevention practices that can

reduce and control the COVID-19 virus spread in manufacturing organizations.

Following the different strategies adopted by key establishments in the fight against the COVID-19 virus spread, the spread, however, has been contained in some parts of the industrial hub of China (AITakarli, 2020). Some of the strategies that have found applications have been discussed in Table 1.

Table 1: Mitigating action for the prevention of COVID-19 Spread in Manufacturing Organisation/Sector

S/N	Mitigating Action for the Prevention of COVID-19 Spread in Manufacturing Firms	Definition
1.	The use of protective materials during manufacturing (A1) Disposable masks and gloves (A2) Disinfecting wipes (A3) Hand sanitizer with 60% alcohol or more (A4) Tissues and paper towels	With the growing research on the COVID-19 spread, it has been established that the use of protective materials can save the lives of manufacturing workers. Hence, manufacturing companies are encouraged to ensure all essential protective materials are on hand throughout their facilities (Kumar <i>et al.</i> , 2021)
2.	Reorganization of the workplace to keep employees at least 6 feet away from each other. (A5) Physical barriers (A6) Reduce staffing (A7) Modify workstations (A8) Change in the work procedures, hours, and shifts of workers (A9) Add additional space out chairs in break rooms	Social distancing has also been proven to check the spread of the COVID-19 virus. It reduces the risk of infection due to cough, sneezing, or speaking by the workers.
3	Regular environmental testing and discipline of the workforce. (A10) Cleaning and disinfection of manufacturing suppliers' products (A11) Spraying or fogging to disinfect manufacturing space (A12) The appropriate use, storage, and cleaning or disposal of protective materials including masks.	The routine application of disinfectants to the manufacturing environmental space and surfaces by spraying or fogging is one of the recommended means of reducing the transmission of the COVID-19 virus. (WHO, 2020)

3.0 DEVELOPMENT OF THE HYBRID MULTI-CRITERIA DECISION-MAKING (H-MCDM) MODEL

In this section, the H-MCDM model, which is based on the Intuitionistic Fuzzy Weighted Geometric (IFWG) operator, the Intuitionistic Fuzzy Hamacher Interactive Weighting Averaging (IFHIWA) operator, and the Intuitionistic Fuzzy

Technique for Order of Preference by Similarity to Ideal Solution (IFTOPSIS) method is introduced. First, the basic definitions and concepts of the Intuitionistic Fuzzy set (IFS) as described in (Atanassov, 1986; Despic & Simonovic, 2000) are presented. This is then followed by the introduction of the aggregation operators and then the Intuitionistic Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (IFTOPSIS) method (Aikhuele & Turan, 2017). Finally, the algorithm of the H-MCDM model is presented.

3.1. Intuitionistic Fuzzy Set (IFS)

The intuitionistic fuzzy set (IFS) was developed by Atanassov (Atanassov, 1986) from the fuzzy set theory originally presented by Zadeh, (1965). The intention here was to provide a better means of expressing imprecise and uncertain information when making decisions. This is particularly important due to the complex nature of most of the presented day cooperate decisions. The mathematical form of the IFS has been expressed in the Definition 1 and 2, as discussed in (Atanassov, 1986; Despic & Simonovic, 2000).

Definition 1

If a set $X = \{x\}$ is fixed, then an IFS of A in the X universe of discourse can be defined by the formations as presented in Equation (1),

$$A = \{ \langle x, \mu_A(x), \nu_A(x) \rangle | x \in X \} \quad (1)$$

where $\mu_A(x)$ and $\nu_A(x)$ are the membership and non-membership functions of the set. These functions can be referred to as the intuitionistic fuzzy numbers (IFN) of the set and are expressed in the form $\alpha = (\mu_A, \nu_A)$, where $\mu_A \in (0,1)$ and $\nu_A \in (0,1)$ respectively.

The IFS is bounded by the constraint $0 \leq \mu_A(x) + \nu_A(x) \leq 1, \forall x \in X$, while the intuitionistic fuzzy hesitation degree of the set which is also referred to or represents the non-determinacy or uncertainty in the set $\{x\}$ that belongs to the IFS of A , is given as;

$$\pi_A(x) = 1 - \mu_A(x) - \nu_A(x) \quad (2)$$

This degree, however, will arise only when there is a relative lack of knowledge, error, or uncertainty of any form in the IFS, particularly when; $1 - \mu_A(x) - \nu_A(x) = 0$. For every element $x \in X$ in A , the IFS A belongs to the fuzzy set, where $0 \leq \pi_A \leq$

1, hence, the intuitionistic fuzzy number (IFN) is given as $\alpha = (\mu_A, \nu_A, \pi_A)$ or as $\alpha = (\mu_A, \nu_A)$ for short.

Definition 2 (Atanassov, 1994)

If the IFN is given as $\alpha = (\mu_A, \nu_A, \pi_A)$ or as $\alpha = (\mu_A, \nu_A)$, when $\lambda > 0$, then the operational laws for the set can be given as,

$$A \cdot B = \{ \langle x, \mu_A(x) \cdot \mu_B(x), \nu_A(x) + \nu_B(x) - \nu_A(x) \cdot \nu_B(x) \rangle | x \in X \} \quad (3)$$

$$A + B = \{ \langle x, \mu_A(x) + \mu_B(x) - \mu_A(x) \cdot \mu_B(x), \nu_A(x) \cdot \nu_B(x) \rangle | x \in X \} \quad (4)$$

$$\lambda A = \{ \langle x, 1 - (1 - \mu_A(x))^\lambda, (\nu_A(x))^\lambda \rangle | x \in X \}, \lambda > 0. \quad (5)$$

$$A^\lambda = \{ \langle x, (\mu_A(x))^\lambda, 1 - (1 - \nu_A(x))^\lambda \rangle | x \in X \}, \lambda > 0 \quad (6)$$

3.2. Intuitionistic Fuzzy Aggregation Operators

The aggregation of information is a very important part of critical decision-making in engineering management and other science-based professions. The information which is normally aggregated using aggregation operators uses a special mathematical function(s) that are used in the quantification of such information and for joining and summarizing the information from the different sources.

Typical aggregation operators that have found applications for joining and summarizing the information in engineering include. The generalized triangular intuitionistic fuzzy geometric averaging operator (Aikhuele & Odofin, 2017), dynamic intuitionistic fuzzy Einstein geometric averaging (DIFWG ϵ) operator (Gümüş & Bali, 2017), and the ordered weighted averaging (OWA) operator (Yager, 1988). In this study, however, the Intuitionistic Fuzzy Hamacher Interactive Weighting Averaging (IFHIWA) operator and the Intuitionistic Fuzzy Weighted Geometric (IFWG) operator have been proposed. Basically for the aggregation of expert information used in the management and prioritization of the different risk-mitigating actions, which have been presented by researchers and the WHO for the prevention of COVID-19 virus spread in

manufacturing organizations. Detail definition of the operation is given below.

Definition 3 (Xu & Yager, 2006)

If $\alpha_{ij} = (\mu_{\alpha_{ij}}, \nu_{\alpha_{ij}})$ represent the IFN for all $(i = j = 1, 2, 3, \dots, n)$, then the Intuitionistic Fuzzy Weighted Geometric (IFWG) operator of the dimension n is a mapping IFWG: $\Omega^n \rightarrow \Omega$ such that:

$$IFWG(d_1, d_2, d_3, \dots, d_n) = \left(\prod_{i=1}^n (\mu_{ij})^{\omega_j}, 1 - \prod_{i=1}^n (1 - \nu_{ij})^{\omega_j} \right)$$

where $\omega_i = (\omega_1, \omega_2, \omega_3, \dots, \omega_n)^T$ is the weighting vector of $\alpha_{ij} (i = j = 1, 2, 3, \dots, n)$ with $\omega_i \in [0.1]$.

Definition 4

If $\sigma_i = \mu_{\sigma_i}, \nu_{\sigma_i}$, represent the IFN for all $(i = 1, 2, 3, \dots, n)$ where $\omega_i = (\omega_1, \omega_2, \omega_3, \dots, \omega_n)^T$ is the weighting vector of $\alpha_i (i = 1, 2, 3, \dots, n)$ with $\omega_i \in [0.1]$, then Intuitionistic Fuzzy Hamacher Interactive Weighting Averaging (IFHIWA) operator of the dimension n is a mapping IFWG: $\Omega^n \rightarrow \Omega$ such that:

$$IFHIWA(\sigma_1, \sigma_2, \sigma_3, \sigma_4, \dots, \sigma_n) = \left[\frac{\prod_{i=1}^n (1 + (\gamma - 1)\mu_{\sigma_i})^{\omega_i} - \prod_{i=1}^n (1 - \mu_{\sigma_i})^{\omega_i}}{\prod_{i=1}^n (1 + (\gamma - 1)\mu_{\sigma_i})^{\omega_i} + (\gamma - 1) \prod_{i=1}^n (1 - \mu_{\sigma_i})^{\omega_i}}, \frac{\gamma \{ \prod_{i=1}^n (1 - \mu_{\sigma_i})^{\omega_i} - \prod_{i=1}^n (1 - \mu_{\sigma_i} - \nu_{\sigma_i})^{\omega_i} \}}{\prod_{i=1}^n (1 + (\gamma - 1)\mu_{\sigma_i})^{\omega_i} + (\gamma - 1) \prod_{i=1}^n (1 - \mu_{\sigma_i})^{\omega_i}} \right] \quad (8)$$

where $\gamma = 2$, it will be given as the interaction function of the membership and non-membership function of the IFWG operator.

3.3. Intuitionistic Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (IF-TOPSIS) Model

The IF-TOPSIS model is a very popular multi-criteria decision-making model that has been applied in so many engineering-based decision-making processes (Aikhuele, 2019; Turan *et al.*, 2017). The model which works on the principle that measures distances in the Euclidean norm assumes that all the attributes/criteria used in the decision-making process are independent (Hung & Chen, 2009; Joshi & Kumar, 2014; Nan *et al.*, 2016). However, this may not be the case for some of the attributes/criteria used in making engineering-based decisions, since so many of them are interrelated in nature and depends on one another (Aikhuele, 2019).

In this paper, these dependency issues in the attributes/criteria used for the decision-making have been addressed by the use of the Intuitionistic Fuzzy Weighted Geometric (IFWG) operator as the measures of the distances between each of the alternatives from the positive and negative ideal solutions. While the Intuitionistic Fuzzy Hamacher Interactive Weighting Averaging (IFHIWA) operator is used for the aggregation of the expert's opinions as relates to the study. The proposed algorithm for the H-MCDM model is presented below. First, the type of problem that the algorithm intended to solve is presented.

3.4. Problem description and the model algorithm

Let's consider an engineering decision-making problem that is multi-criteria in nature. That is if a set of alternatives say $(Al_i = Al_1, Al_2, Al_3, \dots, Al_n)$ are to be evaluated with respect to a set of interrelated attributes/criteria that are dependent on each other $(Atr = Atr_1, Atr_2, Atr_3, \dots, Atr_n)$. If the level of importance (weight) of the different attributes/criteria is known, then the algorithm presented below can be used in solving and making decisions.

Model Algorithm

Step 1: Invite several experts with experience and expertise to evaluate and prioritize the different risk-mitigating actions that have been presented by researchers and the WHO for the prevention of COVID-19 virus spread in manufacturing organizations. To ensure accuracy in the evaluation process, the experts should be selected from the academic and the industry.

Step 2: Develop a questionnaire template with the risk mitigation actions and the attributes/criteria, such that the experts can evaluate their respective influences. This questionnaire template which is also called the intuitionistic fuzzy decision matrix $(Al_{m \times n} = (x_{ij}))$, is used to obtain preference information about the risk mitigation actions and the attributes/criteria from the invited group of experts. The preference information which could be obtained using a scale of linguistic variables (Likert scale) from each of the experts, can also be converted to the intuitionistic fuzzy number (IFN) which is the main computational

language of the H-MCDM model algorithm. The numerical sample of the intuitionistic fuzzy decision matrix after it has been converted to the IFN is presented below.

$$Al_{m \times n}(x_{ij}) = \begin{matrix} Al_i \\ \dots \\ Al_1 \\ Al_2 \\ Al_3 \\ \vdots \\ \vdots \\ Al_n \end{matrix} \begin{bmatrix} Atr_1 & Atr_2 & Atr_3 & Atr_4 & Atr_4 \\ (\mu_{ij}, v_{ij}) & \dots & \dots & \dots & (\mu_{ij}, v_{ij}) \\ (\mu_{11}, v_{11}) & (\mu_{12}, v_{12}) & (\mu_{13}, v_{13}) & (\mu_{14}, v_{14}) & (\mu_{15}, v_{15}) \\ (\mu_{21}, v_{21}) & (\mu_{22}, v_{22}) & (\mu_{23}, v_{23}) & (\mu_{24}, v_{24}) & (\mu_{25}, v_{25}) \\ (\mu_{31}, v_{31}) & (\mu_{32}, v_{32}) & (\mu_{33}, v_{33}) & (\mu_{34}, v_{34}) & (\mu_{35}, v_{35}) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ (\mu_{n1}, v_{n1}) & (\mu_{n2}, v_{n2}) & (\mu_{n3}, v_{n3}) & (\mu_{n4}, v_{n4}) & (\mu_{n5}, v_{n5}) \end{bmatrix} \quad (9)$$

where Al_i is the set of alternatives (the risk mitigation actions), Atr_{1-5} are the attributes/criteria, while (μ_{ij}, v_{ij}) are the IFN.

Step 3: Aggregate the preference information given by the individual experts using the Intuitionistic Fuzzy Hamacher Interactive Weighting Averaging (IFHIWA) operator -equation (8).

Step 4: With the weight vectors of the attributes/criteria, construct the weighted normalization matrix from the aggregated preference information.

Step 5: Determine the Intuitionistic Fuzzy Positive Ideal Solution (IFPIS) and the Negative Ideal Solutions (IFNIS), which are mostly given as the maximum and minimum values respectively, obtained from the weighted normalization matrix for each of the attributes/criteria. Numerical representation of the above according to (Daniel O Aikhuele et al., 2022) is given as,

$$S^+ = \left\{ \left\langle T_j, \left((\max \mu_{ij}(T_j) | j \in B), (\min \mu_{ij}(T_j) | j \in C) \right), \right\rangle | i \in m \right\} \quad (10)$$

$$S^- = \left\{ \left\langle T_j, \left((\min \mu_{ij}(T_j) | j \in B), (\max \mu_{ij}(T_j) | j \in C) \right), \right\rangle | i \in m \right\} \quad (11)$$

where B be a collection of benefit attributes/criteria and C is the collection of cost attributes/criteria when they are categorized as benefit and cost.

Step 6: With the values of the IFPIS and the IFNIS in place, the distances between each of the alternatives to the positive and negative ideal solutions can be calculated using the IFWG operator in equation 7.

Step 8: Compute the Closeness Coefficient (CC) of all the alternatives from step 6 above. This can be obtained using the numerical formation, this has been discussed in (Aikhuele et al., 2020).

$$CC_i = \frac{IFWG(S^-)}{IFWG(S^-) + IFWG(S^+)} \quad (12)$$

Step 9: Rank the alternatives. The flow chart of the model algorithm has been presented in Figure 1.

Invite several experts with a verifiable experience and expertise to evaluate and prioritize the different risk-mitigating actions using a questionnaire with a Likert scale and their corresponding IFN

Determine the Intuitionistic Fuzzy Positive and Negative Ideal solution (IFPIS & IFNIS) and then the closeness coefficient values of the alternatives.

Rank the alternatives

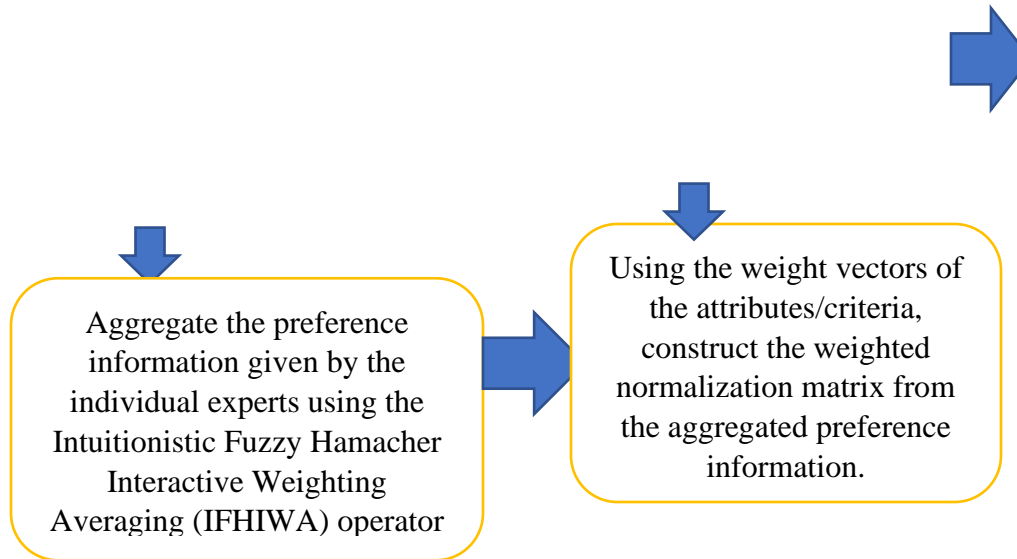


Figure 1: Flowchart of the model algorithm for the prioritization of COVID-19 risk-mitigating actions.

4.0 IMPLEMENTATION OF THE H-MCDM MODEL FOR THE PRIORITIZATION OF COVID-19 RISK-MITIGATING ACTIONS

In this section, the H-MCDM model is implemented for the evaluation and prioritization of the different risk-mitigating actions (See Table 1) that have been presented by researchers and the WHO for the prevention of COVID-19 virus spread in manufacturing organizations by using the following attributes/criteria.

- Safety of the workforce and workplace due to the risk-mitigating actions (SWWRMA)
- Cost of implementing the risk-mitigating actions (CIRMA)
- Transmission level of COVID-19 virus upon the implementation of the risk-mitigating actions (TLIRMA)
- Ease in the implementation of the risk-mitigating actions (EIRMA) and
- Effectiveness/reliability of the risk-mitigating actions (ERRMA) on the manufacturing shop floor.

In the prioritization of the risk-mitigating actions, it is assumed that all related information as regards the spread of COVID-19 in manufacturing organizations is known by the invited experts. Also, the evaluation and prioritization process presented in the study is a unique case study carried out in the city of Lagos, and may not achieve the same results

when a different set of experts are invited or involved in other cities or countries.

Using the model algorithm presented in Section 3.4, four-man expert evaluators with background in health and safety, manufacturing engineering, and reliability management were invited to give their expertise opinion on the risk-mitigating actions with respect to the different attributes/criteria (invited to give data for the evaluation of the risk-mitigating actions). Using their highest educational qualifications, some of which include, a Postgraduate Diploma in Engineering degree for the first expert [E_1], Masters of Engineering for the second expert [E_2], and a Bachelor of Engineering for the third expert [E_3], and Doctor of Engineering for the fourth expert [E_4], the following weight vectors $E_{wv} = \{0.2, 0.3, 0.1, 0.4\}$, were assigned to the experts, this is based on similar studies presented (P. Liu et al., 2014; Wu & Liu, 2013). Here the four-man experts are assigned these weight vectors to incorporate or reflex their influence on the final result. While the weight vectors $At_{wv} = \{0.7530, 0.7884, 0.7646, 0.7806, 0.72551\}$, were assigned to the different attributes/criteria respectively.

5.0 Results and discussion

With the expert's weight vectors, the opinion of the individual experts as it relates to the risk-mitigating actions that have been obtained using the developed

questionnaire template (see Appendix 1) are aggregated using the IFHIWA operator. The obtained linguistic variables from the experts can be found in Table 1AP in the Appendix section, while the aggregated preference information after the linguistic variables have been converted to the IFN is presented in Table 2. Using the weight

vectors assigned to the different attributes/criteria above, a weighted normalization matrix is computed according to Step 4 of the model algorithm. The results of the computed weighted normalization matrix (WNM) for the risk-mitigating actions and the different attributes/criteria are shown in Table 3

Table 2: Experts aggregated preference opinions and information for the risk-mitigating actions

	SWWRMA	CIRMA	TLIRMA	EIRMA	ERRMA
A1	(0.6306, 0.3034)	(0.5917, 0.3371)	(0.5423, 0.3683)	(0.5423, 0.3683)	(0.5481, 0.3685)
A2	(0.5628, 0.3554)	(0.4741, 0.4203)	(0.3518, 0.5291)	(0.6302, 0.2689)	(0.6614, 0.2148)
A3	(0.6464, 0.2723)	(0.5849, 0.3540)	(0.3822, 0.5060)	(0.6616, 0.2383)	(0.6707, 0.2421)
A4	(0.5457, 0.3537)	(0.2562, 0.6007)	(0.6616, 0.2383)	(0.2562, 0.6007)	(0.1000, 0.7000)
A5	(0.6553, 0.2873)	(0.5675, 0.3558)	(0.1635, 0.6610)	(0.6464, 0.2723)	(0.5849, 0.3540)
A6	(0.4148, 0.4668)	(0.6724, 0.1649)	(0.2861, 0.5804)	(0.4000, 0.5000)	(0.5383, 0.3739)
A7	(0.5129, 0.3931)	(0.6500, 0.3000)	(0.3348, 0.5303)	(0.4224, 0.4774)	(0.6416, 0.2713)
A8	(0.6724, 0.1649)	(0.6473, 0.2002)	(0.5383, 0.3739)	(0.5675, 0.3558)	(0.5423, 0.3683)
A9	(0.6085, 0.2830)	(0.5387, 0.3892)	(0.6473, 0.2002)	(0.6371, 0.2206)	(0.6302, 0.2689)
A10	(0.6857, 0.1823)	(0.6266, 0.2407)	(0.1000, 0.7000)	(0.6306, 0.3034)	(0.6807, 0.2043)
A11	(0.6355, 0.3029)	(0.6000, 0.3000)	(0.2257, 0.6209)	(0.6266, 0.2407)	(0.6306, 0.3034)
A12	(0.6857, 0.1823)	(0.6133, 0.3203)	(0.4000, 0.5000)	(0.6616, 0.2383)	(0.6657, 0.2585)

Table 3: The WNM for the risk-mitigating actions and the different attributes/criteria

	SWWRMA		CIRMA		TLIRMA		EIRMA		ERRMA	
A1	0.4749	0.2284	0.4665	0.2658	0.4147	0.2816	0.4233	0.2875	0.3977	0.2673
A2	0.4238	0.2676	0.3737	0.3314	0.2690	0.4045	0.4919	0.2099	0.4799	0.1558
A3	0.4867	0.2051	0.4611	0.2791	0.2922	0.3869	0.5164	0.1860	0.4866	0.1757
A4	0.4110	0.2663	0.2019	0.4736	0.5059	0.1822	0.2000	0.4689	0.0726	0.5079
A5	0.4934	0.2163	0.4474	0.2805	0.1250	0.5054	0.5046	0.2126	0.4243	0.2569
A6	0.3123	0.3515	0.5301	0.1300	0.2188	0.4438	0.3122	0.3903	0.3906	0.2713
A7	0.3862	0.2960	0.5124	0.2365	0.2560	0.4055	0.3297	0.3726	0.4655	0.1968
A8	0.5063	0.1242	0.5103	0.1578	0.4116	0.2859	0.4430	0.2778	0.3935	0.2672
A9	0.4582	0.2131	0.4247	0.3068	0.4949	0.1530	0.4973	0.1722	0.4572	0.1951
A10	0.5163	0.1373	0.4940	0.1897	0.0765	0.5352	0.4923	0.2368	0.4939	0.1482
A11	0.4786	0.2281	0.4730	0.2365	0.1726	0.4748	0.4892	0.1879	0.4575	0.2201
A12	0.5163	0.1373	0.4835	0.2525	0.3058	0.3823	0.5164	0.1860	0.4829	0.1876

The WNM results show that the IFPIS and the IFNIS for the risk-mitigating actions and the different attributes/criteria respectively are determined. In this case, however, it has been given as the maximum and minimum values respectively and has been obtained from each column of the WNM. With these values, the closeness coefficient

of the risk-mitigating actions with respect to the different attributes/criteria are calculated and then ranked. The results of the IFPIS, IFNIS, as well as that of the closeness coefficient of the risk-mitigating actions calculated, have been presented in Table 5 below, along with the ranking order of the risk-mitigating actions.

Table 5: Results of the IFPIS, IFNIS, and the closeness coefficient of the risk-mitigating actions

	SWWRMA	CIRMA	TLIRMA	EIRMA	ERRMA
S^+	(0.516, 0.352)	(0.530, 0.474)	(0.506, 0.535)	(0.516, 0.469)	(0.494, 0.508)
S^-	(0.312, 0.124)	(0.202, 0.130)	(0.077, 0.153)	(0.200, 0.172)	(0.073, 0.148)
	S^+	S^-	cc_i	Ranking	
A1	0.0054	0.1916	0.0276	1	
A2	0.0041	0.1733	0.0229	4	
A3	0.0043	0.1799	0.0235	3	
A4	0.0020	0.1469	0.0135	11	
A5	0.0039	0.1884	0.0204	9	
A6	0.0035	0.1680	0.0206	7	
A7	0.0047	0.1824	0.0249	2	
A8	0.0037	0.1731	0.0212	6	
A9	0.0033	0.1580	0.0203	10	
A10	0.0020	0.1608	0.0125	12	
A11	0.0038	0.1804	0.0206	8	
A12	0.0040	0.1757	0.0221	5	

From the results in Table 5 above, the study can show a prioritization chart of the risk-mitigating actions for the prevention of COVID-19 virus spread in manufacturing organizations, which is with respect to the different attributes/criteria used in the study. The preference and prioritization information chart for the risk-mitigating actions has been depicted in Figure 2. The information chart shows the most suitable risk-mitigating actions to be adopted in the manufacturing organizations, for the prevention of the spread of the COVID-19 virus. According to the proposed H-MCDM model implemented in the study, it is not hard to see that, the use of protective materials during manufacturing operations (Disposable masks and gloves (A1)) is the most recommended risk-mitigating action when evaluated with the

interrelated and interdependent attributes/criteria. Also, from the information chart, we can see that, regular environmental testing and discipline of the workforce (Cleaning and disinfection of manufacturing suppliers' products A10) are the least recommended risk-mitigating actions when evaluated with the interrelated and interdependent attributes/criteria. It is important to note here that, the results presented above are largely influenced by the interrelated and interdependent attributes/criteria used in the study. As the invited experts took time to study the impact of the different risk-mitigating actions with respect to the attributes/criteria, as well as on the overall survival of the manufacturing organizations during and post COVID pandemic.

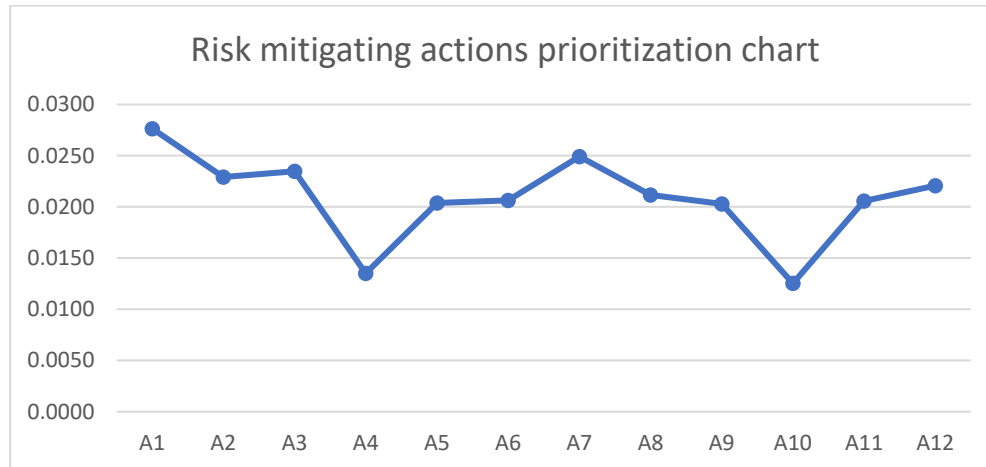


Figure 2: Prioritization chart for the risk-mitigating actions

To validate the proposed H-MCDM model, and to show its feasibility and rationality to address the prioritization problem of the different risk-mitigating actions that have been presented by researchers and the WHO for the prevention of COVID-19 virus spread in manufacturing organizations. A comparative analysis of the results obtained from the proposed H-MCDM model and with the traditional Fuzzy TOPSIS model in literature has been presented in Table 6 and a comparative chart in Figure 3. From Table 6, and

the comparative chart, it is not hard to see that some of the results from the proposed H-MCDM model are in agreement with the traditional TOPSIS model, this can be seen especially in the most recommended risk-mitigating action (A1) and the risk mitigation A5. The risk mitigation actions with variations in the ranking results include A2, A3, A4, A6, A7, A8, A9, A10, A11, and A12. This variation can be traced to the dependency issue of the traditional TOPSIS model which has been addressed and handled in this study by the proposed H-MCDM model.

Table 6: Comparison of the obtained results

	Traditional TOPSIS Model		Proposed H-MCDM model	Ranking
A1	0.5729	1	0.0276	1
A2	0.5488	7	0.0229	4
A3	0.5611	4	0.0235	3
A4	0.5067	12	0.0135	11
A5	0.5668	2	0.0204	9
A6	0.5318	10	0.0206	7
A7	0.5646	3	0.0249	2
A8	0.5357	8	0.0212	6
A9	0.5328	9	0.0203	10
A10	0.5243	11	0.0125	12
A11	0.5512	6	0.0206	8
A12	0.5519	5	0.0221	5

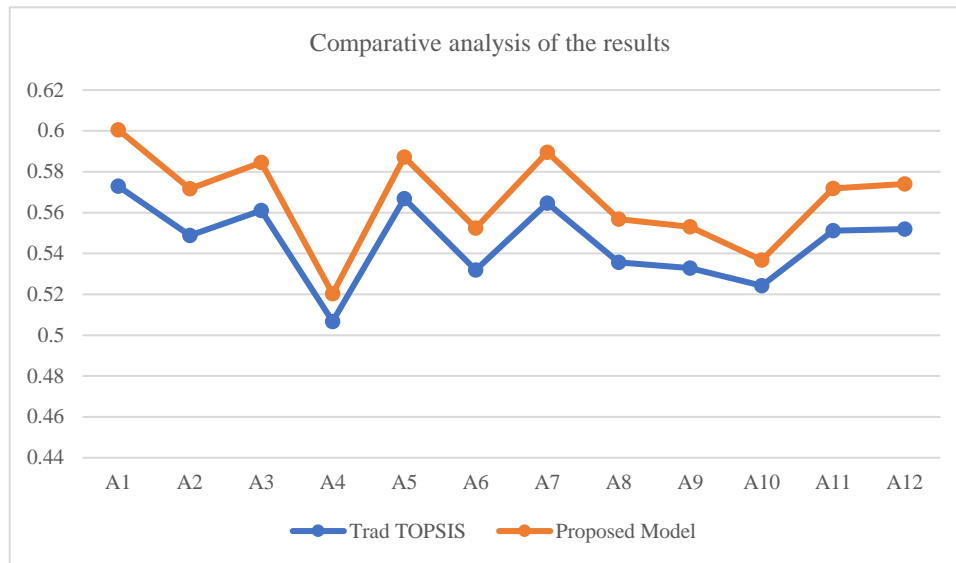


Figure 3: The comparative chart of the H-MCDM model and the Traditional TOPSIS model.

6.0 CONCLUSION

In this paper, a novel H-MCDM model, which is based on the Intuitionistic Fuzzy Weighted Geometric (IFWG) operator, the Intuitionistic Fuzzy Hamacher Interactive Weighting Averaging (IFHIWA) operator, and the Intuitionistic Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (IFTOPSIS) method has been proposed. First, for the evaluation, management, and prioritization of the different risk-mitigating actions, that have been presented by researchers and the WHO for the prevention of COVID-19 virus spread in manufacturing organizations. And secondly, for addressing the dependency and data interaction issues in the traditional TOPSIS model and the data interaction using the IFWG operator in place of the Euclidean distance in the traditional TOPSIS model and the interaction function between the degree of membership and those of non-membership as presented the IFHIWA operator in the model. The new H-MCDM model draws both the advantages of the traditional intuitionistic fuzzy TOPSIS model and that of the two aggregation operators and addresses the dependency and data interaction issues in the traditional TOPSIS model.

Results from the evaluation, management, and prioritization of the different risk-mitigating actions show that the most suitable risk-mitigating

actions to be adopted in the manufacturing organizations, for the prevention of the spread of the COVID-19 virus is the use of protective materials during manufacturing operation (Disposable masks and gloves (A1)). It is important to note here that, the results presented are largely influenced by the interrelated and interdependent attributes/criteria used in the study. As the invited experts took time to study the impact of the different risk-mitigating actions with respect to the attributes/criteria as well as on the overall survival of the manufacturing organizations during and post COVID pandemic. In the future, the model will be applied to solving other manufacturing issues in the industry.

Disclosure of Potential Conflicts of interest

Conflicts of interest: The authors declare that they have no conflict of interest.

Funding: There is no fund to declare/not applicable

Data Availability Statements: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Research involving Human Participants and/or Animals

Ethical approval: All procedures performed in studies involving human participants were in

accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

This paper does not contain any studies with animals performed by any of the authors

Informed consent

Informed consent: Informed consent was obtained from all individual participants included in the study.

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