A Decision Model for Concept Design Evaluation for Mechanical Ventilator Machines Used During the COVID-19 Pandemic

Daniel O. Aikhuele*

Department of Mechanical Engineering, University of Port Harcourt, East-West Road, Port Harcourt, Nigeria

Email: danbishop_22@yahoo.co.uk

Abstract. *Ventilator machine which has been approved for the treatment of the acute respiratory distress syndrome associated with the novel COVID-19 disease, is used for getting in oxygen and carbon dioxide out of human lungs. With the urgent need for the machines in our hospitals, their designs are been localized. To select the best design, considering the many factors associated with its development, a comprehensive study of the concept designs evaluations process has been presented. In this paper, an extended intuitionistic fuzzy multi-criteria decision-making (EIFMCDM) model which is based on the integration of the Complex Intuitionistic Fuzzy Bonferroni Mean (CIFBM) operator and the Intuitionistic Fuzzy (IF) Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) method has been proposed for concepts design evaluation of some new mechanical ventilator machine prototypes. The EIFMCDM model, which allows for multi-dimensional fuzzy information typically associated with real problems like concept design selection to be captured in the evaluation process, addresses a significant challenge in the concept design evaluation literature. Results from the concept design evaluation shows that the concept design described with the code VD2, VD4 and with the ranking values 0.525 and 0.439 respectively has the best and least designs, and the chances to be manufactured and used for COVID-19 treatment. This study has presented a new model for concept design evaluation, and attempt has been made to validate the feasibility of the model performance, the study conclude therefore that the model is feasible.*

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1. Introduction

COVID-19, which is a virus from the corona family, has since claimed more than three million lives across the globe [1]. The virus which was first discovered in Wuhan, China, around December 2019, is transmitted through the droplets generated from infected persons having cough, sneezing, or exhales. It has since spread to more than 200 countries and regions worldwide, where it has infected so many people [2].

The COVID-19 virus which is the latest member of the corona family, causes several severe diseases, including MERS, and SARS [3], that has infected and killed a lot of people in the past. Symptoms of the COVID-19 virus include, respiratory complications, shortness of breath, fever, cough, and sometimes dyspnea. In more severe cases, patients infected with the novel COVID-19 virus, have been found to have diseases such as pneumonia where the air sacs either in one or both lungs are filled with fluid or pus. Another symptom of the virus is the acute kidney injury. This disease reduces the function of the kidney, thereby increasing the risk of mortality inpatient. Acute respiratory distress syndrome, which is a form of lung injury [4].

According to the WHO, if a patient is diagnosed with the acute respiratory distress syndrome, a common disease associated with the present COVID-19 epidemic, such patient should be treated using the mechanical ventilator machine. The mechanical ventilator machine, which can be used to get in oxygen and carbon dioxide out of the lungs, has seen been established as the mainstay's treatment for the acute respiratory distress syndrome. This however, has resulted in the high global demand -panic buying [5] for the ventilator machines. Hence, the need for the localization, optimization and development of new ventilator designs, which according to medical researchers, could save more lives especially among COVID-19 patients with the severe acute respiratory distress syndrome.

Optimizing the ventilator design will enable changes or adjustments to the overall design and its parameters [6] and will make the final product more effective, innovative, cost-efficient, competitive, and more desirable to customers. Admittedly, with the increase in the death rate globally and the many cases of acute respiratory distress syndrome due to the COVID-19 virus, several concept designs of the ventilator machine have been made by different researchers and designers alike. However, before these concept designs are push through the product developmental stages, there is the need for a proper design concept evaluation.

Concept design evaluation, which is a multi-criteria decision-making process plays a critical role in the development and optimization of new or existing redesigned products. Research has shown that it has a significant impact on the downstream developmental processes/stages, the successes of these developmental stages can be determined or tract to the concept design evaluation stage. In carrying out concept design evaluation, several methods and approaches have been developed by different researchers in literature; this study, however, will be considering a few of them.

Ulrich and Eppinger [7] reported a non-numerical approach for early product development analysis during design concept screening. Similarly, Pugh [8] presented a method for design concept selection. Other methods that have found application in the concept design evaluation process includes the design concept decision matrixes [9], the analytical hierarchy process (AHP) methods, presented in [10–12], grey relation analysis method [13], the quality function deployment method [14–16] and the fuzzy set concept methods [14,17–22].

Stratton et al.,[23], introduce a hierarchical design concept selection method where some core sustainability features (environmental and economic) were used in the decision-making phases of the concept design evaluation process. Aikhuele and Turan,[24], proposed a method that is based on a modified score function and a weighted Normalized Hamming distance in a fuzzy Delphi and a modified technique for order preference by similarity to the ideal solution (M-TOPSIS) model, which they used for the selection of printed circuit board design concepts and. Buchert et al., [25] suggested a method that combines several methodologies to evaluate the different phases in the concept design process, including a sustainable concept design selection.

With the many methods that have been applied in the concept design evaluation literature, it is not hard to see that the fuzzy set concept methods have found more applications in the design concept evaluation process. This issue can be tract to the unique ability of fuzzy set methods to handle and address uncertainty, fuzziness, and vagueness in the decision-making process of the concept design evaluation stage. To further improve the fuzzy set methods and address a major challenge that has not been considered in the methods in literature i.e. the need to allow for multi-dimensional fuzzy information typically associated with real problems like concept designs selection to be captured in the evaluation process.

In this paper, an extended intuitionistic fuzzy multi-criteria decision-making (EIFMCDM) model which is based on the integration of the Complex Intuitionistic Fuzzy Bonferroni Mean (CIFBM) operator and the Intuitionistic Fuzzy (IF) Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) method has been proposed. The model, which is similar to the dynamic intuitionistic fuzzy method for design concept evaluation presented in [26], uses the Complex Intuitionistic Fuzzy Number (CIFN) for its computation. The motivation for CIFN for the concept design evaluation can be found in the advantages of the new model as presented below:

1) The CIFN used in this study allows for multi-dimensional fuzzy information generally associated with real problems like concept design evaluation of new products to be captured in the evaluation process, which to the best of our knowledge is not possible with existing concepts design evaluation methods.

2) Parameters for selecting concept design alternatives are often interrelated, and they directly impact the decision and decision-making process. The model designed with CIFN can address the interrelationship issues, which is not possible with the currently existing design concept model.

3) Unlike the IFS methods that use two grades of functions -the membership and non-membership function- to capture fuzzy information presented in some of the concept design evaluation problems. The CIFN captures multi-dimensional fuzzy information via the following functions; real membership function, imaginary membership function, real non-membership function, and an imaginary non-membership function.

4) Using the CIFN in concept design evaluation, opinions of design experts can be quickly processed as the CIFN is more advanced and suitable for gathering information than the IFS and traditional fuzzy sets. The CIFN has four grades of membership function; hence it considers the opinions of the design experts from four dimensions before arriving at a preferred decision/alternative.

5) The model with CIFN is more flexible and broader than the traditional IFN with two parameters (p and q) that reflect the mode of the decision-makers and decision-making process.

The rest of the paper is organized as followed: in section 2, the new intuitionistic fuzzy set (IFS) multi-criteria decision-making method was presented. This section is followed by a numerical illustration of the application of the proposed model in section 3. Finally, closing remarks are presented in section 4.

2. Material and Methods

In developing the integrated model, the concept of the traditional intuitionistic fuzzy set (IFS) was discussed. This is followed by the introduction of the complex intuitionistic fuzzy set (CIFS) and mathematical aggregation operator - Complex Intuitionistic Fuzzy Bonferroni Mean (CIFBM) operator. The concept of the traditional TOPSIS method and an algorithm of the integrated new model are also presented in this section.

2.1 Intuitionistic Fuzzy Set (IFS)

The intuitionistic fuzzy set (IFS) was developed by Atanassov [27] from the traditional fuzzy set theory initially introduced by Zadeh [28]. The intention here was to provide a better means of expressing imprecise and uncertain information when making decisions. The unique feature of the IFS is in the introduction of membership and non-membership, and the hesitation functions in the fuzzy environment and for dealing with multi-criteria decision-making problems [29,30]. These three functions allow the final decisions made from using the IFS to be viewed and evaluated from three dimensions; hence, providing a more accurate and reliable decision. This consideration is significant due to the complex nature of most of the presented day cooperate decisions. The mathematical form of the IFS has been expressed in Definition 1.

Definition 1 [27]

Let assume $X = \{x\}$ a set in the universal discourse, then an *IFS Z* in *X* can be defined as;

$$Z = \{\langle x, \mu_z(x), v_z(x)\rangle | x \in X\} \quad (1)$$

where $\mu_z(x)$ and $v_z(x)$ are the membership and non-membership functions of the set. The *IFS Z* X is therefore bounded by the constraint

$$0 \leq \mu_A(x) + v_A(x) \leq 1 \text{ and}$$
$$\mu_A(x), v_A(x) \in [0,1], \forall x \in X.$$

The pair $\mu_z(x)$ and $v_z(x)$ which are the characteristic features of the intuitionistic fuzzy numbers (IFN), can further be expanded to include the hesitation concept and function $\pi_z(x)$ as;

$$\pi_z(x) = 1 - (\mu_z(x) + v_z(x))$$

2.2 Intuitionistic Fuzzy Set (IFS)

The CIFS, which is an extension and a generalization of the traditional IFS, is characterized by multiple functions on a complex argument plane. These functions which include; real membership function, imaginary membership function, real non-membership function, and an imaginary non-membership function address issues like uncertainty, falsity, hesitation, and periodicity. The mathematical form of the CIFS has been expressed in Definition 2.

Definition 2 [30]

If φ is a CIFS, it can be defined in the form, $\varphi = \{(x, \mu_\varphi(x), v_\varphi(x)) : x \in U\}$ where $\mu_\varphi, v_\varphi : U \to \{b : b \in C, |b| \leq 1\}$ is defined as $\mu_\varphi(x) = r_\varphi(x) e^{i2\pi(\mu_{r\varphi}(x)}$ and $v_\varphi(x) = k_\varphi(x) e^{i2\pi(\omega_{k\varphi}(x))}$ and bound by the condition;

$$0 \leq r_\varphi(x), k_\varphi(x), \omega_{r_\varphi}(x), \omega_{k_\varphi}(x), r_\varphi(x) + k_\varphi(x), \omega_{r_\varphi}(x) + \omega_{k_\varphi}(x) \leq 1$$

, such that a pair of the CIFS is denoted by $\varphi_i = [(r_i, \omega_{ri}), (k_i, \omega_{ki})]$ which is the CIFN.

2.3 Aggregation Operators

Using a group of expert's opinions in the management of complex decisions in engineering and sciences requires the aggregation of such opinions to make a robust and comprehensive decision. The aggregation of opinions and information plays a very important role in the model used in making decisions. The information are aggregated with mathematical functions that consist of an intuitionistic fuzzy number (IFN) and complex intuitionistic fuzzy number (CIFN). Aggregation helps to summarize the information from different sources (experts). This paper used CIFN to aggregate, and its mathematical formation is given in the definitions below:

Definition 3 [32]

If $\varphi_i = [(r_i, \omega_{ri}), (k_i, \omega_{ki})]$ represent the *CIFN* for all $i = (1,2,3,4, \ldots\ldots, p)$, then the Complex Intuitionistic Fuzzy Bonferroni Mean (CIFBM) operator of the dimension *n* is a mapping CIFBM: $\Omega^n \to \Omega$ such that:

$$\mathrm{CIFBM}(\varphi_1, \varphi_2, \varphi_3, ,,, \varphi_n = \left[\begin{array}{c} \left(\left(1 - \prod_{i=1}^{n}(1 - r_t{}^p r_s{}^q)^{\frac{1}{n(n-1)}}\right)^{\frac{1}{p+q}}, \left(1 - \prod_{i=1}^{n}(1 - \omega_t{}^p \omega_s{}^q)^{\frac{1}{n(n-1)}}\right)^{\frac{1}{p+q}}\right); \\ \left(\left(1 - \prod_{i=1}^{n}(1 - (1 - k_t)^p (1 - k_s)^q)^{\frac{1}{n(n-1)}}\right)^{\frac{1}{p+q}}, \left(1 - \prod_{i=1}^{n}(1 - (1 - \omega_{kt})^p (1 - \omega_{ks})^q)^{\frac{1}{n(n-1)}}\right)^{\frac{1}{p+q}}\right) \end{array}\right] \quad (3)$$

where $p, q > 0$ are real numbers, *n* is the number of CIFN presented by the experts, r_t, r_s is the real membership function, ω_t, ω_s the imaginary membership function, k_t, k_s is the real non-membership function, and ω_{kt}, ω_{ks} the imaginary non-membership function.

2.4 TOPSIS Method

The Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS) method initially proposed by Hwang & Yoon [33], has remained one of the leading Multi-criteria Decision-making (MCDM) tool that has found application in both engineering and in management. Several authors have extended the method which uses the shortest and farthest distance from the positive and negative ideal solutions have extended the method which uses the shortest and farthest distance from the positive and negative ideal solutions to suit their different applications. In this paper, however, the TOPSIS method is extended to incorporate the Complex Intuitionistic Fuzzy Set (CIFS) such that the decision computation is carried out using the CIFN.

This is achieved through the integration of an aggregation operator like the CIFWBM in the new model. In implementing the new integrated intuitionistic TOPSIS model based on the integration of the Complex Intuitionistic Fuzzy Bonferroni Mean (CIFBM) operator and the Intuitionistic Fuzzy (IF) TOPSIS method. Reliable information in the form of a CIFN is collected from a group of experts and then aggregated before used in the computation and final decision-making [34]. Based on the concept of CIFS, the aggregation operators and the TOPSIS model are used to form the new model algorithm, which is presented in the following steps.

2.4.1 The proposed model algorithm

The algorithm for the proposed model has been presented in the following steps. It starts with the different formula notation.

CC_i= Closeness coefficient of the alternatives

$Z = (x_{ij})_{mxn}$= Intuitionistic fuzzy decision matrix

S^+= Complex intuitionistic fuzzy positive ideal (CIFPI) solution

S^-= Complex intuitionistic fuzzy negative ideal (CIFNI) solution

$ZC = (y_{ij})_{mxn}$.= Comprehensive complex intuitionistic decision matrix

$E^2(A)$= Intuitionistic entropy

Step 1: Select a group of experts E_i with equal work experiences and expertise on the particular subject with alternatives that need evaluation, the experts are asked to give their preference judgment to the alternatives related to some selected criteria. Selection of experts from academia and industry will improve the model's accuracy.

Step 2: Formulate a questionnaire for the MCDM problem and ask the experts to evaluate the alternatives based on the pre-determined criteria using the linguistic terms presented in Table 1. Use the obtained experts' opinions and judgment in the construction of the linguistic intuitionistic fuzzy decision matrix $Z = (x_{ij})_{mxn}$, the mathematical form of the matrix is given in equation (4) which is obtained by converting the linguistic terms into the CIFN.

Linguistic terms	**CIFN**
Some extent (SE)	• ((0.6, 0.3), (0.1, 0.2))
Moderate extent (ME)	• ((0.5, 0.4), (0.2, 0.3))
Great extent (GE)	• ((0.7, 0.5), (0.1, 0.1))
Very great extent (VE)	• ((0.8, 0.3), (0.2, 0.1))

Table 1 Linguistic scale and its CIFN for data collection

$$Z = (x_{ij})_{mx3} = \begin{bmatrix} (r_{11}, \omega_{r11}), (k_{11}, \omega_{k11}) & (r_{12}, \omega_{r12}), (k_{12}, \omega_{k12}) & (r_{13}, \omega_{r13}), (k_{13}, \omega_{k13}) \\ (r_{21}, \omega_{r21}), (k_{21}, \omega_{k21}) & (r_{22}, \omega_{r22}), (k_{22}, \omega_{k22}) & (r_{23}, \omega_{r23}), (k_{23}, \omega_{k23}) \\ \vdots & \vdots & \vdots \\ (r_{m1}, \omega_{rm1}), (k_{m1}, \omega_{km1}) & (r_{m2}, \omega_{rm2}), (k_{m2}, \omega_{km2}) & (r_i, \omega_{ri}), (k_i, \omega_{ki}) \end{bmatrix} \quad (4)$$

Step 3: Use the CIFBM operator to aggregate the experts' preference judgment to construct the comprehensive complex intuitionistic decision matrix $ZC = (y_{ij})_{mxn}$.

Step 4: With the intuitionistic entropy method proposed by Ye [35], the weight vector of the criteria is to generate from $ZC = (y_{ij})_{mxn}$ utilizing mathematical computation.

$$E^2(A) = \left\{Sin \frac{\pi * [1 + \mu_{AL}(x_i) + pW_{\mu A}(x_i) - v_{AL}(x_i) - qW_{vA}(x_i)]}{4} + Sin \frac{\pi * [1 - \mu_{AL}(x_i) - pW_{\mu A}(x_i) + v_{AL}(x_i) + qW_{vA}(x_i)]}{4} - 1\right\} * \frac{1}{\sqrt{2} - 1} \quad (5)$$

Step 5: With the generated weight vector of the criteria, construct a weighted normalization matrix.

Step 6: With the generated weighted normalization matrix, the complex intuitionistic fuzzy positive ideal (CIFPI) solution and the complex intuitionistic fuzzy negative ideal (CIFNI) solution respectively are determined using equations (6) and (7)

$$S^+ = \left\{ \langle \begin{matrix} T_j, \left((max\mu_{ij}(T_j) \mid j\epsilon Z), (min\mu_{ij}(T_j) \mid j\epsilon G) \right), \\ \left((minv_{ij}(T_j) \mid j\epsilon Z), (maxv_{ij}(T_j) \mid j\epsilon G) \right) \end{matrix} \rangle \mid i \in m \right\} \quad (6)$$

$$S^- = \left\{ \langle \begin{matrix} T_j, \left((min\mu_{ij}(T_j) \mid j\epsilon Z), (max\mu_{ij}(T_j) \mid j\epsilon G) \right), \\ \left((maxv_{ij}(T_j) \mid j\epsilon Z), (minv_{ij}(T_j) \mid j\epsilon G) \right) \end{matrix} \rangle \mid i \in m \right\} \quad (7)$$

where Z and G denote a set of benefits and cost attributes when the attributes are categorized into benefit and cost.

Step 7: Estimate the alternatives' closeness coefficient values using the $max\mu_{ij}(T_j)$ in the *CIFPI* solution and $min\mu_{ij}(T_j)$ for the *CIFNI* solution.

$$cc_i = \frac{S^-}{(S^- + S^+)} \quad (8)$$

Step 8: Rank the alternatives in descending order - using the results obtained in Step 7.

3. Results

In this section, the new proposed EIFMCDM model is based on the integration of the Complex Intuitionistic Fuzzy Bonferroni Mean (CIFBM) operator and the Intuitionistic Fuzzy (IF) TOPSIS method is applied for the evaluation of the concept designs of some mechanical ventilator machines. The concept designs of the machines which have been presented in Figure 1(a, b, c and d), are part of the research intervention by the COVID-19 committee of the College of Engineering, Bells University of Technology, Ota, Nigeria.

For convenience, the concept designs of the mechanical ventilator machines were coded as VD1, VD2, VD3, and VD4. All relevant information for the evaluation process and the deterministic connection between every decision and the corresponding outcome are known. In evaluating the concept designs, several functionality criteria are considered to select the best design for manufacturing and launching, some of the criteria considered in this regard include;

(1) Medical (FC1): Measures the extent to which a machine can control infection, humidity exchange rate, and positive end-expiratory pressure. Also, the capacity of a machine to measure a user-specified breath per min inspiratory and expiratory ratio and the tidal volume falls under this criterion.

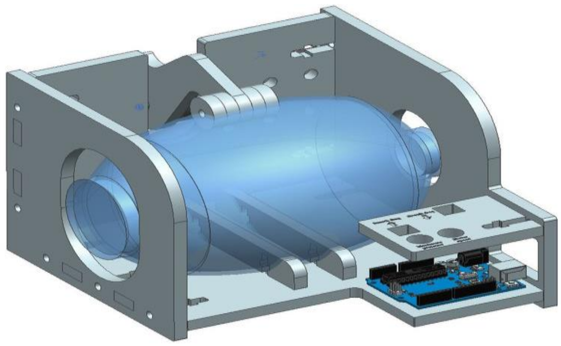
(2) Mechanical factor (FC2): This functionality criteria consider the machine's portability, the machine's power requirements, repairability and nearness to spare parts and the mechanical and electrical software system.

(3) Economic factor (FC3): The economic factor considers the cost of a ventilator machine.

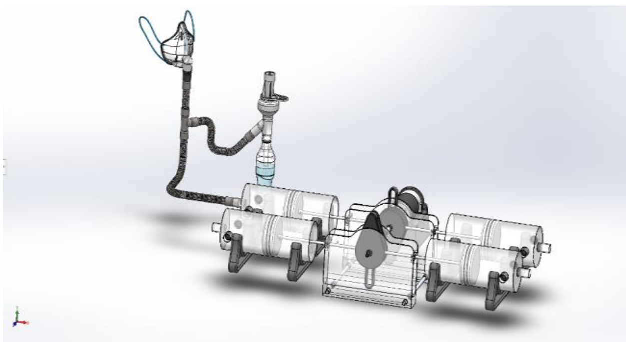
(4) User-interface and repeatability factor (FC4): Measures the presents of features like an alarm when the power is low or out, loss of breathing circuit integrity, and high airway pressure. Others include accurate breath frequency and indicators for correct reading.

In using the algorithm of the proposed model as presented in Section 2.4.1, a group of experts with equal expertise in academia (one (1) medical researchers and two (2) mechanical engineers and researchers) was invited to give their expert opinion on the mechanical ventilator machines. Using the linguistic terms and the CIFN in Table 1, the following linguistic intuitionistic fuzzy decision matrix $Z = (x_{ij})_{mxn}$, and their equivalents mathematical matrix have been given in Table 2.

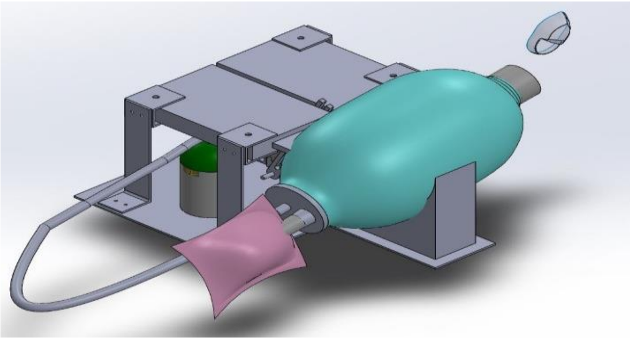
(a)



(b)



(c)



(d)

Fig. 1 (a)- VD1: This is conceptual design comprises of an adjustable membrane which is controlled by a pneumatic pump, **(b)**- VD2: This concept design is a simple and inexpensive one that can be manually operated by squeezing the bag-valve resuscitator. Also, a mechanical paddle can be attached such that the bag-valve resuscitator can be squeezed by a paddle with the aid of a small motor. It helps in directing air through a tube to the patient's airway. *Remark:* This design is modified from an open-source 3D CAD file, **(c)**- VD3: This concept design consists of simple parts made from locally sourced materials; it is a fully mechanical non-invasive ventilator. It consists of a crankshaft assembly, cylinder pump, PEEP valve, and an electric motor, and **(d)**- VD4: This concept design consists of a quick return mechanism that converts power in the ventilator machine from rotational to translational based, such that it allows the compression and decompression of the bag valve mask with a sliding motion. *Remark:* This design is a modification from an open-source 3D CAD file.

	FC1			FC2			FC3			FC4		
	E1	E2	E3	E1	E2	E3	E1	E2	E3	E1	E2	E3
VD1	SE	ME	ME	VE	SE	GE	GE	ME	SE	ME	GE	GE
VD2	ME	SE	GE	GE	VE	VE	VE	GE	ME	ME	GE	GE
VD3	GE	ME	VE	SE	GE	SE	ME	VE	ME	SE	ME	ME
VD4	SE	GE	SE	ME	VE	ME	ME	GE	SE	ME	GE	GE
VD1	((0.6, 0.3), (0.1, 0.2))	((0.5, 0.4), (0.2, 0.3))	((0.5, 0.4), (0.2, 0.3))	((0.8, 0.3), (0.2, 0.1))	((0.6, 0.3), (0.1, 0.2))	((0.7, 0.5), (0.1, 0.1))	((0.7, 0.5), (0.1, 0.1))	((0.5, 0.4), (0.2, 0.3))	((0.6, 0.3), (0.1, 0.2))	((0.5, 0.4), (0.2, 0.3))	((0.7, 0.5), (0.1, 0.1))	((0.7, 0.5), (0.1, 0.1))
VD2	((0.5, 0.4), (0.2, 0.3))	((0.6, 0.3), (0.1, 0.2))	((0.7, 0.5), (0.1, 0.1))	((0.7, 0.5), (0.1, 0.1))	((0.8, 0.3), (0.2, 0.1))	((0.8, 0.3), (0.2, 0.1))	((0.8, 0.3), (0.2, 0.1))	((0.7, 0.5), (0.1, 0.1))	((0.5, 0.4), (0.2, 0.3))	((0.5, 0.4), (0.2, 0.3))	((0.7, 0.5), (0.1, 0.1))	((0.7, 0.5), (0.1, 0.1))
VD3	((0.7, 0.5), (0.1, 0.1))	((0.5, 0.4), (0.2, 0.3))	((0.8, 0.3), (0.2, 0.1))	((0.6, 0.3), (0.1, 0.2))	((0.7, 0.5), (0.1, 0.1))	((0.6, 0.3), (0.1, 0.2))	((0.5, 0.4), (0.2, 0.3))	((0.8, 0.3), (0.2, 0.1))	((0.5, 0.4), (0.2, 0.3))	((0.6, 0.3), (0.1, 0.2))	((0.5, 0.4), (0.2, 0.3))	((0.5, 0.4), (0.2, 0.3))
VD4	((0.6, 0.3), (0.1, 0.2))	((0.7, 0.5), (0.1, 0.1))	((0.6, 0.3), (0.1, 0.2))	((0.5, 0.4), (0.2, 0.3))	((0.8, 0.3), (0.2, 0.1))	((0.5, 0.4), (0.2, 0.3))	((0.5, 0.4), (0.2, 0.3))	((0.7, 0.5), (0.1, 0.1))	((0.6, 0.3), (0.1, 0.2))	((0.5, 0.4), (0.2, 0.3))	((0.7, 0.5), (0.1, 0.1))	((0.7, 0.5), (0.1, 0.1))

Table 2 Linguistic intuitionistic fuzzy decision matrix

With the linguistic intuitionistic fuzzy decision matrix $Z = (x_{ij})_{mxn}$ above and their equivalents mathematical matrix, the three expert's judgment, and opinions are aggregated by following Step 3 in the proposed model algorithm using the CIFBM operator. In this study, all quantitative parameters in concept design evaluation which otherwise have been captured as p, q, and γ in the model have been given for convenience the following fixed values [1,1 and 2] respectively. The result of the computation (using these values) which is refers to as the comprehensive complex intuitionistic decision matrix $ZC = (y_{ij})_{mxn}$ are given in Table 3. This is followed by the computation of the weight vectors of the different criteria. In this case, the weight vectors of the different criteria have been determined using the intuitionistic entropy method, which is according to Step 4 of the proposed model algorithm. The result of the computation is given in Table 3. Furthermore, by using the generated weight vector of the criteria, a weighted normalization matrix is constructed, results of the weighted normalization matrix are shown in Table 4.

	FC1	FC2	FC3	FC4
VD1	((0.533, 0.365), (0.166, 0.267))	((0.700, 0.361), (0.132, 0.132))	((0.599, 0.397), (0.132, 0.198))	((0.633, 0.466), (0.132, 0.161))
VD2	((0.599, 0.397), (0.132, 0.198))	((0.767, 0.361), (0.166, 0.100))	((0.667, 0.397), (0.166, 0.161))	((0.633, 0.466), (0.132, 0.161))
VD3	((0.667, 0.397), (0.166, 0.161))	((0.633, 0.361), (0.100, 0.166))	((0.595, 0.365), (0.200, 0.233))	((0.533, 0.365), (0.166, 0.267))
VD4	((0.633, 0.361), (0.100, 0.166))	((0.595, 0.365), (0.200, 0.233))	((0.599, 0.397), (0.132, 0.198))	((0.633, 0.466), (0.132, 0.161))
Criteria Weight Vector	0.382	0.184	0.188	0.247

Table 3 The comprehensive complex intuitionistic decision matrix

	FC1	FC2	FC3	FC4
VD1	((0.203, 0.139), (0.063, 0.102))	((0.129, 0.066), (0.024, 0.024))	((0.112, 0.074), (0.025, 0.037))	((0.156, 0.115), (0.033, 0.040))
VD2	((0.229, 0.151), (0.050, 0.076))	((0.141, 0.066), (0.031, 0.018))	((0.125, 0.074), (0.031, 0.030))	((0.156, 0.115), (0.033, 0.040))
VD3	((0.254, 0.151), (0.063, 0.061))	((0.116, 0.066), (0.018, 0.031))	((0.112, 0.069), (0.038, 0.044))	((0.132, 0.090), (0.041, 0.066))
VD4	((0.242, 0.138), (0.038, 0.063))	((0.109, 0.067), (0.037, 0.043))	((0.112, 0.074), (0.025, 0.037))	((0.156, 0.115), (0.033, 0.040))

Table 4 Weighted normalization results

With the result of the weighted normalization matrix in place, the complex intuitionistic fuzzy positive ideal (CIFPI) solution and the complex intuitionistic fuzzy negative ideal (CIFNI) solution respectively are determined. However, for convenience, the maximum and minimum values of the concept design with respect to the criteria have been used as the CIFPI solution and CIFPI solution respectively. With the values of the CIFPI solution and that of the CIFPI solution in place, the closeness coefficient of the concept design for the mechanical ventilator machines is estimated. The results of the evaluations are shown in Table 5 along with the ranking order of the concept design for the mechanical ventilator machines.

	S^+	S^-	cc_i	Ranking
VD1	0.024659	0.020665	0.456	3
VD2	0.024946	0.027558	0.525	1
VD3	0.022426	0.022906	0.505	2
VD4	0.025808	0.020164	0.439	4

Table 5 Closeness coefficient of the concept design for the mechanical ventilator machines

4. Discussion and comparison analysis

The result of the ranking order for the concept design for the mechanical ventilator machine prototypes shows that the concept design with the code VD2 and VD4 has the most and least chances to be manufactured and will likely perform better in the market based on the model and criteria considered. This study verifies the feasibility and rationality of the proposed model used to evaluate the concept designs; some similar literature methods have been used in the comparison analysis. The methods include, the value and ambiguity index-based ranking method proposed, the weighted aggregated sum product assessment (WASPAS) method by Chakraborty & Zavadskas, (2014), and the intuitionistic fuzzy VlseKriterijumska Optimizacija I Kompromisno Resenje (IF-VIKOR) method. The method results all show some kind of consistency. The most ranked and least ranked concept design for the mechanical ventilator machines is found to be the same as those of the proposed model, details of the comparative analysis are shown in Table 6.

With the results from the proposed model, it is not hard to see that the model has conveniently overwhelmed the many weaknesses of a previously existing model in literature, some of which include, the use of multi-dimensional fuzzy information in the concept designs selection process. The use of experts from both from the academia and industry and the aggregation of the expert's opinions in the decision-making process (Safarzadeh et al., 2018). The elimination of complexity in the concept design evaluation process with reasonable and accurate knowledge and information through the use of the CIFN, as well as issues surrounding the ranking of alternatives in a more consistent way. With the use of the CIFN in the proposed model, the fuzziness, uncertainty, and vagueness in the data obtained for concept design evaluation for the mechanical ventilator machines have been handled, accounted for, and addressed in the paper.

	CC_i	Ranking	WASPAS	Ranking	VIKOR Qi	Ranking	Value-index ranking method	Ranking
VD1	0.456	3	0.6751	4	0.836	3	1.008	3
VD2	0.525	1	1.1833	1	0.000	1	0.995	1
VD3	0.505	2	0.7875	2	0.510	2	0.999	2
VD4	0.439	4	0.7547	3	1.000	4	1.011	4

Table 6 Comparison analysis

With the application of the EIFMCDM model for evaluation of the concept designs of the mechanical ventilator machines, the following benefits can be derived;

- The preservation of knowledge gained during the evaluation process; the knowledge gained during the evaluation process can be stored in a versioned repository for future cooperate decision-making and for other concept designs.
- The model allows the user to reuse parts of the information and knowledge gained in the evaluation process in new related projects, thereby saving time and money. This is made possible through the clear steps and algorithm presented in the model and finally,
- It allows for both quantitative and qualitative factors as its related constraints to be evaluated simultaneously.

The model is flexible, and it allows the incorporation of several design parameters in the concept design evaluation process. Some of these parameters accounted for in the model are p, q, and γ. By varying these parameters, more results about the proposed model can be generated for further analysis of this model's performance.

5. Conclusions

The novel coronavirus, otherwise called the COVID-19 virus, has claimed more than three million lives across the globe and has spread to more than 200 countries and regions worldwide. According to WHO, patients diagnosed with acute respiratory distress syndrome, which is a common disease observed during the present COVID-19 epidemic, are to be treated using the mechanical ventilator machine. The mechanical ventilator machine, which helps get in oxygen and carbon dioxide out of the lungs, has seen get in oxygen and carbon dioxide out of the lungs and has been established as the mainstay's treatment for the acute respiratory syndrome. It, however, has resulted in the high global demand for new and efficient mechanical ventilator machines. Hence, the need for the optimization and development of new mechanical ventilator design could save more lives, especially among COVID-19 patients with severe acute respiratory distress syndrome.

In this paper, an extended intuitionistic fuzzy set (IFS) multi-criteria decision-making model has been proposed for the evaluation of the concepts designs of the mechanical ventilator machines. The proposed was designed using Complex Intuitionistic Fuzzy Weighted Bonferroni Mean (CIFWBM) operator and the Intuitionistic Fuzzy (IF) Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) method. Results (ranking order) of the concept design for the mechanical ventilator machines show that the concept design with the description code VD2 has the most chances to be manufactured and likely to perform better than the other designs in the market criteria considered. This study verified and validated the proposed model's feasibility and rationality using similar models in the literature. The methods that have been used in this study include, the value and ambiguity index-based ranking method proposed, the weighted aggregated sum product assessment (WASPAS) method, and the intuitionistic fuzzy VlseKriterijumska Optimizacija I Kompromisno Resenje (IF-VIKOR) method. The results from the methods show some kind of consistency where the most ranked and least ranked concept design for the mechanical ventilator machines are found to be the same as those of the proposed model. In the future, the model will be applied to other areas of engineering and medicine by considering several test situations as well as improved to reflex its flexibility and ability to address real-time decision-making problems. Furthermore, it could be improved as a hybrid failure mode and effect analysis model to manage the mechanical ventilator machine. While, the linguistic scale used in the model could be analyzed using the score, accuracy and certainty functions.

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Biography

Daniel O. Aikhuele, lectures at the Department of Mechanical Engineering, University of Port Harcourt, Rivers State, Nigeria. He holds a PhD degree in Manufacturing Engineering from the Universiti Malaysia Pahang, Pekan, Malaysia. An MSc degree in Advanced Manufacturing Systems from the Teesside University, Middlesbrough, United Kingdom and a B.Eng. degree in Materials and Production Engineering from the Ambrose Alli University, Ekpoma, Nigeria. His primary research interest includes, reliability management, product development and evaluation, energy management and Intuitionistic fuzzy multi-criteria analysis.