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Evaluating strategies for implementing industry 4.0: a hybrid expert oriented approach of B.W.M. and interval valued intuitionistic fuzzy T.O.D.I.M.

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ABSTRACT

Developing and accepting industry 4.0 influences the industry structure and customer willingness. To a successful transition to industry 4.0, implementation strategies should be selected with a systematic and comprehensive view to responding to the changes flexibly. This research aims to identify and prioritise the strategies for implementing industry 4.0. For this purpose, at first, evaluation attributes of strategies and also strategies to put industry 4.0 in practice are recognised. Then, the attributes are weighted to the experts' opinion by using the Best Worst Method (B.W.M.). Subsequently, the strategies for implementing industry 4.0 in Fara-Sanat Company, as a case study, have been ranked based on the Interval Valued Intuitionistic Fuzzy (I.V.I.F) of the T.O.D.I.M. method. The results indicated that the attributes of 'Technology', 'Quality', and 'Operation' have respectively the highest importance. Furthermore, the strategies for "new business models development', 'Improving information systems' and 'Human resource management' received a higher rank. Eventually, some research and executive recommendations are provided. Having strategies for implementing industry 4.0 is a very important solution. Accordingly, multi-criteria decision-making (M.C.D.M.) methods are a useful tool for adopting and selecting appropriate strategies. In this research, a novel and hybrid combination of B.W.M.-T.O.D.I.M. is presented under I.V.I.F. information.

1. Introduction

Developments in information and communication technology leads us to form new facts in many fields such as manufacturing, resulting in a new concept as the 4th industrial revolution (intelligent manufacturing and continuous manufactory).

Industry 4.0 requires the most developed level of information and communication. This does not mean to achieve mere automation like machine tools, robot, Assembly lines, computer aided design (C.A.D.)/computer aided manufacturing (C.A.M.)/computer aided engineering (C.A.E.) systems, enterprise resource planning (E.R.P.) system, and supply chain management (S.C.M.) system; however, it means to achieve a high level of mental tasks such as understanding (why it happens), predicting (what happens) and adaption (what decisions should be made and executed). That is why industry 4.0 requires cyber-physical systems (C.P.S.), Internet of Things (I.o.T.), Internet of Content and Knowledge (I.o.C.K.), Cloud Computing and analysing big data that act according to the digital concepts together (Ullah, 2019).

Countries that implement the Industry 4.0 applications effectively can improve competitive advantages, labour market and operational processes (Maresova et al., 2018). These developments in manufacturing will lead to an increase in economic growth (Bal & Erkan, 2019) as well as European commission report in 2017 (European Commission, 2017) about key lessons from national industry 4.0 policy initiatives in Europe.

In industry 4.0, the convergence of Automation Technology (A.T.) and Information Technology (I.T.) has been raised. This cohesion on various systems needs a set of efficient equipment and connections to provide reliability and security in the system with interoperability (Saturno et al., 2017). In this regard, I.o.T. systems and C.P.S. have a vital role as technologies for production forecasting systems. A smart system in which network assets operate automatically with self-awareness in forecasting, rooting and arranging defective events (Diez-Olivan et al., 2019). The industry 4.0 can be fulfilled only when the organisations are ready to convert into digital technology, consequently, the organisations should select appropriate infrastructures for achieving new technological development in industry 4.0 (Manavalan & Jayakrishna, 2019).

To implement industry 4.0, many strategies are suggested to be selected systematically. Having strategies for implementing industry 4.0 is a very important solution (Mattsson et al., 2020). Note that traditional manufacturing business models are not matched with the emerging industry 4.0 technology. Issues including paying attention to the security of I.T., reliability and the stability necessary for machine-to-machine connections, maintaining the integration of production processes, preventing I.T. explosion, protecting the industrial technical knowledge, lack of sufficient skill, lack of common willingness to be changed by stockholders and losing many jobs to automatic and controlled processes by I.T., is necessary for the success of industry 4.0. Considering these issues, some strategies are adopted that can flexibly respond to changes (Sung, 2018).

The real-world problems are usually complicated and it is not possible to have one single attribute for optimal decision-making. The problems about decision-making often include four main elements as a set of alternatives, a set of attributes, decision-making matrix and the weight of these attributes. Implementing industry 4.0 is a multi-criteria decision-making problem (M.C.D.M.) due to the existence of multiple attributes and uncertainty.

In decision-making problems, the assessments carried out by the experts are as verbal expressions consistent with their experiences. These verbal assessments are ambiguous and difficult to analyse. Fuzzy set, gray numbers, and statistics are used to cope with uncertainty situations, among which the fuzzy set has a prominent role. The theory of

fuzzy sets is a tool for describing the subjective and judicial judgments of decision-makers that is expended to the intuitionistic fuzzy set (I.F.S.) and then interval valued intuitionistic fuzzy set (I.V.I.F.S.) (Zavadskas et al., 2014), however, despite developing various models, only I.V.I.F.S. considers the degree of doubt in decision-makers.

By determining the degree of membership and non-membership in the closed intervals, I.V.I.F.S. is one of the most suitable tools for ranking. Besides, several methods are introduced for solving M.C.D.M. problems among which the T.O.D.I.M. method is one of the newest methods ranking the alternatives by using paired comparisons. T.O.D.I.M.-I.V.I.F. method is one of the best and newest ranking methods which is not much applied. On one side, the best worst method (B.W.M.) is also the newest paired comparison-based weighing method. The prominent feature of this method, in comparison with other weighing methods, is that it requires less comparative data which, consequently, leads to more robust comparisons. Meaning that it gives a more reliable response and has a lower inconsistency rate (Brunelli & Rezaei, 2019). By and large, to implement industry 4.0, many strategies are suggested to be selected systematically. Opting strategies for implementing industry 4.0 is a very important solution, in the real-world, organisations and companies face limited resources, including financial, human, technological, and so on. In case these organisations aim to get into the implementing Industry 4.0 without a strategy, they will fail and waste time and money. Therefore, the purpose of the present study is to identify and prioritise strategies for implementing industry 4.0; thus, this research enables companies to move further in this direction by focusing more on the specific conditions governing their proprietary business environment. In this regard, the objectives of the present study are to identify the attributes for evaluating strategies for implementing industry 4.0, weighting and determining the relative importance of these attributes, identifying strategies for implementing industry 4.0, prioritising these strategies according to the identified attributes and eventually introducing the most optimal ones. Accordingly, M.C.D.M. methods are a useful tool for adopting and selecting appropriate strategies. In this research, a novel and hybrid combination of B.W.M.-T.O.D.I.M. is presented under I.V.I.F. information.

This research is organised as follows. First, the present research introduces basic concepts in section 2, after reviewing the industry 4.0 literature in section 3. In section 4, I.V.I.F., T.O.D.I.M., B.W.M., and T.O.D.I.M.-I.V.I.F. techniques are introduced as part of the research methodology. In section 5 a case study of Fara-Sanat Company is discussed. Moreover, in addition to reviewing the results, some suggestions for future research are provided in section 6.

2. Basic concepts

Three industrial revolutions occurred in the world so far. Industrialisation by developing the stream machine began in the early eighteenth century. The second generation of the industry began in the early nineteenth century by developing the use of electricity and mass production lines, and in the third generation, the electronic and I.T. was used for production automation. German Federal Government suggested the industry 4.0 as an emerging structure in which manufacturing and logistics systems in the form of C.P.S. manufacturing systems use the network information and

communication for exchanging the wide-spreading and automatic information of the current world (Vaidyaa et al., 2018). Industry 4.0 is a global state of the art movement in the manufacturing, production and operations systems to match the recent developments in information and communication technology. The modern communication systems and protocols, C.P.S.s, Artificial Intelligence Methods, Big data, I.o.T., cloud computing, etc. are some examples of these developments (Hajiagha et al., 2015; Mahdiraji et al., 2015; Diez-Olivan et al., 2019), presented as follows:

- **Cyber-physical systems.** Briefly called C.P.S., a connected system that is controlled or managed by information systems. C.P.S. is referred to as a network of cyber space-based systems with the computing and communicating abilities and physical components as sensors and drivers placing in a single cycle. Sensors send the information to the cloud computing points and analysis applications, and after being processed by data analysing algorithms, drivers receive the information and lead to decision-making or action. This intelligent information system improves the people interact with products, services and connected devices in real-time (Manavalan & Jayakrishna, 2019).
- **Artificial intelligence.** Computer-based systems that can think with no need for human (Diez-Olivan et al., 2019).
- **Big data.** A set of data for supporting the decisions in real-time including four dimensions of data size, data diversity, new-data generating speed, and data value analysis (Vaidyaa et al., 2018).
- **Internet of things.** A global network connecting various physical devices through standard protocols, special software, sensors, etc. In this system, things indicate a series of special responses automatically (Vaidyaa et al., 2018). Note that I.o.T. is a fundamental sector of industry 4.0 to deal with an intelligent factory and supply chain (Manavalan & Jayakrishna, 2019).
- **Cloud computing.** Implementing practical applications with high performance needs to parallel and distributed a cloud-like environment which includes a set of virtual interconnected computers. It represents a software providing the users in every point of the world with the services among the available virtual computing sources (Razavi Hajiagha et al., 2015; Manavalan & Jayakrishna, 2019).

In industry 4.0, the designing phase of the product is related to managing the life cycle of the product by manufacturing and logistics phases. Consequently, three levels of implementing technology can be identified from one point of manufacturing (Diez-Olivan et al., 2019) described as follows.

- **Vertical integration.** This concept is in the field of manufacturing and automation, referring to the integration of various information and communication technology systems in different levels of hierarchies. This kind of integration assists the manufacturing systems and makes them transformative.
- **Horizontal integration.** Includes the integration of information and communication technologies in mechanisms and factors involving in various levels of manufacturing and planning phases of business.

- **Circular integration.** Vertical and horizontal integration are linked to connecting the final user and life cycle of the product. Note that the production loop terminates by this integration.

3. Theoretical literature

Since 1995, researchers did many types of research on industry 4.0 which are mentioned at the following; nonetheless, comprehensive research on identifying and prioritising strategies for implementing industry 4.0 has not been carried out. Schumacher et al. (2016) to expand the focus of predominant technology in industry 4.0 models by using the organisational dimensions, developed a model including nine dimensions and 62 attributes for evaluating the maturity of industry 4.0. In this model, using a re-designing strategy, nine dimensions including products, costumers, operation, technology, leadership, policy, culture, and employees are used. Chen et al. (2017) mentioned redesign, improved information systems, and organisational strategies after describing the industry 4.0 and the challenges. Saturno et al. (2017) analysed the interoperability between the system and machines in industry 4.0 by using the A.H.P. method. Li et al. (2018) at first, investigated the I.T. development and then studied the reference model for developing and implementing the intelligent standards; eventually, they developed a standard framework.

Moktadir et al. (2018) evaluated the drawbacks of using industry 4.0 in the manufacturing operation in the Bangladesh leather industry by using the B.W.M. approach. The findings showed that a lack of technological infrastructures is one of the most important challenges that can prevent implementing industry 4.0. In research by Luthra and Mangla (2018), they evaluated 18 challenges of industry 4.0 in the supply chain by the A.H.P. method. Longo et al. (2019) concluded that training activities play a vital role in implementing responsive systems with high performance in the factories and they suggested the industry 4.0-based solution for emergency training of the employees.

It is inferred from the previous studies that the strategies have categorised publicly and only one point has considered for grouping them not all the dimensions. Thus, it can not be used for projects with special features that a research vacuity can be seen on categorising the strategies and covering all the potential strategies with considering the special projects. Therefore, the strategies for resolving the research vacuity are identified and studied by referring to multiple resources. Due to the lack of research and executive works in the industry 4.0 area, there is not a deep understanding of this concept among the researchers and craftsmen. Hence, this research takes a step towards solving this scientific dilemma. Furthermore, the main weakness of the studies carried out is that most of them are researches on the strategies of industry 4.0 that are not performed by using the combined I.V.I.F. techniques. The theory of the fuzzy set is a strong tool for describing the subjective and judicial judgments of decision-makers in ambiguous and uncertainty conditions. Moreover, I.V.I.F.S. is one of the most suitable tools for ranking by determining the membership and non-membership in closed intervals. In this research, due to the importance and increasing universality of industry 4.0, we study the strategies for implementing industry 4.0 by using T.O.D.I.M.-I.V.I.F. and B.W.M. methods.

Table 1. Strategies of industry 4.0.

Code	Strategy	Definition	Resource
S1	Human resource management strategies	These strategies determine that what does the organisation tends to do about the performances and policies of managing human resources and how these should be integrated with the company's strategy and also with each other.	Bedolla et al., 2017; Longo et al., 2019; Rennung et al., 2016; Simons et al., 2017; Telukdarie et al., 2018
S2	Improving information systems strategies	This strategy defines the relation of an organisation to the users, the general management and entities out of that organisation.	Chen & Goh, 2019; Erdogan et al., 2018; Manavalan & Jayakrishna, 2019
S3	Work organisation and design-oriented strategies	This strategy applies the design area for managing the creative process and developing the structure and organisation. This strategy aims to achieve the strategic goals and missions of the organisation.	Chen & Goh, 2019; Chen et al., 2017; Erdogan et al., 2018; Legat & Vogel-Heuser, 2017; Longo et al., 2019; Majstorovic et al., 2017; Rennung et al., 2016; Simons et al., 2017; Wang et al., 2019
S4	Resources and standardisation related strategies	They are strategies related to standardisation of a process to define the least technical specifications necessary for the product quality. Moreover, deciding how to find the required resources for obtaining the goal of the strategy.	Chen et al., 2017; Chen et al., 2017; Erdogan et al., 2018; Li et al., 2018; Telukdarie et al., 2018; Wang et al., 2019
S5	New business models development strategies	Business growth strategy is known as a practical strategy for achieving growth in business and as important assets for the companies.	Erdogan et al., 2018; Legat & Vogel-Heuser, 2017; Manavalan & Jayakrishna, 2019; Rennung et al., 2016; Simons et al., 2017
S6	Operation optimisation strategies	The main goal of industrial companies is the maximum return on investment. Accordingly, the manufacturing process should be the most desirable and optimal choice which is available.	Legat & Vogel-Heuser, 2017; Majstorovic et al., 2017; Mattsson et al., 2020

Source: Authors.

Industry 4.0 is a strategic approach using recent innovations in technology for manufacturing. The strategy is an action plan designed for achieving a special goal. The strategies of industry 4.0 are presented in Table 1.

In industry 4.0, the market condition, various kinds of technological and manufacturing solutions, and selecting them is a challenge for investing, especially given to the difference in the advantages that each of them provides for the customer. For bringing balance to automation, attributes for assessing the strategy of implementing industry 4.0 are developed (Mahdiraji et al. 2012; Mahdiraji et al., 2015; Saturno et al., 2017). Table 2 represents the attributes for assessing the strategies of implementing industry 4.0 quoted from the research literature (Erdogan et al., 2018; Sung, 2018).

4. Methodology

This research is an applied one in point of the objectives and analytical-descriptive on collecting information because it identifies and prioritises the strategies for implementing the industry 4.0. The present research has used library methods (books, articles) to identify the assessment attributes for strategies of implementing industry 4.0 and also strategies of implementing this industry. On the other hand, the field study method has been used for distributing the questionnaire of experts and professionals of Fara San'at

Table 2. Attributes for assessing the strategy of implementing industry 4.0.

Code	Attribute	Definition
C1	Leadership	The readiness of leaders, management capabilities, central coordination with industry 4.0, etc.
C2	Costumer	Using the information from the customer, digitalisation of sale/services, qualification of digital media
C3	Product	Personalisation of the product, digitalisation of products, integrating the products into other systems
C4	Operation	Segmentation of processes, modelling, and simulation, inter-departmental collaboration, etc.
C5	Culture	Sharing the knowledge, innovation, and cooperation in the company, the value of information and communication technology in the company, etc.
C6	Staffs	ICT Qualifications of staff, the familiarity of staff with the new technology, the independence of staff, etc.
C7	Technology	Having modern ICT, using mobile devices and machine-to-machine communications, etc.
C8	Organisation	Implementing the industry 4.0 map, the current resources for research, adopting business models, etc.
C9	Quality	The compliance with the characterisation and requirements of industry 4.0, reliability and sustainability of the product, on-time delivery, and customer satisfaction, etc.

Source: Authors.

company to determine the relative importance of assessment attributes of strategies for implementing industry 4.0 and ranking these strategies.

To select the experts, a purposive judicial sampling method has been used as their judgement is directly involved in the results of research and selecting experts is one of the main stages of the current study. In this regard, the decision-makers of the company consist of four groups of experts, with specifications as follows:

- These groups consisted of 20 experts (four groups of five experts);
- The experts participated in this research for two different rounds of evaluating the criterias and strategies as groups. Each group managed two meetings (nearly four hours) for each section (four in total) to fill the questionnaires between May to September 2019;
- Excellent background in the automotive industry and auto part industry of the country (at least eight years);
- At least an M.A. or M.S. degree;
- Relatively fully familiar with the industry 4.0 area and technology;
- Interested in cooperating in this research.

In this study, at first, the research literature on industry 4.0 and attributes of strategies for implementing industry 4.0 is identified by reviewing the literature. After that, a questionnaire is prepared for experts for paired comparison of indicators. Eventually, weighting the attributes and ranking of strategies for implementing industry 4.0 is studied by using B.W.M. and T.O.D.I.M.-I.V.I.F. methods. Research stages are illustrated in Figure 1. Detailed information in each step is discussed further.

4.1. The best-worst method

One of the most recent and developed evaluating methods is called B.W.M. This method focuses on comparing the most important and least important criterion with
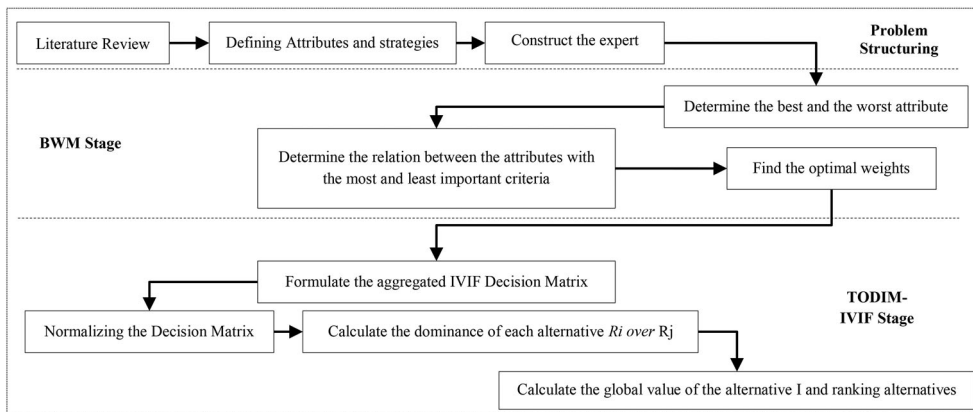
Figure 1. Research framework. *Source:* Authors.

other possible factors. By employing a linear and non-linear mathematical model, the optimal values of each criterion are calculated (Rezaei, 2015). This method is used in a variety of contexts such as humanitarian supply chain (Sahebi et al., 2017), medical tourism management (Abadi et al., 2018), education management (Nafari et al., 2017), technology selection (Mokhtarzadeh et al., 2018), marketing (Mahdiraji et al., 2019) and facility location (Kheybari et al., 2019). The well-known non-linear version of this model is described as follows (Rezaei, 2015):

1. The decision attributes $\{c_1, c_2, \ldots, c_n\}$ are defined by decision-makers.
2. The most and least important criteria are distinguished by decision-makers.
3. The importance of the most prominent criteria over other criterias is determined. In this regard, the scale from 1 to 9 is allocated. The resulting Best-to-Others vector is known as $A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn})$. Where a_{Bj} denotes the importance of the best criteria over attribute j when $a_{BB} = 1$.
4. The importance of each criterion over the least important factor is determined with a similar scale of step 3. The Others-to-Worst vector is shown with $A_W = (a_{1W}, a_{2W}, \ldots, a_{nW})^T$, where a_{jW} presents the preference of the criteria j over the least important attribute W when $a_{WW} = 1$.
5. Find the optimal weights $(w_1^*, w_2^*, \ldots, w_n^*)$. By solving model (1) through any possible optimisation packages, the values result. In this regard, the maximum absolute differences $\{|w_B - a_{Bj}w_j|, |w_j - a_{jw}w_w|\}$ of all attributes is aimed to minimise.

$$\text{minmax}_j \left\{ \left| \frac{w_B}{w_j} - a_{Bj} \right|, \left| \frac{w_j}{w_w} - a_{jw} \right| \right\}$$
$$\text{s.t.} \quad \sum_j w_j = 1 \tag{1}$$
$$w_j \geq 0, \text{ for all } j$$

Table 3. Consistency index table.

a_{BW}	1	2	3	4	5	6	7	8	9
Consistency index	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

Source: Rezaei (2015).

As a solution, the model transfers to a non-linear form as (2) (Rezaei, 2016).

$$\min \xi$$
$$\text{s.t.}$$
$$|w_B - a_{Bj}w_j| \leq \xi, \text{ for all } j$$
$$|w_j - a_{jw}w_w| \leq \xi, \text{ for all } j \qquad (2)$$
$$\sum_j w_j = 1$$
$$w_j \geq 0, \text{ for all } j$$

By employing non-linear optimisation packages such as LINGO or GAMS, the optimal weights $(w_1^*, w_2^*, \ldots, w_n^*)$ and the optimal value of ξ^* are achievable. The ξ^* is the consistency ratio of each decision-maker in comparing the most and least important criteria over other attributes. In this regard for the ξ^* close or equal to zero, the decision-maker has opted for more consistent comparisons. Based on equation (3) the consistency ratio of the comparisons is calculated.

$$Consistency \ Ratio = \frac{\xi^*}{Consistency \ Index} \qquad (3)$$

Note that the consistency index for different best-worst comparisons is chosen from Table 3 according to Rezaei (2016).

Moreover, in the linear form of B.W.M., the value of ξ^* is performed for pairwise comparisons consistency (Rezaei, 2016).

4.2. Basic concepts of interval valued intuitionistic fuzzy sets

In I.F.S.s, each element is given a non-membership value in addition to its membership degree. Usually, these sets are characterised by three functions that represent membership, non-membership and uncertainty degree (Atanassov, 1986). An intuitive fuzzy set A of reference set X is defined as (4) (Zavadskas et al., 2014; Hajiagha et al., 2014).

$$A = \left\{ \langle x, \ \mu_A(x), \ \nu_A(x) \rangle | x \epsilon X, \right\} \qquad (4)$$

According to this definition, membership degrees and non-membership degrees are defined as (5) and (6), relatively.

$$\mu_A : X \ \rightarrow [0, \ 1] \qquad (5)$$

$$v_A : X \rightarrow [0, \ 1] \tag{6}$$

Note that, always equation (7) is considered between membership degrees and non-membership degrees.

$$0 \leq \mu_A(X) + \nu_A(X) \leq 1 \tag{7}$$

I.F.S.s are generalised to I.V.I.F. sets by Atanassov and Gargov (1989) (Atanassov & Gargov, 1989). For every $x \epsilon X$, $\mu_{\sim A}(x)$ and $\nu_{\sim A}(x)$ are the interval values that $\mu_{AU}(x)$, $\mu_{AL}(x)$, $\nu_{AL}(x)$ and $\nu_{AU}(x)$ constitute the upper and lower limits of this interval, respectively. The I.V.I.F. set is defined as (8) and (9) (Büyüközkan & Göçer, 2018).

$$A = \left\{ \langle x, \ \left[\mu_{AL}(x), \ \mu_{AU}(x) \right], \ \left[\nu_{AL}(x), \nu_{AU}(x) \right] \rangle | x \epsilon X, \right\} \tag{8}$$

$$0 \leq \mu_{AU}(X) + \nu_{AU}(X) \leq 10 \leq \mu_{AL}(X) + \nu_{AU}(X) \leq 1 \tag{9}$$

The interval intuitive fuzzy set is represented as $\tilde{A} = ([a, \ b], \ [c, \ d])$. If $\tilde{A}_1 = ([a_1, \ b_1], \ [c_1, \ d_1])$ and $\tilde{A}_2 = ([a_2, \ b_2], \ [c_2, \ d_2])$ are two I.V.I.F.s, the operators are defined as equations (10)–(13) (Büyüközkan & Göçer, 2018).

$$\tilde{A}_1 + \tilde{A}_2 = ([a_1 + a_2 - a_1 a_2, \ b_1 + b_2 - b_1 b_2], \ [c_1 c_2, d_1 d_2]) \tag{10}$$

$$\tilde{A}_1.\tilde{A}_2 = ([a_1, a_2, b_1 b_2], \ [c_1 + c_2 - c_1 c_2, \ d_1 + d_2 - d_1 d_2]) \tag{11}$$

$$\lambda \tilde{A} = \left(\left[1 - (1 - a_1)^\lambda, \ 1 - (1 - b_1)^\lambda \right], \ \left[c_1^\lambda, \ d_1^\lambda \right] \right) \quad \lambda > 0 \tag{12}$$

$$\tilde{A}_1^\lambda = \left(\left[a_1^\lambda, \ b_1^\lambda \right], \ \left[1 - (1 - c_1)^\lambda, \ 1 - (1 - d_1)^\lambda \right] \right) \quad \lambda > 0 \tag{13}$$

The distance between two I.V.I.F. sets is also defined as follows (Krohling & Pacheco, 2014):

$$d(\tilde{a}_1, \tilde{a}_2) = \frac{1}{4} [|a_1 - a_2| + |b_1 - b_2| + |c_1 - c_2| + |d_1 - d_2|]^{\frac{1}{2}} \tag{14}$$

Let $\tilde{A}_1$ and $\tilde{A}_2$ be two I.V.I.F.N.s; therefore, the following results are emanated (Zavadskas et al., 2014):

- If $s(\tilde{A}_1) < s(\tilde{A}_2)$, then $(\tilde{A}_1) < (\tilde{A}_2)$;
- If $s(\tilde{A}_1) = s(\tilde{A}_2)$ then:
- If $h(\tilde{A}_1) = h(\tilde{A}_2)$ then $(\tilde{A}_1) = (\tilde{A}_2)$;
- If $h(\tilde{A}_1) < h(\tilde{A}_2)$ then $(\tilde{A}_1) < (\tilde{A}_2)$.

4.3. Interval valued intuitionistic fuzzy T.O.D.I.M

T.O.D.I.M. is a method based on pairwise comparison of the alternatives that are used to aid an M.C.D.M. This method (an acronym in Portuguese for Interactive and M.C.D.M.) evaluates the priority of one alternative over another by using the value function framework of the prospect theory. This value function presents an S-shaped growth curve. Moreover, the overall performance of each alternative is evaluated by applying an additive function (Llamazares, 2018). This method is used in a variety of contexts such as personnel selection (Jia et al., 2013; Ji et al., 2018), failure mode and effect analysis (Huang et al., 2017), supplier selection (Qin et al., 2017), portfolio allocation (Alali & Tolga, 2019), plant site selection (Wu et al., 2018), etc.

The T.O.D.I.M. method was first developed with fuzzy and intuitive fuzzy numbers, then developed by Krohling and Pacheco (2014) to the I.V.I.F. numbers (Mahdiraji et al., 2014; Krohling & Pacheco, 2014; Hajiagha et al., 2015). In this study, an extended version of the T.O.D.I.M. method, T.O.D.I.M.-I.V.I.F., is presented that can be applied to the decision environment with ambiguity and uncertainty. Suppose the decision problem is a set of (M) number of alternatives including $\tilde{A}_1, \tilde{A}_2, \ldots, \tilde{A}_m$ and (N) number of attributes including $\tilde{c}_1, \tilde{c}_2, \ldots, \tilde{c}_n$. The ranking of each (I) alternative in each (J) attribute is based on I.V.I.F. numbers. Moreover, (K) also is the number of decision-makers involved in the decision-making process. The decision-maker (K) determines his views and evaluations on the importance of weight. Ultimately, (W) is the weights of attributes. The steps for implementing T.O.D.I.M.-I.V.I.F. are as follows (Krohling & Pacheco, 2014; Jamalnia et al., 2014).

Step 1. Identifying attributes and alternatives to the decision-making problem;

Step 2. Determining linguistic variables;

Step 3. Formulate the I.V.I.F. Decision Matrix (Table 4);

Step 4. Normalising the Decision Matrix. Normalise the I.V.I.F. decision matrix $\tilde{A} = [x_{ij}]$ where $\tilde{x}_{ij} = \left([a_{ij}, b_{ij}], [c_{ij}, d_{ij}] \right)$ into the IVIF decision matrix $\tilde{R} = [r_{ij}]$ where $\tilde{r}_{ij} = \left([\mu^l_{ij}, \mu^u_{ij}], [v^l_{ij}, v^u_{ij}] \right)$ with $i = 1, \ldots, m$ and $j = 1, \ldots, n$ by using (15).

$$\mu^l_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^m (a_{ij}^2 + b_{ij}^2)}}$$

$$\mu^u_{ij} = \frac{b_{ij}}{\sqrt{\sum_{k=1}^m (a_{ij}^2 + b_{ij}^2)}}$$

$$v^l_{ij} = \frac{c_{ij}}{\sqrt{\sum_{k=1}^m \left(c_{ij}^2 + d_{ij}^2\right)}} \qquad (15)$$

$$v^u_{ij} = \frac{d_{ij}}{\sqrt{\sum_{k=1}^m (c_{ij}^2 + d_{ij}^2)}}$$

Step 5. Calculate the dominance of each alternative R_i over each alternative R_j by using (16) and (17).

Table 4. Aggregated IVIF decision matrix.

C_m	$\cdots$	C_2	C_1	
W_m	$\cdots$	W_2	W_1	W_C
$\sim x_{1m}$	$\cdots$	$\sim x_{12}$	$\sim x_{11}$	A_1
$\sim x_{2m}$	$\cdots$	$\sim x_{22}$	$\sim x_{21}$	A_2
$\vdots$	$\ddots$	$\vdots$	$\vdots$	$\vdots$
$\sim x_{nm}$	$\cdots$	$\sim x_{n2}$	$\sim x_{n1}$	A_n

Source: Authors.

$$\delta\left(\tilde{R}_i,\ \tilde{R}_j\right) = \sum_{c=1}^{m} \emptyset_c\ \delta\left(\tilde{R}_i,\ \tilde{R}_j\right) \qquad \forall(i,\ j) \tag{16}$$

$$\delta\left(\tilde{R}_i,\ \tilde{R}_j\right) = \begin{cases} \sqrt{w_c.}\ d\left(\tilde{r}_{ic}, \tilde{r}_{jc}\right), & if\ \left(\tilde{r}_{ic} > \tilde{r}_{jc}\right) \\ 0, & if\ \left(\tilde{r}_{ic} = \tilde{r}_{jc}\right) \\ -\dfrac{1}{\theta}\sqrt{\dfrac{1}{w_c}}.\ d\left(\tilde{r}_{ic}, \tilde{r}_{jc}\right), & if\ \left(\tilde{r}_{ic} < \tilde{r}_{jc}\right) \end{cases} \tag{17}$$

Note that $\emptyset_C\left(\tilde{R}_i,\ \tilde{R}_j\right)$, illustrates the partial dominance and demonstrates the effect of the attribute c to the function $\delta\left(\tilde{R}_i,\ \tilde{R}_j\right)$ when comparing the alternative i with alternative j. The values $\tilde{r}_{ic}$ and $\tilde{r}_{jc}$ are the rating of the alternatives i and j, respectively concerning each criterion. Moreover, w_c is the importance weight of attribute c obtained by using the B.W.M. method. The term $d\left(\tilde{r}_{ic}, \tilde{r}_{jc}\right)$ illustrates the distance between the two I.V.I.F. numbers $\tilde{r}_{ic}$ and $\tilde{r}_{jc}$, emanated from (14). Accordingly, three different situations are predictable in equation (17).

i.   if $\tilde{r}_{ic} > \tilde{r}_{jc}$, it represents gain;
ii. if $\tilde{r}_{ic} = \tilde{r}_{jc}$, it is null;
iii. if $\tilde{r}_{ic} < \tilde{r}_{jc}$, then loss occurs. The parameter θ represents the attenuation factor of the losses. For each criterion, the final matrix of dominance is resulted by collecting the partial matrices of dominance.

Step 6. Calculate the final value of each alternative via normalising the final matrix based on the equation (18).

$$\varepsilon_i = \frac{\sum \delta(i,\ j) - min \sum \delta(i,\ j)}{max \sum \delta(i,\ j) - min \sum \delta(i,\ j)} \tag{18}$$

Sorting the ε_i presents the final rank for alternative (i). Remark that desirable alternatives are chosen from higher values of ε_i.

5. Data analysis and results

After reviewing the literature, implementation strategies of the Industry 4.0 and its evaluation attributes are identified by Tables 1 and 2, respectively. As stated in the research methodology, the decision-making team consists of 4 groups of experts from managers and experts. After identifying the attributes for Industry 4.0 implementation strategies (Table 2), the weighting of each of the attributes by using the B.W.M.

Table 5. Preference vector of the most important attribute over other of expert group 1.

Attributes Most important Attribute	Leadership	Costumer	Product	Operation	Culture	Staffs	Technology	Organisation	Quality
Technology	6	3	5	4	9	4	1	6	2

Source: Authors.

method following the steps outlined above is obtained. To this end, the most important and least important attributes are identified by experts in this field. In the next step, the preference vector of the most important attribute is compared to the other attributes. To determine this vector, experts are asked to determine the priority of the most important attribute over the other attributes from 1 to 9. As a case in point, Table 5 represents this vector for the first group of experts.

Then the preference vector of the other attributes is determined relative to the least important attribute. The same step is used to determine this vector. Table 6 represents this vector for the first group of experts.

Eventually, by solving the model (2) using LINGO 15 software, the optimal values of $(w_1^*, w_2^*, \ldots, w_n^*)$ and ξ^* are obtained, as shown in Table 7. It should be noted that the opinions of each group of experts are formed and solved in the form of the mathematical model described and the weights considered by each group of experts. Then, the mean weights for all the groups of experts and the final weights are obtained.

After Identifying attributes and alternatives of decision-making problems, linguistic variables are determined as Table 8.

Subsequently, the I.V.I.F. aggregate decision matrix is formed to aggregate the group of decision-makers' views into one matrix. For this purpose, equation (19) is utilised by using equations (10) and (12). It is important to note that the weight of the experts in this article is equal.

$$\tilde{X}_{ij} = \frac{1}{K}\left[\sum_{k=1}^{p} \tilde{X}_{ij}\right], \quad i = 1, \ldots, m, \quad j = 1, \ldots, n; \tag{19}$$

Normalisation of the aggregated Decision Matrix by Using (15) as shown in Table 9.

The dominance of Ri over Rj is resulted by using equation (16) and equation (17). Afterward, the global score of each alternative is resulted by normalising the final matrix of dominance according to the equation (18) and illustrated in Table 10.

According to Table 10, the highest strategy is related to the strategy for developing new business models.

6. Implications and conclusions

Developing the industry is an integrated, complicated and agile process between humans and machines. Industry 4.0 increases production through information and communication technology. In this industry, the networks connected to the human and robots such as I.o.T. with shared and analysed information, with Big Data and Cloud Computing in the whole of the value chain will provide the possibility of the

Table 6. Preference vector of the other attributes to the least important of expert group 1.

least important attribute Attributes	Culture
Leadership	4
Costumer	7
Product	5
Operation	6
Culture	1
Staffs	6
Technology	9
Organisation	4
Quality	8

Source: Authors.

Table 7. optimal weights of attributes.

Attribute	Leadership	Costumer	Product	Operation	Culture	Staffs	Technology	Organisation	Quality
Code	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8	W_9
weight	0.07	0.08	0.07	0.15	0.03	0.08	0.26	0.08	0.18

Table 8. IVIF linguistic variables (Oztaysi et al., 2017).

IVIFS	Linguistic terms
([0.65,0.75],[0.10,0.25])	Absolutely High (AH)
([0.60,0.70],[0.15,0.30])	Very High (VH)
([0.55,0.65],[0.20, 0.35])	High (H)
([0.50, 0.60],[0.25, 0.40])	Medium High (MH)
([0.45, 0.55],[0.30, 0.45])	Approximately Equal (AE)
([0.25, 0.4]),[0.50, 0.60])	Medium Low (ML)
([0.20, 0.35],[0.55, 0.65])	Low (L)
([0.15, 0.30],[0.60, 0.70])	Very Low (VL)
([0.10, 0.25],[0.65, 0.75])	Absolutely Low (AL)

Source: Authors.

Table 9. Normalised aggregated decision matrix.

Ai Cj	Leadership	...	Quality
Human resource management strategies	([0.36, 0.41],[0.07, 0.17])	:	([0.22, 0.28],[0.27, 0.39])
Improving information systems strategies	([0.32, 0.38],[0.11, 0.21])	:	([0. 31, 0.37],[0.12, 0.25])
Work organisation and design-oriented strategies	([0.09, 0.17],[0.39, 0.45])	:	([0.27, 0.32],[0.20, 0.33])
Resources and standardisation related strategies	([0.28, 0.33],[0.16, 0.26])	:	([0.21, 0.27],[0.28, 0.41])
New business models development strategies	([0.28, 0.34],[0.15, 0.25])	:	([0.28, 0.33],[0.19, 0.32])
Operation optimisation strategies	([0.08, 0.17],[0.04, 0.46])	:	([0.25, 0.31],[0.22, 0.35])

Source: Authors.

efficient and flexible manufacturing. Industry 4.0 increases the time and cost efficiency and improves the quality of the product about active technologies, methods, and tools. As a result, industry 4.0 helps the industry to achieve a unique and expressive level of operational performance and productivity growth.
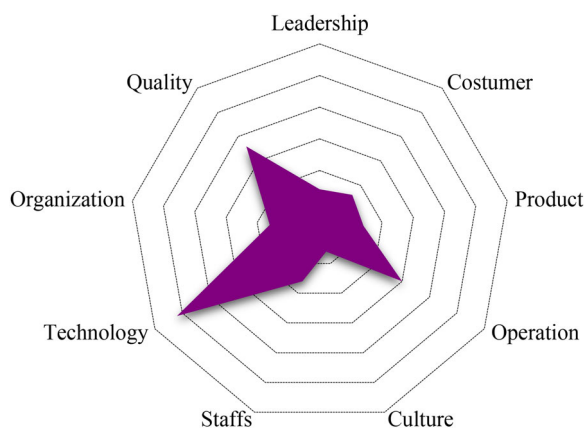
Therefore, the transition to industry 4.0 and implementing this industry is very essential. However, the research literature indicates that no research was conducted on the strategies for implementing industry 4.0 by the I.V.I.F.S. method. Hence, this research is conducted for identifying and ranking the strategies for implementing industry 4.0 to resolve the current deficiencies. This research used a combination of best-worst and I.V.I.F. T.O.D.I.M. methods which are the novel and practical methods in the M.C.D.M. methods. Furthermore, one of the innovations of this research is to deal with the new era in human life or the industry 4.0 revolution and its implementation attributes. We are about to technology revolution, a revolution that

Table 10. Ranking of the Industry 4.0 Implementation Strategies.

$Q(\sim R_i, \sim R_j)$	Human resource management strategies	Improving information systems strategies	Work organisation and design-oriented strategies	Resources and standardisation related strategies	New business models development strategies	Operation optimisation strategies	$\sum \delta(i, j)$	ε_i	Rank
Human resource management strategies	0.00	−1.59	−1.46	−0.05	−2.12	−1.04	−6.27	0.67	3
Improving information systems strategies	−1.97	0.00	−0.81	−0.77	−1.92	0.83	−4.65	0.84	2
Work organisation and design-oriented strategies	−2.63	−1.73	0.00	−1.42	−2.61	−0.78	−9.16	0.35	4
Resources and standardisation related strategies	−2.81	−2.74	−2.08	0.00	−2.76	−1.58	−11.98	0.05	5
New business models development strategies	−1.57	−0.48	−0.39	−0.27	0.00	−0.50	−3.21	1.00	1
Operation optimisation strategies	−2.83	−2.69	−1.76	−1.82	−3.31	0.00	−12.40	0.00	6
$\min \sum \delta(i, j)$							−12.40		
$\max \sum \delta(i, j)$							−3.21		

Source: Authors.

**Figure 2.** Evaluation of attributes. *Source:* Authors.

fundamentally causes massive changes in personal work and communication. This great transition is not similar to any human experience on scale and complexity and requires a coherent and comprehensive study and analysis; thus, it is essential to all the experts and policymakers in this area to recognise the strategies for implementing industry 4.0 accurately.

Furthermore, in addition to the experts and policymakers, all the organisations and industrial activists can use the results of this research for promoting the performance of its system, improving the quality and eventually increasing productivity because the growth of industrial productivity is always influenced by the growth of technology. This claim can be illustrated by the industrial revolution which begins at first by using stream engines in the manufacturing factory.

The results from weighting the attributes for implementing the industry 4.0 indicated that Technology, Quality and Operation attributes, respectively, have the highest importance as Figure 2.

Moreover, Strategies for the development of new business models, improving information systems and human resource management are placed in the high ranking as Figure 3.

Given the most important strategy, successful transition to the industry 4.0 needs systematic changes in the way Fara San'at company works which deeply require to reform the structures, strategies, ecosystems, and technologies. Fara San'at company is obliged to review, rebuild, develop and innovate in the business models to survive and confront the external complexity. Traditional business models are not matched with the emerging technologies in the industry 4.0. Developing the business model by providing a common understanding, analysing and improving business management, developing a clear perspective and providing a patent were influences on renewing the competitive advantage of Fara San'at. The Business Model Development Framework includes value propositions (clear explanation of industry 4.0 suggestions and how to solve problems or create value for stockholders), customer relations (maintaining a strong relationship with customer sections considering to the industry 4.0), distribution channels (industry 4.0 can develop channels for reaching to the costumer section by using the communication and I.T.), key partners (a network
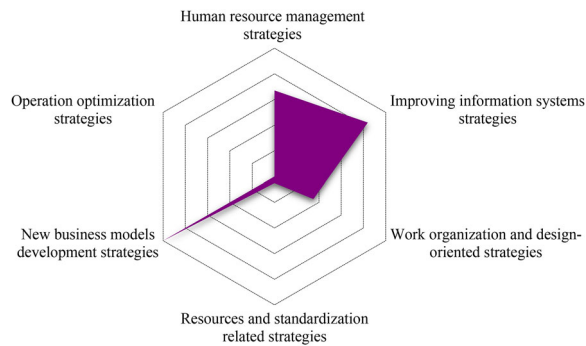
Figure 3. Ranking and score of industry 4.0 implementation strategies. *Source:* Authors.

provided by the suppliers and partners), key resources (all the assets related to the support of industry 4.0 operation), key activities (all the activities related to the intelligent industry that should be supported), cost structure (all the costs required for operation 4.0 including infrastructures and maintaining types of equipment, training the human resources, etc.) and income flows (how industry 4.0 can make money). In other words, developing business states how Fara San'at company offers its products to the customer and still make profit.

The researchers have recommended various methods for supporting business model development including scenario analysis, user-oriented approaches, and the convergence between products. Industry 4.0 requires to develop business models that relate technical capabilities to the real economic value by developing innovative logic and new information and communication technologies. On one side, industry 4.0 needs advanced and comprehensive systems for relating an organisation to the users, the general management and outside institutes. Recently, decision-makers and managers of leading organisations have understood that the information is not required only for trading and selling the products, but they can be a driver engine of the industry and plays a vital role in its success or failure. The information system in industry 4.0 is based on the I.o.T. The I.o.T. is used to connect different devices through the Internet by which programmes and various devices can interact with each other or even with a human by connecting to the Internet. Promoting the infrastructures, encouraging the cooperation of data centres, formulating certain strategies for managing and analysing data, the transparency against security concerns for successful use of the I.o.T. are essential. Intelligent technologies refer to complex energy technologies (smart networks) used in transportation and traffic systems. Technology is the starting point for rewriting all the other issues. Despite different views in industry 4.0, I.C.T.s are very essential for industry 4.0. Moreover, Fara San'at company not only needs complicated I.T., but also educated and learning human forces.

There are some limitations in this research such as considering only the external relationships between the attributes, evaluating the effectiveness of the proposed hybrid approach by only one case study, using an expert oriented method and relying on a limited number of experts, and finally not reviewing and validating the conceptual model of research (attributes and strategies). The following research proposals are suggested for future research to address these limitations. First of all, the

researchers can apply other multi-criteria I.V.I.F. decision-making techniques for weighting the assessment attributes like Paprica, C.O.D.A.S., E.D.A.S., etc. to rank the strategies for industry 4.0. Moreover, to achieve more documented results, the number of experienced experts can be increased and also other theories like Rough Number Theory and Grey Set Theory can be employed for considering the uncertainty and ambiguity of subjective opinions by experts. Furthermore, methods such as D.E.M.A.T.E.L. and A.N.P. are applicable for considering the internal relations and interactions between the attributes. Besides, using more case studies to illustrate the effectiveness of this hybrid approach could be productive. Alongside designing a statistical approach such as exploratory and confirmatory factor analysis to cover the expert oriented limitation of M.C.D.M. methods that need a limited number of experts and also validating the conceptual model of research (attributes and strategies) are suggested.

Disclosure statement

No potential conflict of interest was reported by the authors.

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