Selecting the Best Strategy for Industry 4.0 Applications with a Case Study

Melike Erdogan, Betul Ozkan, Ali Karasan and Ihsan Kaya

Abstract In this paper, we try to find the best strategy for Industry 4.0 implementation. For this aim, we determine the aggregated strategies for applying this concept and criteria that are used to select the best strategy. With the criteria set out in this context, basic strategies should be applied as a priority, considering for example human resources, work organization and design, information systems, and effective use of resources, and the development of new business models and standardization are specified. Since this selection is a process in which many different measures need to be considered, multi-criteria decision-making (MCDM) methods based on AHP-VIKOR methodologies have been applied to find the best strategy. Fuzzy set theory was beneficial for coping with uncertainties in the selection process.

Keywords Fuzzy sets · Industry 4.0 · Multi-criteria decision making
Strategy selection

Introduction

The world has changed as fast as it has ever existed since the industrial revolution. This revolution has been followed by second and third generations, called Industry 2.0 and Industry 3.0, in order to able to meet the increases in demand that have accompanied human population growth. From that moment, investments in industry and industrial products and their returns have reciprocally increased in excessive amounts. Today, we are taking steps to transition to a new concept called Industry 4.0 in order to bring this development further to meet the demands of the growing human population. This concept aims to introduce technical advances such as wireless network systems, cyber-physical systems, the Internet of Things, and cloud computing in industry. Not only scientists but also politicians have been evaluating

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this transition process since the 2000s. As a result of this evaluation process, many strategies have been suggested to select in a systematic way. Since this process considers many criteria, both qualitative and quantitative, which are used for comparison of strategy alternatives, it is very difficult for experts to make decisions. In order to deal with this multi-expert and multi-criteria environment, we will decide how many criteria exist in it, build a set of possible strategies, collect the appropriate information about strategies with respect to criteria, and evaluate them to reach the goal by using multi-criteria decision making (MCDM) (Tzeng and Huang 2011). This kind of evaluation requires the utilization of expert systems so that data can be expressed more explanatory to handle uncertainties, and thereby more knowledgeable decisions can be taken. There are many models dealing with the uncertainty of strategy problems in the literature. Among these models, stochastic selection models (Klein et al. 2009), heuristic optimization models (Beloglazov et al. 2012), simulation models (Goh et al. 2007), and fuzzy MCDM (Kaya and Kahraman 2011; Opricovic and Tzeng 2004) are the most frequently applied techniques. In this paper, an integrated fuzzy MCDM methodology is suggested for the Industry 4.0 strategy selection problem. There are several integrated fuzzy MCDM methodologies in the literature, such as fuzzy Analytic Network Process (ANP) and the fuzzy Preference Ranking Organization METHod for Enrichment of Evaluations (PROMETHEE) (Vinodh et al. 2014); fuzzy Analytic Hierarchy Process (AHP) and fuzzy Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) (Chen and Chen 2010); fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL) and Fuzzy ANP and Fuzzy TOPSIS (Gorecky et al. 2017). In this paper, a fuzzy MCDM methodology consisting of AHP and VIKOR methods is used to determine the best Industry 4.0 strategy. For this aim, the criteria weights have been calculated by using fuzzy AHP and fuzzy VIKOR has been used to determine the best strategy. The rest of this paper is organized as follows: Section "Literature Review" presents the literature review concerning Industry 4.0. Section "The Proposed Methodology" presents the proposed model. Section "Real Case Study" describes a real case study for the selection of the most appropriate Industry 4.0 strategy. Finally, the obtained results and future research suggestions are discussed in Section "Conclusion and Suggestions for Future Work".

Literature Review

Industry 4.0 has drawn much attention by academicians and researchers in recent years and the number of studies has increased dramatically. Some of the studies of Industry 4.0 can be summed up as follows. Gorecky et al. (2017) presented the design, implementation, and presentation of a virtual training system, VISTRA, for future factories (Grundstein et al. 2017). They selected the automotive industry because it is one of the leading industries adopting future factory concepts and technologies such as cyber-physical systems and the Internet of Things. Grundstein et al. (2017) performed a study of the autonomous production control (APC) method in job shop manufacturing (Barbosa et al. 2017). This control method integrates all control tasks (order release, sequencing, and capacity control) to meet due dates. They compared the APC method with other method combinations and found that the APC method has the potential to meet the due dates better. Barbosa et al. (2017) studied two key concepts of Industry 4.0 vision, namely Cyber Physical Systems (CPSs) and Intelligent Product (IP). They suggested that the integration of these two approaches is beneficial for future smart industries. They presented the integration of these approaches via two real world cases. Fleischmann et al. (2017) mentioned new methodologies for monitoring systems based on CPSs and presented a condition monitoring system for a handling unit in a test cell. Kolberg et al. (2016) presented an ongoing work concerning the digitization of lean production methods using CPS. Lean production is inadequate for meeting the market demand for customized products. Industry 4.0 technologies are combined with lean production, which is called lean automation. They gave the example of a kanban method to explain their work. Sepulcre et al. (2016) mentioned that the Industry 4.0 concept targets the interconnection and computerization of traditional industries to improve their adaptability and utilize their resources efficiently. Oesterreich and Teuteberg (2016) reviewed applications of technologies related to Industry 4.0 in the construction industry. They evaluated the literature from different perspectives like political, economic, social, technological, environmental, and legal ones and gave recommendations for future research. Chang and Wu (2016) mentioned that Industry 4.0 offers smart productivity based on the industrial Internet of Things, big data, and CPSs in manufacturing industries. Rennung et al. (2016) analyzed the service industry from the perspective of Industry 4.0. They interviewed experts and evaluated the applicability of scientific approaches to service networks for the project "Industry 4.0". Veza et al. (2015) studied a partner-selection problem. They used the PROMETHEE method to evaluate virtual enterprises. The problem was applied to a production network of smart factories in Industry 4.0. Forstner and Dümmler (2014) claimed that the smart factory is the central element of Industry 4.0 and established a foundation value to enable the integration of value chains across companies.

The Proposed Methodology

We apply a fuzzy MCDM approach to detect the best strategy for applying the Industry 4.0 concept. The following subsections explain the adopted methodology in the fuzzy environment.

Fuzzy Set Theory

Fuzzy set theory was introduced by Zadeh (1965) as a class of objects with a continuum of grades of membership. Such a set is characterized by a membership function that assigns to each element a grade of membership varying in a closed interval ranging from zero to one.

Fuzzy Analytic Hierarchy Process

The AHP was proposed by Saaty (1980) to solve complex multi-criteria decision problems (Rezaie et al. 2014; Kaya and Kahraman 2014) and is based on the concept of simplifying complex decision problems into elements (Zare et al. 2016). In this paper, Buckley's fuzzy AHP (1985) is used to determine the weights of criteria in order to select the best strategy in Industry 4.0 (Hsieh et al. 2004; Kahraman et al. 2014).

Fuzzy VIKOR

VIKOR was developed by Opricovic and Tzeng to find a compromise solution for MCDM issues. This method has been applied to many areas such as risk assessment (Gupta et al. 2016), machine selection (Wu et al. 2016), plant location selection (Gul et al. 2016), supplier selection (Kaya and Kahraman 2010), and so on. VIKOR is an MCDM method that ranks alternatives and determines the compromise solution that is the closest to the "ideal" (Opricovic and Tzeng 2004). The steps of the fuzzy VIKOR methodology are as follows (Tuzkaya et al. 2010; Kaya and Kahraman 2010):
n represents the number of feasible alternatives, $A_i = \{A_1, A_2, \ldots, A_n\}$ and $\tilde{x}_{ij}$ is the rating of alternative A_i with respect to criterion j.
Step 1: Construct the fuzzy multi-criteria decision-making problem in matrix format:

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{11} & \ldots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \ldots & \tilde{x}_{2n} \\ \vdots & \vdots & & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \ldots & \tilde{x}_{mn} \end{bmatrix} \quad (1)$$

Step 2: Determine the best $\tilde{f}_j^* = (l_j^*, m_j^*, u_j^*)$ and worst $\tilde{f}_j^- = (l_j^-, m_j^-, u_j^-)$ values of all criterion functions, $j = 1, 2, \ldots, m$.

$\tilde{f}_j^* = \max_i \tilde{x}_{ij}, \tilde{f}_j^- = \min_i \tilde{x}_{ij}$, if the jth criterion belongs to the benefit criteria,

$\tilde{f}_j^* = \min_i \tilde{x}_{ij}, \tilde{f}_j^- = \max_i \tilde{x}_{ij}$, if the jth criterion belongs to the cost criteria.

Step 3: Compute the normalized fuzzy difference $\tilde{d}_{ij}$, j = 1, …, m and i = 1, …, n.

$$\tilde{d}_{ij} = (\tilde{f}_j^* \Theta \tilde{x}_{ij})/(\tilde{f}_j^* \Theta \tilde{f}_j^-) \tag{2}$$

if the jth criterion belongs to the benefit criteria,

$$\tilde{d}_{ij} = (\tilde{x}_{ij} \Theta \tilde{f}_j^*)/(\tilde{f}_j^* \Theta \tilde{f}_j^-) \tag{3}$$

if the jth criterion belongs to the cost criteria.

Step 4: Calculate the values $\tilde{S}_i = (S_i^l, S_i^m, S_i^u)$ and $\tilde{R}_i = (R_i^l, R_i^m, R_i^u)$, j = 1, 2, …, m by using the equations below:

$$\tilde{S}_i = \sum_{j=1}^{m} \oplus (\tilde{w}_j \otimes \tilde{d}_{ij}) \tag{4}$$

$$\tilde{R}_i = \max_j (\tilde{w}_j \otimes \tilde{d}_{ij}) \tag{5}$$

where $\tilde{S}_i$ refers to the measure of separation of A_i from the fuzzy best value and $\tilde{R}_i$ to the measure of separation of A_i from the fuzzy worst value.

Step 5: Defuzzify the values of $\tilde{S}_i$ and $\tilde{R}_i$ by using the graded mean integration approach; for triangular fuzzy numbers, the fuzzy number $\tilde{C} = (c_1, c_2, c_3)$ can be transformed into a crisp number by employing the equation below:

$$P(\tilde{C}) = C = \frac{c_1 + 4c_2 + c_3}{6} \tag{6}$$

Step 6: Calculate the values Qi, i = 1, 2, …, n by using the equation below:

$$Q_i = v(S_i - S^*)/(S^- - S^*) + (1 - v)(R_i - R^*)/(R^- - R^*) \tag{7}$$

where $S^* = \min S_i$, $S^- = \max_i S_i$, $R^* = \min R_i$, and $R^- = \max_i R_i$ and $v \in [0, 1]$ represents the weight for the decision-making strategy of maximum group utility, whereas $1 - v$ means the weight of the individual regret.

Step 7: Rank the alternatives according to the values of S, R, and Q in decreasing order.

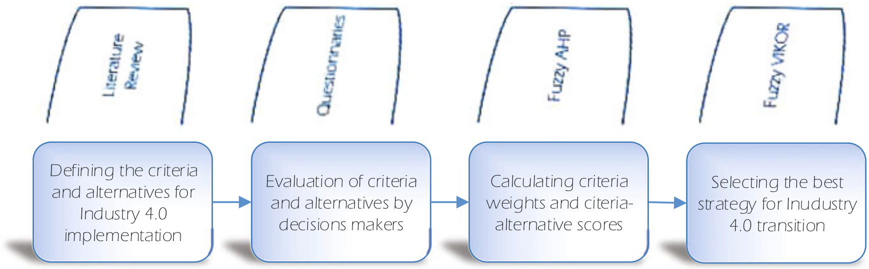

Fig. 1 Flowchart of the proposed methodology

Step 8: Propose a compromise solution, called alternative $A^{(1)}$, which is the best ranked solution according to the measure Q(minimum) if the following two conditions are satisfied:

Condition 1 The acceptable advantage $Q\left(A^{(2)}\right) - Q\left(A^{(1)}\right) \geq DQ$, where $A^{(2)}$ is the alternative with second position in the ranking list according to Q and DQ = 1/(n − 1).

Condition 2 For acceptable stability in decision making, alternative $A^{(1)}$ must also be the best ranked according to S and/or R.

If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of:

- Alternatives $A^{(1)}$ and $A^{(2)}$ if only the condition C2 is not satisfied, or
- Alternatives $A^{(1)}$, $A^{(2)}$,…, $A^{(n)}$ if the condition C1 is not satisfied; $A^{(n)}$ is determined by the relation $Q\left(A^{(n)}\right) - Q\left(A^{(1)}\right) < DQ$ for the maximum n (the positions of these alternatives are "in closeness").

A flowchart of our suggested methodology can be seen in Fig. 1.

Real Case Study

This paper aims to find the best strategy for the implication of the Industry 4.0 initiative of companies. In the selection process, fuzzy MCDM methodology is applied to obtain results that are closer reality. First of all, the criteria that are used to evaluate the strategies for Industry 4.0 are defined. Figure 2 shows the hierarchy of criteria and alternatives that are considered in the scope of this paper. Ten criteria and five alternatives are determined for this study. Then, the weights of the criteria are calculated to find their importance levels in the decision-making process. In this phase, fuzzy AHP methodology with the evaluations obtained from three experts is used. These experts are the people who study Industry 4.0 in their academic fields. They were asked to evaluate the criteria according to a scale presented on a

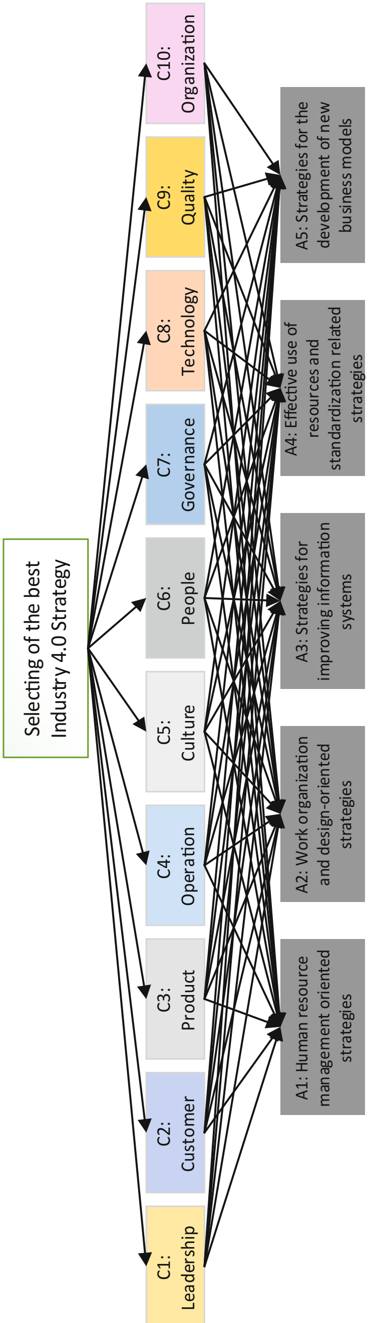

Fig. 2 Hierarchical representation of the criteria and alternatives

Table 1 Weights of each criterion

Criterion	Weights
$C1$	(0.134, 0.199, 0.268)
$C2$	(0.072, 0.112, 0.170)
$C3$	(0.063, 0.072, 0.087)
$C4$	(0.066, 0.095, 0.140)
$C5$	(0.048, 0.072, 0.106)
$C6$	(0.027, 0.034, 0.058)
$C7$	(0.077, 0.094, 0.124)
$C8$	(0.077, 0.097, 0.123)
$C9$	(0.109, 0.140, 0.169)
$C10$	(0.062, 0.084, 0.117)

questionnaire. After that, we checked the consistency of evaluations for each expert. If there was any inconsistent evaluation, the questionnaires were sent back to the experts for reevaluation. This process was repeated until all the evaluations were consistent, which meant that the consistency ratio was lower than 0.1.

The fuzzy AHP process is conducted to calculate the criteria weights. Table 1 shows the weights in triangular fuzzy numbers. According to the results, criterion 1, "*Leadership*", was determined as the most important criterion. The least important one was "C_6: *People*".

After obtaining the criteria weights, fuzzy VIKOR steps were initiated. Firstly, experts were consulted again to score the alternatives according to the criteria. Linguistic expressions were converted to triangular fuzzy numbers according to the scale presented in the proposed methodology section. Then three decision makers' evaluations were aggregated and the best and worst values for each criterion were revealed. Then the S, R, and Q values for each alternative were calculated. Table 2 shows the S, R, and Q values.

When we analyze the results, we can see that the alternative that has the minimum Q value is Alternative 3. This alternative also takes the minimum S and R values, which means that Condition 1 is satisfied. When we look at the acceptable advantage, $Q\left(A^{(2)}\right) - Q\left(A^{(1)}\right) \geq DQ$, where $A^{(2)}$ is the alternative with second position in the ranking list according to Q,

Table 2 Resulting values for each alternative

Alternative	S Value	R Value	Q Value
$A1$	1.044	0.409	0.560
$A2$	1.232	0.423	0.775
$A3$	0.804	0.169	0.000
$A4$	0.991	0.362	0.444
$A5$	1.279	0.560	1.000

$$DQ = 1/(n-1) = 1/(5-1) = 0.25$$
$$Q\left(A^{(2)}\right) - Q\left(A^{(1)}\right) = 0.444 - 0.000 = 0.444$$

Because the value of $Q\left(A^{(2)}\right) - Q\left(A^{(1)}\right)$ is bigger than DQ, we also claim that the best alternative is found as to be Alternative 3, "*Strategies for improving information systems*". The worst alternative is the one that does not need to be considered in the first stages, Alternative 5, "*Developing new business models*".

Conclusion and Suggestions for Future Work

In this paper, we aimed to find the best strategy for transition to Industry 4.0 by using a fuzzy MCDM with the integration of fuzzy AHP and VIKOR methodologies. To this end, criteria and alternatives were determined from experts' ideas and a literature review. The criteria used to evaluate the strategies were weighted by using fuzzy AHP methodology and the impacts of alternatives on criteria were provided by experts for application to fuzzy VIKOR. The most important criterion in the decision-making process was determined to be leadership. As a result of the work, it emerged that the best alternative was the strategies designed to improve information systems. It is not surprising that the alternative of developing information systems, which is also referred to as the Internet of Things, takes first place in the adoption of Industry 4.0. The last alternative was found to be developing new business models. The development of new business models is also very important in the implementation of this concept, but it does not appear to be a priority strategy.

As suggestions for future papers, different MCDM methods can be used, extensions of fuzzy sets can be considered, or the criteria and alternatives can be divided in more detail.

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