AN INTEGRATED METHODOLOGY FOR THE ASSESSMENT OF I4.0 MATURITY LEVEL

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ABSTRACT

The ability to adapt to changes in information and communication technologies is essential for all organizations. Companies that fail to correctly perceive the need for these changes and delay their implementation are doomed to disappear. In this context, the term Industry 4.0 is used to refer to digital improvement studies. It aims to increase profitability by reducing production costs without increasing the focus areas of companies. Determining the level of digitalization is as important as completing the digitalization infrastructure to bring Industry 4.0 to life. In this way, companies can determine their current digitalization status and maintain their competitiveness. They can also decide the steps needed to implement Industry 4.0. Currently, there are many methods and models used to determine the level of digitalization. However, this study takes a distinctive approach by aiming to develop an integrated methodology tailored for quantifying Industry 4.0 maturity in companies. To begin, the dimensions used within the Industry 4.0 maturity assessment were extracted from the literature. Then, a focus group approach was utilized by experts to eliminate the unimportant dimensions. Next, Interval-Valued Spherical Fuzzy AHP (IVSF-AHP) was used to determine the importance weights of the determined dimensions. Finally, the Industry 4.0 maturity level of an aviation/defense company was calculated by applying the proposed methodology based on the data collected via the questionnaire. Therefore, this proposed methodology provides a potent instrument for accurately appraising progress in digital transformation, refining strategies, and securing success in an evolving technology-driven environment.

Keywords: Industry 4.0; maturity level; IVSF-AHP

1. Introduction

Industry 4.0 (I4.0), which was first introduced at the Hannover Fair in 2011, has since become popular in various areas (Vogel-Heuser & Hess, 2016). It has become indispensable for institutions, especially when shifting from machine-based manufacturing to the digital production (Oztemel & Gursev, 2020). Within this transition process, a key component is "smart factories" (Steiner, 2019). Smart factories mainly include advanced robotics, sophisticated sensors, Internet of Things (IoT), digital fabrication, artificial intelligence, data analytics, cloud computing, mobile devices, and autonomous vehicles (Geissbauer et al., 2016). Hence, as stated by Zayat et al. (2023), the entry of I4.0 technologies provided various alternative solutions for different cases that occur in companies. Particularly larger companies in the production sector are taking important steps towards I4.0 to not lag behind developments in technology.

When companies show an effort to adapt to digitalization and fulfill the requirements of I4.0, they exhibit a desire to maintain their competitiveness with other companies. For successful implementation of I4.0, companies must know their existing maturity level in order to plan the steps that need to be taken toward digitalization. This study aims to provide a methodology for measuring the I4.0 maturity level. This allows the company to be able to choose the most suitable way to structure processes within the company. Studies measuring the level of companies within the scope of I4.0 have become very common today. According to the results of these studies, companies make important strategic decisions in their Industry 4.0 journey.

In this study, an integrated methodology for measuring the I4.0 maturity level was developed to use in manufacturing companies. The study was conducted in a defense industry company operating in the aviation sector in Turkey. The reason for choosing this company is that it is one of the largest companies in Turkey. The proposed methodology began with a review of the most used dimensions within the scope of I4.0. In this framework, the 10 most used dimensions within the scope of I4.0 were determined based on a literature review. Later, these dimensions were presented to five different decision makers (DMs) who are experts in their fields and their opinions about the determined dimensions were collected with a focus group study intended to reduce the number of dimensions and highlight the most important ones. Because of the joint evaluations of the experts, the final criteria list was determined. Then, the criteria were weighted with the Interval-Valued Spherical Fuzzy AHP (IVSF-AHP) method, which is one of the essential methods in the literature to handle the uncertainty and hesitation level of decision makers' evaluations. These importance weights of the criteria that were calculated were used as input in the I4.0 maturity level calculation phase. Finally, a questionnaire to assess the maturity level of the company in terms of I4.0 was distributed to the managers of the selected company to calculate the maturity level. The collected results were evaluated considering the calculated IVSF weights of each criterion and the final maturity score was achieved.

Hence, the contributions of the study are as follows:

- Five dimensions including data management, smart factory, smart products, strategy and organization, and technology and resources were determined based on the literature review and expert opinions to assess the I4.0 maturity level.
- IVSF-AHP was used to obtain the importance weights of the assessment dimensions.

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- A questionnaire was prepared to collect the required assessment data.
- The I4.0 maturity level of an aviation/defense company was obtained with the proposed methodology.

2. Literature review

In recent years, many studies have been conducted to assess I4.0 maturity levels. Some of the studies considered in the literature review including the objectives, methods, application fields, and considered dimensions of the related studies are summarized in Table 1. According to Rafeal et al. (2020), several maturity models for I4.0 have been launched in recent years. Some of these specifically target certain sectors; however, there are no models developed for a vital industry such as the machine tool industry. Rafael et al. conducted a study with a new model adapted to machine tool companies with a design based on pre-approved developments and standards regarding the conformity model was conducted. Another study focusing on a specific sector was performed by Sarı (2020); in this paper, a maturity model specific to the food sector that evaluates the use of basic I4.0 technologies with the AHP method was proposed. Akcan (2019) used the TOPSIS method to prioritize dimensions and projects that businesses from different sectors should focus on to reach I4.0 by applying the impulse model. In addition, the ANOVA test was applied to make comparisons between sectors. Bandara et al. (2019) created a model to aid the banking sector's adoption of I4.0. This maturity model was divided into the following five stages: initial, managed, defined, established, and digitally oriented, with seven dimensions including Technology and Resources, Governance, Strategy and Organization, Product and Services, Customers, Employees, and Operations.

In addition to many sector-oriented studies in the literature, there are also country and/or region-based studies. Branco et al. (2019) analyzed the I4.0 readiness of EU countries in manufacturing, identifying five homogeneous groups. The Netherlands and Finland were the leading countries, while Hungary, Bulgaria, and Poland fell short in the score chart. Gülseren and Sağbaş (2019) examined the current status of digital transformation in the world and in Turkey. This study aimed to evaluate the digital maturity level used for economic improvement and to recognize improvements that are necessary in digital transformation to gain global competitiveness. Stentoft et al. (2019) reported the outcome of a questionnaire/survey completed by 308 SMEs in Denmark. Ramos et al. (2020) examined the maturity models by comparing them in different industries in Brazil. Batz et al. (2020) presented a new maturity model to assess the Logistics 4.0 level of companies in Poland.

In the literature, one of the major areas that researchers mainly focus on is determining the assessment dimensions. Kiraz et al. (2019) aimed to determine where the institutions were in I4.0 and developed the IMPULS model, which is based on the following six main criteria: Smart Operations, Strategy and Organization, Smart Products, Smart Operations, Smart Factory, Data Based Services and Employees. According to the results of the study, the criterion that affected the I4.0 level the most was Strategy and Organization. Ustaoğlu (2019) proposed a new maturity model to determine a company’s readiness level for digital transformation. In the study, the following five dimensions were used: Leadership, Strategy, People, Partnership and Resources, Product, Process, and Services.

Castro et al. (2020) provided a self-assessment tool that evaluates the level of readiness for I4.0 of a company, mainly SMEs. The related tool used the following six dimensions: strategy and organization, smart factory, smart operations, smart products, data-driven services, human resources and provided a report with recommendations for improvement. A similar study for SMEs was performed by Sriram and Vinodh (2020). They used the COPRAS method with 15 readiness factors. Szejka et al. (2020) used the following five dimensions: development, logistics, marketing and sales, production, services. Hizam-Hanafiah et al. (2020) also studied an I4.0 maturity model with essential model dimensions. From 2000 to 2019, the SLR approach was used to examine 97 papers from academic journals and industry reports using the PRISMA approach and a content analysis strategy. Following the examination, the six most significant factors for organizations were determined to be strategy, technology, leadership, people, innovation and, processes. Furthermore, they discovered that in order to improve their I4.0 readiness, firms must first increase their technological readiness.

More recently, many researchers have developed maturity models and most include strategy, leadership, digital skills (or human layer), digital technologies (or technology layer), and operations as the main dimensions (Al-Ali & Marks, 2022; Duncan, 2022; Alsufyani and Gill, 2021; Cordes and Musies, 2021; Yezhebay et al., 2021; Salume et al., 2021; Almasbekkyzy et al.,2021; Aslanova & Kulichki, 2020) Hongxiong and Xiaowen (2022) focused on ecological construction of the supply chain and digital performance as dimensions in addition to the most common dimensions such as strategy, infrastructure etc. Goumeh and Barfooroush (2022) also made an extensive dimension analysis and developed a maturity model, which consisted of ecosystem and law as dimensions. Aras and Büyüközkan (2023) examined the literature in detail using the PRISMA approach and considered 70 models developed by both academicians and consultancy firms. Their model included six main dimensions and 24 sub-dimensions.

Table 1
Literature review for I4.0

Reference	Method	Application field	# of dimensions
Aras and Büyüközkan (2023)	Systematic literature review (PRISMA)	Maturity Model	6
Al-Ali and Marks (2022)	Digital transformation maturity assessment	Education sector	5
Hongxiong and Xiaowen (2022)	Evaluation index system	Automotive industry	5
Duncan et al. (2022)	Systematic literature review	Healthcare	7
Goumeh and Barforoush (2021)	Maturity model for digital banking providers	Banking industry	6
Alsufyani and Gill (2021)	Systematic literature review	Enterprise architecture design	5
Cordes and Musies (2021)	Questionnaire	Retail sector companies	10
Yezhebay et al. (2021)	Literature review, Semi-structured interviews, workshops	SMEs	6

Reference	**Method**	**Application field**	**# of dimensions**
Almasbekkyzy et al. (2021)	Integration of different maturity models	Aerospace production enterprise Aerospace service enterprise An audit company A construction company	4
Salume et al. (2021)	Questionnaire	Retail sector companies	8
Aslanova and Kulichkina (2020)	Systematic literature review	Textile industry Oil and gas equipment manufacturing organization	5
Sarı (2020)	AHP	Food industry	9
Rafeal et al. (2020)	Questionnaire	Machine tool company	6
Castro et al. (2020)	Special tool (SHIFTo4.0)	Portuguese companies	6
Szeika et al. (2020)	ACATECH + AHP	Maturity model	5
Hizam-Hanafiah et al. (2020)	Systematic literature review	Model for I4.0 readiness	6
Batz et al. (2019)	Questionnaire	Logistics	3
Vrchota and Pech (2019)	Questionnaire	Model for I4.0 readiness	3
Kiraz et al. (2019)	Fuzzy Cognitive Maps	Model for I4.0 readiness	6
Nick et al. (2019)	Questionnaire	Hungarian companies	6
Pacchini et al. (2019)	´´	Model for I4.0 readiness	9
Akcan (2019)	TOPSIS	Different sectors (Textile, metal-mining, electric-electronic, energy, other)	7
Gajšek et al. (2019)	Questionnaire	Steel production company	4
Ustaoğlu (2019)	´´	Textile industry, Automotive supply industry	5
Büyüközkan and Güler (2019)	AHP, ARAS, HFL, HSLTS	Banking sector	4
Bandara et al. (2019)	Questionnaire	Banking sector	7
Azevedo et al. (2019)	´´	Manufacturing company	6
Bibby and Dehe (2018)	Semi-structured interviews, workshops and item scoring	Defense sector	3
Özçelik et al. (2018)	AHP	Machinery manufactures	9
Stefan et al. (2018)	Questionnaire	SMEs	3
Brozzi et al. (2018)	´´	SMEs in manufacturing and construction sector	3
Asdecker and Felch (2018)	´´	Supply chains	3
Akdil et al. (2018)	´´	Retail company	3
Hamidi et al. (2018)	´´	SMEs	6
Tavčar et al. (2018)	´´	Automotive suppliers	6
Carolis et al. (2017)	´´	Manufacturing sector	4
Leyh et al. (2017)	´´	Manufacturing, System Engineering, Service provider, Commerce	4

The literature review revealed that I4.0 and the I4.0 maturity level of firms are relatively new concepts that every firm must properly adjust to in order to survive in their field. This review showed the increasing trend of I4.0 and maturity assessment studies; most of the studies are recent, and every year studies considering this topic have increased. According to the review of 45 articles, the top 10 most used dimensions are strategy and organization, data management, employees, technology and resources, smart factory, smart operations, smart products, culture, customers, and leadership. Of the top 10 dimensions, the most selected dimension was strategy and operations, and the least

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selected dimension was leadership. The most used methods are AHP, ANP, TOPSIS, BWM, HFL, HFLTS, PROMETHEE, ACATECH, Fuzzy Cognitive Maps, and ARAS.

This study aimed to develop a model that measures the I4.0 maturity level of the selected company by using various dimensions and multi-criteria decision-making based methods (MCDM). The dimensions were determined based on the literature review, and the weights of dimensions were calculated using IVSF-AHP which is one of the most up-to-date methods in the literature. In spherical fuzzy sets, decision makers define a membership function on the surface of a sphere. In this way, they can generalize other fuzzy set extensions and assign the parameters of the membership function to a larger area independently. Thus, spherical fuzzy sets provide more flexibility for decision makers and, as a result, cause less information corruption (Ayyıldız & Taskin, 2022). The proposed model was applied in an aviation company operating in the defense industry sector in Turkey. Additionally, uncertainty in model development is also considered. Hence, this study fills the gap in the literature by exhibiting the synergistic use of IVSF-AHP with maturity assessment models and the specifically applying it to a firm in the aviation/defense industry.

3. Proposed methodology

3.1 General framework of the proposed methodology

Determining the I4.0 maturity level of companies is one of the fundamental fields of maturity assessments. In general, maturity models are often used for companies that want to more systematically evaluate a particular aspect of the organization or a process it carries out. Measuring any aspect of an organization in a meaningful way is critical to see strengths, weaknesses, and highlight areas for improvement. With the current rapid changes in digitalization technologies, determining the level of digitalization is critically important for companies. For this reason, digitalization level measurement studies are widely accepted and applied by many companies. These studies allow companies to see their current situation and make plans for the future.

In this study, an integrated model that aims to calculate a final score showing the I4.0 maturity level is proposed. A flowchart of the process is provided in Figure 1. The proposed methodology was applied in an aerospace company operating in the defense industry and the maturity level was calculated. In this framework, the 10 most used dimensions within the scope of I4.0 were determined based on a literature review. Later, these dimensions were presented to five different decision makers (DMs) who are experts in their fields to gather their opinions about the dimensions. A final criteria list was determined as a result of the joint evaluations of the DMs.

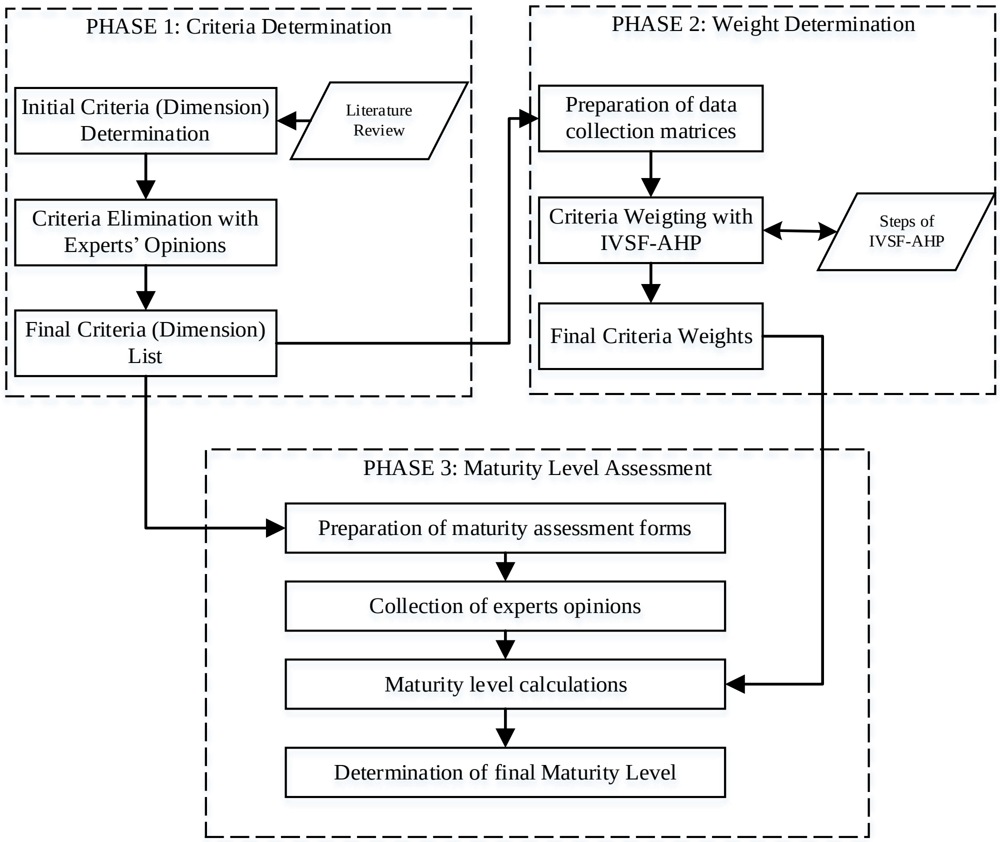

Figure 1 Flowchart of the proposed model

For the pairwise comparisons of the determined dimensions, the opinions of the DMs about the dimensions were collected and the criteria weights were obtained using the Interval Valued Spherical Fuzzy Analytical Hierarchy Process (IVSF-AHP) methodology. Finally, a questionnaire to assess the maturity level of the company in terms of I4.0 was distributed to the managers of the selected company to calculate the maturity level. However, since each of the dimensions contain different information, the assessment answers were not easily acquired from a single source. The required data was obtained from the related department manager or the technical staff dealing with the topic. The results were evaluated considering the calculated IVSF weights of each criterion and the final maturity score was determined.

The steps presented in Figure 1 are explained in the order of implementation phases. However, before the application section is presented, the preliminaries of the IVSF-AHP method used in determining the criteria weights are detailed in the following section.

3.2 IVSF-AHP

It is a well-known fact that in every real-life application where expert opinions are collected for consensus creation for further evaluations, there is a level of hesitation and/or uncertainty in the opinions of DMs for many reasons such as time pressure, lack of information, and evaluation deficiencies. In the decision analysis literature, fuzzy logic methods have been developed in order to eliminate these uncertainties. Building on the success of classical fuzzy logic sets (Zadeh, 1996) in addressing uncertainty and ambiguity, advanced methods have emerged over time. Various versions, such as intuitive fuzzy sets (Atanassov, 1986), neutrosophic fuzzy sets (Smarandache, 2003), and hesitant fuzzy sets (Torra, 2010) have been proposed to yield effective solutions to deal with vagueness in many decision making problems (Akman et al., 2022; Nahavandi et al., 2023, Poveda, 2023). A more recent addition is the concept of spherical fuzzy sets, introduced by Gündoğdu and Kahraman (2019). This approach offers decision-makers a broader domain for assigning membership functions, enhancing their flexibility and precision.

A single value spherical fuzzy set (SFS) is defined with a membership degree ($\mu_{\widetilde{A}_S}(x)$), non-membership degree ($\nu_{\widetilde{A}_S}(x)$) and the degree of indeterminacy ($\pi_{\widetilde{A}_S}(x)$). Each of these parameters can have a value between 0 and 1, and the sum of the squares is limited to a maximum of 1. Gündoğdu and Kahraman (2019) stated that in a universal set U, a SFS set $\widetilde{A}_S$ a is defined as $\widetilde{A}_S = \left\{x, \left(\mu_{\widetilde{A}_S}(x), \nu_{\widetilde{A}_S}(x), \pi_{\widetilde{A}_S}(x)\right) \mid x \in \mathrm{U}\right\}$ where $\mu_{\widetilde{A}_S}(x) : \mathrm{U} \rightarrow [0,1]$, $\nu_{\widetilde{A}_S}(x) : \mathrm{U} \rightarrow [0,1]$, $\pi_{\widetilde{A}_S}(x) : \mathrm{U} \rightarrow [0,1] \quad \forall x \in \mathrm{U}$ and $0 \leq {\mu_{\widetilde{A}_S}}^2(x) + {\nu_{\widetilde{A}_S}}^2(x) + {\pi_{\widetilde{A}_S}}^2(x) \leq 1$.

Interval valued SF sets (IVSF) use an interval instead of a single point to represent the uncertainty in each parameter, thus providing a better analysis when decision makers are not sure about their preferences. In a universal set U, an IVFS set $\widetilde{A}_S$ a is defined as $\widetilde{A}_S = \left\{\langle u, \left(\left[{\mu_{\widetilde{A}_S}}^L(u), {\mu_{\widetilde{A}_S}}^U(u)\right], \left[{\nu_{\widetilde{A}_S}}^L(u), {\nu_{\widetilde{A}_S}}^U(u)\right], \left[{\pi_{\widetilde{A}_S}}^L(u), {\pi_{\widetilde{A}_S}}^U(u)\right]\right)\rangle \mid u \in \mathrm{U}\right\}$ where $0 \leq {\mu_{\widetilde{A}_S}}^L(u) \leq {\mu_{\widetilde{A}_S}}^U(u) \leq 1$, $0 \leq {\nu_{\widetilde{A}_S}}^L(u) \leq {\nu_{\widetilde{A}_S}}^U(u) \leq 1$, $0 \leq {\pi_{\widetilde{A}_S}}^L(u) \leq {\pi_{\widetilde{A}_S}}^U(u) \leq 1$. (Gündoğdu & Kahraman, 2021). Here, for each $u \in U$, ${\mu_{\widetilde{A}_S}}^U(u), {\nu_{\widetilde{A}_S}}^U(u)$ and ${\pi_{\widetilde{A}_S}}^U(u)$ represent the upper degrees of parameters.

Gündoğdu and Kahraman (2021) denoted the IVSF set to simplify the presentation of basic operations as $\tilde{\alpha} = \langle [a,b], [c,d], [e,f] \rangle$. Therefore, the basic arithmetic operations of IVSF sets were defined as follows (Gündoğdu & Kahraman, 2021; Duleba et al., 2021). Let $\tilde{\alpha}_1 = \langle [a_1,b_1], [c_1,d_1], [e_1,f_1] \rangle$ and $\tilde{\alpha}_2 = \langle [a_2,b_2], [c_2,d_2], [e_2,f_2] \rangle$ be two IVSFS then,

- Union;

$$\tilde{\alpha}_1 \cup \tilde{\alpha}_2 = \{[max\{a_1,a_2\}, max\{b_1,b_2\}], [min\{c_1,c_2\}, min\{d_1,d_2\}], [min\{e_1,e_2\}, min\{f_1,f_2\}]\} \quad (1)$$

- Intersection;

$$\tilde{\alpha}_1 \cup \tilde{\alpha}_2 = \{[min\{a_1,a_2\}, min\{b_1,b_2\}], [max\{c_1,c_2\}, max\{d_1,d_2\}], [min\{e_1,e_2\}, min\{f_1,f_2\}]\} \quad (2)$$

- Product;
$\tilde{\alpha}_1 + \tilde{\alpha}_2 =$
$$\left\{\begin{matrix} [((a_1)^2 + (a_2)^2 - (a_1)^2(a_2)^2)^{0.5}, ((b_1)^2 + (b_2)^2 - (b_1)^2(b_2)^2)^{0.5}], [c_1c_2, d_1d_2], \\ \begin{bmatrix} \left((1-(a_2)^2)(e_1)^2 + (1-(a_1)^2)(e_2)^2 - (e_1)^2(e_2)^2\right)^{0.5}, \\ \left((1-(b_2)^2)(f_1)^2 + (1-(b_1)^2)(f_2)^2 - (f_1)^2(f_2)^2\right)^{0.5} \end{bmatrix} \end{matrix}\right\} \quad (3)$$

- Multiplication of two sets ($\tilde{A}_S \times \tilde{B}_S$);
$\tilde{\alpha}_1 \times \tilde{\alpha}_2 =$
$$\left\{\begin{matrix} [a_1a_2, b_1b_2], [((c_1)^2 + (c_2)^2 - (c_1)^2(c_2)^2)^{0.5}, ((d_1)^2 + (d_2)^2 - (d_1)^2(d_2)^2)^{0.5}], \\ \begin{bmatrix} \left((1-(c_2)^2)(e_1)^2 + (1-(c_1)^2)(e_2)^2 - (e_1)^2(e_2)^2\right)^{0.5}, \\ \left((1-(d_2)^2)(f_1)^2 + (1-(d_1)^2)(f_2)^2 - (f_1)^2(f_2)^2\right)^{0.5} \end{bmatrix} \end{matrix}\right\} \quad (4)$$

- Multiplication by a scalar ($\tilde{\alpha} \times \lambda$)
$$\lambda \times \tilde{A}_S = \left\{\left[\left(1-(1-a^2)^\lambda\right)^{0.5}, \left(1-(1-b^2)^\lambda\right)^{0.5}\right], [c^\lambda, d^\lambda], \left[\left((1-a^2)^\lambda - (1-a^2-e^2)^\lambda\right)^{0,5}, \left((1-b^2)^\lambda - (1-b^2-f^2)^\lambda\right)^{0,5}\right]\right\} \quad (5)$$

- Exponential value of set $\tilde{\alpha}$ with parameter $\lambda > 0$
$$\tilde{\alpha}^\lambda = \left\{[a^\lambda, b^\lambda], \left[\left(1-(1-c^2)^\lambda\right)^{0.5}, \left(1-(1-d^2)^\lambda\right)^{0.5}\right], \left[\left((1-c^2)^\lambda - (1-c^2-e^2)^\lambda\right)^{0.5}, \left((1-d^2)^\lambda - (1-d^2-f)^\lambda\right)^{0.5}\right]\right\} \quad (6)$$

Additionally, when $w = (w_1, w_2, \dots, w_n)$ and $w_i \in [0,1], \sum_{i=1}^n w_i = 1$, the following operations are also defined for IVSF sets.

- Interval-valued Spherical Weighted Arithmetic Mean (IVSWAM)
$$IVSWAM_w(\tilde{\alpha}_1, \dots, \tilde{\alpha}_n) = w_1\tilde{\alpha}_1 + \cdots + w_n\tilde{\alpha}_n =$$
$$= \left\{\left[(1-\prod_{i=1}^n (1-a_i{}^2)^{w_i})^{0.5}, \left(1-\prod_{i=1}^n \left(1-b_i{}^2\right)^{w_i}\right)^{0.5}\right], [(\prod_{i=1}^n c_i{}^{w_i}), (\prod_{i=1}^n d_i{}^{w_i})], \left[(\prod_{i=1}^n (1-a_i{}^2)^{w_i} - \prod_{i=1}^n (1-a_i{}^2-e_i{}^2)^{w_i})^{0.5}, \left(\prod_{i=1}^n \left(1-b_i{}^2\right)^{w_i} - \prod_{i=1}^n \left(1-b_i{}^2 - f_i{}^2\right)^{w_i}\right)^{0.5}\right]\right\} \quad (7)$$

- Interval-valued Spherical Geometric Mean (IVSWGM)
$$IVSWGM_w(\tilde{\alpha}_1, \dots, \tilde{\alpha}_n) = \tilde{\alpha}_1{}^{w_1} + \tilde{\alpha}_2{}^{w_2} + \cdots + \tilde{\alpha}_n{}^{w_n} =$$
$$= \left\{[\prod_{i=1}^n a_i{}^{w_i}, \prod_{i=1}^n b_i{}^{w_i}], \left[(1-\prod_{i=1}^n (1-c_i{}^2)^{w_i})^{0.5}, \left(1-\prod_{i=1}^n \left(1-d_i{}^2\right)^{w_i}\right)^{0.5}\right], \left[(\prod_{i=1}^n (1-c_i{}^2)^{w_i} - \prod_{i=1}^n (1-c_i{}^2-e_i{}^2)^{w_i})^{0.5}, \left(\prod_{i=1}^n \left(1-d_i{}^2\right)^{w_i} - \prod_{i=1}^n \left(1-d_i{}^2 - f_i{}^2\right)^{w_i}\right)^{0.5}\right]\right\} \quad (8)$$

In this study, the AHP method with IVSFs extension is preferred in weight determination of the determined I4.0 maturity model criteria. The steps of the method that are presented in Figure 2 were applied, then the obtained criteria weights were used as inputs in maturity assessment.

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Step 1: Development of the hierarchical structure of the problem and pairwise matrices

↓

Step 2: Collection of decision-maker opinions for the criteria when $\tilde{\alpha} = \langle [a, b], [c, d], [e, f] \rangle$

$$M = \begin{bmatrix} 1 & \widetilde{\alpha_{12}} & \dots & \widetilde{\alpha_{1n}} \\ \widetilde{\alpha_{21}} & 1 & \dots & \widetilde{\alpha_{2n}} \\ \dots & \dots & \dots & \dots \\ \widetilde{\alpha_{n1}} & \widetilde{\alpha_{n2}} & \dots & 1 \end{bmatrix}$$

↓

Step 3: Consistency check for the comparison matrices. CR value is calculated by calculating the CI value as follows. The consistency value should be less than 0.1.

$\boldsymbol{CI} = \frac{\boldsymbol{\lambda_{max} - n}}{\boldsymbol{n-1}}$ where $\boldsymbol{\lambda_{max}}$ represents the largest eigenvalue and n represents the number of criteria

CR = CI /RI where RI is the matrix table value determined by Saaty.

↓

Step 4: Aggregation of decision maker's opinions with $IVSWAM_w(\tilde{\alpha}_1, \dots, \tilde{\alpha}_n)$

↓

Step 5: Constitution of the IVSF weights of each criterion with $IVSWGM_w(\tilde{\alpha}_1, \dots, \tilde{\alpha}_n)$.

↓

Step 6: Determination of weights of each criterion by defuzzification of fuzzy values using $S(\widetilde{w}_i^s)$

$$S(\widetilde{w}_i^s) = \frac{a^2 + b^2 - c^2 - d^2 - \left({}^{e}/_{2}\right)^2 - \left({}^{f}/_{2}\right)^2}{2} + 1$$

↓

Step 7: Normalization of scores to determine final weights: $\widetilde{w}_i^s = \frac{S(\widetilde{w}_i^s)}{\sum_{i=1}^{n} S(\widetilde{w}_i^s)}$

Figure 2 Steps of IVSF-AHP methodology

Conventional MCDM methods might not fully address uncertainty and ambiguity within decision problems. In general, DMs use exact numbers given in a scale for their evaluations. However, in some cases, it is not possible to express assessments with exact numbers. Therefore, fuzzy extensions of the AHP have developed over time since fuzzy sets can be used to overcome uncertainties in human judgments. More recently, SFSs have been presented as a useful tool for expressing uncertain information in the literature. Ayyıldız and Taskin (2022) presented an extensive literature review on the use of SFSs with MCDM techniques. The AHP and TOPSIS methodologies were used in most of the publications examined within the scope of the study. The AHP method, which was first proposed by Saaty (1980), is one of the most frequently used MCDM techniques in the literature since the method is a practical approach with a simple hierarchical structure which allows DMs to easily evaluate both qualitative and quantitative criteria so relative priorities can be determined for a given set of alternatives. Duleba et al. (2021) reviewed the fuzzy extensions of the AHP and their review summarized several studies that used different types of fuzzy sets with AHP.

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4. Application of the proposed methodology

Currently, digitalization has an important place in sectors such as aviation, where competitiveness is very important. For this reason, determining the I4.0 maturity level is an important step in the success of aviation companies. However, in order to make necessary and productive steps toward I4.0, it is critical for a company to know its current situation. Therefore, the proposed method was applied in the selected aviation company to provide a real-life example.

4.1 Determination of dimensions

Initially, a general review of the premier online databases such as Science Direct, JSTOR, Web of Science, Emerald, ProQuest online, etc. was conducted starting in 2012. The review began in 2012 because the maturity model developed by Camgemini consulting firm (Westerman et al., 2012) is generally accepted as the earliest model in the literature. However, it is well known that the dimensions have changed over time because of the dynamic structure of the business world; therefore, more current studies (especially after 2017) were also used for criteria determination.

During the review, Science Direct, JSTOR, Web of Science and Emerald were used to find academic studies, while Google was used to find models developed by consultancy firms. ProQuest database was used to search for global dissertations and theses. The keywords Digital Maturity, Digital Transformation, Digital Maturity Assessment, Digital Transformation Maturity, Digital Readiness, Digital Readiness Model, and Digital Readiness Assessment were used. After an initial literature review, strategy and organization, smart factory, smart operations, smart products, employees, data management, culture, customers, leadership, and technology and resources were identified as the ten most mentioned dimensions. Details of these dimensions are provided in Table 2.

These dimensions were presented to five DMs who are experts in their fields. With a focus group approach, DMs prioritized the dimensions and determined the top five by prioritizing the list of 10 dimensions. Because of the joint evaluations of the DMs, the final criteria were determined to be smart factory, strategy and organization, technology and resources, smart products and data management.

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Table 2
Definition of dimensions and their examples obtained from the literature study

Dimensions	Contents	References
Strategy and Organization	I4.0 roadmap implementation Available resources for realization Adaption of new business models	Aras and Büyüközkan (2023), Al-Ali and Marks (2022), Hongxiong and Xiaowen (2022), Duncan et al. (2022), Goumeh and Barforoush (2021), Hizam-Hanafiah et al. (2020)
Smart Factory	Ergonomic facility design Digitalization in production, storage and transportation	Bibby and Dehe (2018), Klötzer and Pflaum(2017), Hamidi et al.(2018), Kiraz et al. (2019)
Smart Operations	Decentralization of operational processes Modeling & Simulation Interdisciplinary and interdepartmental cooperation	Goumeh and Barforoush (2021), Cordes and Musies (2021), Akdil et al. (2018), Hamidi et al.(2018), Kiraz et al. (2019)
Smart Products	Personalization of products Digitalization of products Product integration	Akdil et al. (2018), Klötzer and Pflaum(2017), Hamidi et al.(2018), Kiraz et al. (2019)
Employees	Information and communications technology authorizations of employees Innovative employees for new technology Self-determination of employees	Aras and Büyüközkan (2023), Al-Ali and Marks (2022), Duncan et al. (2022), Cordes and Musies (2021), Hamidi et al. (2018)
Data management	Existence of current information and communications technologies	Aras and Büyüközkan (2023), Duncan et al. (2022), Aslanova and Kulichkina (2020), Schumacher et al. (2018), Gimbel et al. (2018), Hamidi et al. (2018), Gökalp et al.(2017)
Culture	Sharing of information Cross company collaboration and open innovation Company's approach to information and communications technology	Barry et al. (2022), Cordes and Musies (2021), Almasbekkyzy et al. (2021)
Customers	Use of customer data Digitalization of customer services	Al-Ali and Marks (2022), Goumeh and Barforoush (2021), Cordes and Musies (2021)
Leadership	Leaders' attitude, competencies and methods Central coordination existence	Aras and Büyüközkan (2023), Al-Ali and Marks (2022), Yezhebay et al. (2021), Salume et al. (2021), Hizam-Hanafiah et al. (2020), Rossmann (2018)
Technology and Resources	Latest technology devices Using machine-to-machine communication	Al-Ali and Marks (2022), Goumeh and Barforoush (2021), Cordes and Musies (2021)

4.2 Weight determination of dimensions with IVSF-AHP

After the elimination of certain dimensions, pairwise comparisons were conducted by the five experts in order to calculate the weights of the smart factory, strategy and organization, technology and resources, smart products and data management dimensions using the IVSF-AHP method as presented in Figure 2. The methodology was applied step-by-step as follows:

- ***Steps 1 and 2:*** Pairwise matrices were developed based on the determined dimensions in Part 4.1. A matrix structure was prepared and presented to the DMs

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with an evaluation scale and brief explanation of the evaluation system. In the study, the opinions of DMs were collected using the 9-point AHP scale as presented in Table 3. The collected score indexes were transformed into IVFS as presented by Kutlu Gündoğdu and Kahraman (2021) in their linguistic terms used for the pairwise comparisons table.

Table 3
Linguistic scale for DMs evaluations (Kutlu Gündoğdu and Kahraman, 2021)

Linguistic terms	Score Index	IVSF-AHP Scale		
		$[\mu_{\tilde{A}_S}{}^L(u), \mu_{\tilde{A}_S}{}^U(u)]$	$[v_{\tilde{A}_S}{}^L(u), v_{\tilde{A}_S}{}^U(u)]$	$[\pi_{\tilde{A}_S}{}^L(u), \pi_{\tilde{A}_S}{}^U(u)]$
AMI-Absolutely more important	9	$[0.85, 0.95]$	$[0.10, 0.15]$	$[0.005, 0.15]$
VHI-Very high importance	7	$[0.75, 0.85]$	$[0.15, 0.20]$	$[0.15, 0.20]$
HI-High importance	5	$[0.65, 0.75]$	$[0.20, 0.25]$	$[0.20, 0.25]$
SMI-Slightly more important	3	$[0.55, 0.65]$	$[0.25, 0.30]$	$[0.25, 0.30]$
EI-Equally important	1	$[0.50, 0.55]$	$[0.45, 0.55]$	$[0.30, 0.40]$
SLI-Slightly low importance	1/3	$[0.25, 0.30]$	$[0.55, 0.65]$	$[0.25, 0.30]$
LI-Low importance	1/5	$[0.20, 0.25]$	$[0.65, 0.75]$	$[0.20, 0.25]$
VLI-Very low importance	1/7	$[0.15, 0.20]$	$[0.75, 0.85]$	$[0.15, 0.20]$
ALI-Absolutely low importance	1/9	$[0.10, 0.15]$	$[0.85, 0.95]$	$[0.005, 0.15]$

DMs were asked to evaluate the determined dimensions using the given scale in Table 3; therefore, pairwise matrices are collected. As an example, evaluation of one of the DMs is presented in Table 4.

Table 4
Example of a DM’s evaluation

	Data Management	Smart Factory	Smart Products	Strategy and Organization	Technology and Resources
Data Management	1.000	5.000	3.000	0.200	0.330
Smart Factory	0.200	1.000	1.000	0.111	0.143
Smart Products	0.330	1.000	1.000	0.143	0.200
Strategy and Organization	5.000	9.000	7.000	1.000	1.000
Technology and Resources	3.000	7.000	5.000	1.000	1.000

- ***Step 3:*** Before moving on to further analysis to determine the weights, a consistency analysis was performed for the comparisons presented by the decision makers. Because of the analysis made in this context, all values were found to be below 0.1. These values show the consistency in the data of the decision makers as stated in the literature. For the DM’s evaluation given in Table 4, the consistency ratio is 0.031. The remaining consistency ratio values for other DMs were calculated as 0.081, 0.065, 0.053, 0.097. These values show the consistency in the data of the decision makers as stated in the literature.
- ***Step 4:*** The evaluations were aggregated with $IVSWAM_w(\tilde{\alpha}_1, \ldots, \tilde{\alpha}_n)$ as stated in Figure 2. Equation 7 was applied by considering that DMs have equal weights thus aggregated results are achieved as presented in Tables 5-9.

Table 5
Aggregated pairwise comparison for the Data Management dimension

	Data Management					
	A	**B**	**c**	**d**	**e**	**f**
Data Management	0.500	0.550	0.450	0.550	0.300	0.400
Smart Factory	0.178	0.226	0.702	0.803	0.175	0.228
Smart Products	0.214	0.263	0.626	0.726	0.214	0.264
Strategy and Organization	0.466	0.556	0.404	0.482	0.206	0.262
Technology and Resources	0.536	0.634	0.280	0.338	0.240	0.292

Table 6
Aggregated pairwise comparison for the Smart Factory dimension

	Smart Factory					
	A	**B**	**c**	**d**	**e**	**f**
Data Management	0.732	0.845	0.162	0.214	0.159	0.217
Smart Factory	0.500	0.550	0.450	0.550	0.300	0.400
Smart Products	0.526	0.615	0.315	0.381	0.251	0.313
Strategy and Organization	0.694	0.811	0.182	0.234	0.179	0.237
Technology and Resources	0.775	0.880	0.138	0.189	0.131	0.191

Table 7
Aggregated pairwise comparison for the Smart Products dimension

	Smart Products					
	A	**B**	**c**	**d**	**e**	**f**
Data Management	0.641	0.744	0.206	0.257	0.209	0.257
Smart Factory	0.388	0.455	0.467	0.554	0.256	0.323
Smart Products	0.500	0.550	0.450	0.550	0.300	0.400
Strategy and Organization	0.639	0.744	0.228	0.287	0.197	0.248
Technology and Resources	0.727	0.839	0.164	0.216	0.160	0.219

Table 8
Aggregated pairwise comparison for the Strategy and Organization dimension

	Strategy and Organization					
	A	**B**	**c**	**d**	**e**	**f**
Data Management	0.552	0.654	0.316	0.385	0.202	0.258
Smart Factory	0.197	0.245	0.663	0.764	0.194	0.247
Smart Products	0.312	0.382	0.550	0.638	0.211	0.265
Strategy and Organization	0.500	0.550	0.450	0.550	0.300	0.400
Technology and Resources	0.616	0.714	0.243	0.301	0.229	0.285

Table 9
Aggregated pairwise comparison for the Technology and Resources dimension

	Technology and Resources					
	A	**B**	**c**	**d**	**e**	**f**
Data Management	0.335	0.405	0.486	0.573	0.243	0.295
Smart Factory	0.141	0.191	0.769	0.869	0.136	0.191
Smart Products	0.175	0.224	0.706	0.806	0.171	0.225
Strategy and Organization	0.303	0.350	0.581	0.683	0.241	0.310
Technology and Resources	0.500	0.550	0.450	0.550	0.300	0.400

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- ***Step 5:*** The aggregated results were used in the constitution of IVSF weights of each criterion as stated in Figure 2. Therefore, $IVSWGM_w(\widetilde{\alpha}_1, \ldots, \widetilde{\alpha}_n)$ as given in Equation 8 was used. In the calculations, w is equal to 0.2 since there are five dimensions (w=1/n). Weights for each criterion in IVSF structure are presented in Table 10.

- ***Step 6:*** To calculate the final weights of each criterion, IVSF weights of each criterion are defuzzified via $S(\widetilde{w}_i^s)$ function as stated in Figure 2. All scores for each criterion are presented in Table 10.

Table 10
Determined weights for dimensions

	a	*b*	*c*	*d*	*e*	*f*	$S(\widetilde{w}_i^s)$	Final $\widetilde{w}_i^s$
Data Management	0.534	0.620	0.354	0.432	0.233	0.304	1.160	0.238
Smart Factory	0.249	0.306	0.639	0.745	0.210	0.271	0.581	0.119
Smart Products	0.314	0.377	0.559	0.658	0.229	0.293	0.730	0.150
Strategy and Organization	0.500	0.578	0.407	0.493	0.234	0.311	1.069	0.220
Technology and Resources	0.622	0.713	0.282	0.352	0.226	0.301	1.328	0.273

- ***Step 7:*** Finally, scores that were calculated by $S(\widetilde{w}_i^s)$ function are normalized as stated in Figure 2 and the final weights were obtained. The weights for each criterion namely, data management, smart factory, smart products, strategy and organization, technology and resources are 0.238, 0.119, 0.150, 0.220, and 0.273, respectively. The analysis shows that DMs give higher importance to the technology and resources dimension than to other dimensions. This is followed by data management with a weight value of 0.238.

The calculated weights based on the IVSF-AHP methodology were used as inputs in the maturity level assessment of the company.

4.3 Maturity level assessment

Various methods and models are available for companies to measure their digitalization levels for different purposes. However, in this study the maturity level measurement formula, which is given in Equation 9 is preferred since it is one of the most widely used in the literature (Schumacher et al., 2016), where "M" represents maturity level, "D" represents dimensions, "I" stands for item, "q" is the weighting factor and "n" is the number of maturity item.

$$M_D = \frac{\sum_{i=1}^{n} M_{DIi} * g_{DIi}}{\sum_{i=1}^{n} g_{DIi}} \tag{9}$$

For this study, a maturity assessment form was developed and completed by the managers of the selected company to determine the level of maturity. The questionnaire (see Appendix Table A1) consists of 24 questions; five questions for strategy and organization, four questions for technology and resources, five questions for smart factory, six questions for smart products and four questions for data management. A Likert scale from 1 to 5 where 1 refers to "Strongly Disagree" and 5 refers to "Strongly Agree" was used.

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After the responses were collected, a final score was calculated using Equation 9. For each dimension (D), an overall score was calculated. Each question in the questionnaire for the related dimension represents items (I) and q is equally distributed among the items. For example, the smart factory dimension has five questions, or five items, and each item has equal importance (their weights, q, are equal). Therefore, average maturity scores for data management, smart factory, smart products, strategy and organization, technology and resources are 3.25, 2.4, 2, 3.25, and 2.75, respectively.

These average maturity scores are weighted by predetermined scores that are gathered from the IVSF-AHP methodology. Therefore, weighted maturity scores for data management, smart factory, smart products, strategy and organization, technology and resources are 0.775, 0.287, 0.300, 0.659, and 0.750, respectively. In the final calculation, the maturity level of the aviation company was calculated by the summation of each dimension's score and was found to be 2.770. According to the final score, the maturity level of the company was determined based on the definitions presented in Table 11.

Table 11
Characteristics of the maturity levels

Level	**Definition**
Level 1 : Initial	Unpredictable and insufficient process. Reactive management.
Level 2 : Managed	Process is partially planned and implemented. Reactive management.
Level 3 : Defined	Process characterized for the organization. Proactive.
Level 4 : Quantitatively Managed	Measurable and controlled processes.
Level 5 : Optimizing	Improvement of process is the main focus.

The level of compliance indicates that the company is between level 2 (Managed) and level 3 (Defined). While the company's scores for data management and strategy and organization are not bad, there is more work to do to improve the smart factory, smart products and technology and resources dimensions. Hence, it seems that the company is making progress towards I4.0 but has not shown sufficient improvement yet.

The results attained from the IVSF-AHP approach were compared with the results derived from the conventional AHP method by applying the weight determination steps of the proposed methodology using the conventional nine-point scale of the AHP; thus, the most important criterion is technology and resources (0.316). The weights of the remaining criteria are as follows: data management (0.299), strategy and organization (0.194), smart products (0.098), and smart factory (0.093). The conducted average maturity scores which for data management, smart factory, smart products, strategy and organization, technology and resources are 3.25, 2.4, 2, 3.25, and 2.75, respectively, are weighted by the conventional AHP-based scores. Therefore, the final maturity scores for data management, smart factory, smart products, strategy and organization, technology and resources are 0.972, 0.223, 0.196, 0.582, and 0.869, respectively. Figure 3 presents the comparison of the results.

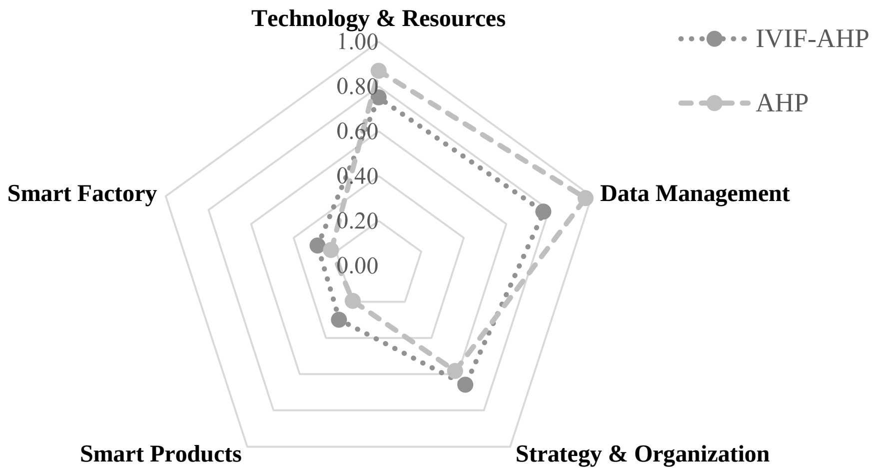

Figure 3 Comparison of IVSF-AHP and conventional AHP-based results

The comparison of the results shows that the final maturity scores achieved by the conventional AHP application align with the calculations performed using the IVSF-AHP method. In the final calculation using the conventional AHP results, the maturity level of the aviation company was 2.842, whereas it was 2.770 with the IVSF-AHP. Although the results indicate similar outcomes for the criteria and the overall level of the company (which is between level 2 (Managed) and level 3 (Defined) in both cases), the IVSF-AHP is considered better due to its ability to handle uncertain information inherent in an I4.0 maturity assessment. The slight difference in the final scores indicates that the IVSF-AHP provides a more refined and nuanced assessment due to its ability to handle uncertainties. This is particularly beneficial when dealing with data that is not entirely precise or deterministic, making the IVSF-AHP a suitable choice for capturing the complexities and uncertainties inherent in the evaluation of maturity levels.

5. Conclusion

The maturity level assessment serves as a compass, guiding companies through the intricacies of digital transformation. By precisely gauging their current digital maturity, organizations can pinpoint strengths, identify gaps, and strategically allocate resources. In this study, an integrated methodology including the IVSF-AHP and maturity assessment methods was developed. In the first stage, the related dimensions used for I4.0 maturity level assessment were extracted from the literature, and the dimensions having less priority (strategy and organization, smart factory, smart operations, smart products, employees, data management, culture, customers, leadership, technology and resources) were eliminated. Then, the remaining dimensions were weighted using the IVSF-AHP method. According to the obtained weights, technology and resources is the most important dimension contributing to the I4.0 target of the aviation company considered in this study. Finally, the maturity level of the aviation company was 2.770 using the dimension weights. The level of compliance shows that the company is between level 2 (Managed) and level 3 (Defined).

From a broader point of view, this assessment offers a roadmap for making informed choices, fostering innovation, and staying ahead in a rapidly evolving landscape. According to this study, managers of both the company where the application was made and other companies operating in the field of production can determine their I4.0 levels and take important actions toward digitalization. However, there are some limitations to the proposed methodology including the insufficiency of AHP in cases where dependency occurs between the dimensions and the limited number of experts utilized during the comparison of the dimensions. Finally, the methodology was only used in the aviation/defense sector which limits the scope of its application.

It is important to know the dimensions that need to be developed in order to make progress, and this model provides managers with this knowledge to make important decisions based on their specific company structures. Recommendations and guidelines to determine the maturity level of companies in future research studies include using other MCDM techniques to determine dimension importance weights and adapting the proposed methodology to firms in other sectors.

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APPENDIX

Table A1
Questionnaire for I4.0 Maturity Assessment

INDUSTRY 4.0 MATURITY ASSESSMENT QUESTIONNAIRE						
The following questions will be used in the determination of the company's current I4.0 maturity level. The agreement scale from 1 (Strongly disagree) to 5 (Strongly agree) will be used while responding to the questions in the survey.						
Dimension	**Questions**	**Scale**				
		1	**2**	**3**	**4**	**5**
Strategy & Organization	The company has allocated a budget to integrate I4.0 into the company and to ensure digitalization.					
	The company has created a roadmap for I4.0 and digitalization, and there is a vision statement on this subject.					
	Trainings on I4.0 are organized for company employees.					
	The company has an employee profile with sufficient competence and a suitable environment for the integration of I4.0 into the company and post-integration.					
	The company makes investments for I4.0.					
Technology & Resources	The company has a flexible, iterative and collaborative approach to technological developments.					
	A budget is allocated so that the resources used within the company are compatible with technological developments.					
	The company uses M2M technology, which enables devices to be remotely monitored, managed and communicated with each other.					
	Efforts are made to use the latest technology for the relevant processes in the company.					
Smart Factory	The facility has an ergonomic design and there are sensors to prevent work accidents.					
	There is digitalization in production, transportation and storage operations at the facility.					
	The facility is capable of collecting data from processes and equipment for digital modeling.					
	The facility discovers knowledge through data analysis.					
	Equipment in the facility is integrated into IT infrastructure.					
Smart Products	The company has ICT functions in the products.					
	The company collects data when the product is in the "use" stage.					
	The company uses data analytics models to create data-based services.					
	Products can be tracked through their whole lifecycle.					

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	Products can communicate with other products, machines and systems.					
	Products can collect data from the environment and other systems, and store it on their system or in the cloud.					
Data Management	The company has integrated data based services for the clients.					
	The company's data is secured, maintained and audited regularly with routine tests for validity.					
	The company collects data related to their operational and strategic concerns.					
	The company has defined the principles and goals of data management. Data quality is aimed to be improved, supported and monitored by senior management.					

REFERENCES

Akcan, T. (2019). Evaluation of the readiness and the maturity levels of companies for Industry 4.0 [in Turkish: *İşletmelerin Endüstri 4.0'a hazırlık ve olgunluk seviyelerinin incelenmesi*.] [Master's thesis, Thesis Number: 619331]. Pamukkale University Institute of Pure and Applied Sciences, PAU. https://hdl.handle.net/11499/28610

Akdil, K. Y., Ustundag, A., & Cevikcan, E. (2018). Maturity and readiness model for Industry 4.0 strategy. In Ustundag, A., Cevikcan, E., (Eds.), *Industry 4.0: Managing the Digital Transformation* (pp. 61–94). Cham, Switzerland: Springer International Publishing.

Akman, G., Boyacı, A. İ., & Kurnaz, S. (2022). Selecting the suitable e-commerce marketplace with neutrosophic Fuzzy AHP and EDAS methods from seller's perspective in the context of Covid-19. *International Journal of the Analytic Hierarchy Process*, *14*(3), 1–36. Doi: https://doi.org/10.13033/ijahp.v14i3.994

Al-Ali, M., & Marks, A. (2022). A digital maturity model for the education enterprise. *Perspectives: Policy and Practice in Higher Education*, *26*(2), 47–58. Doi: https://doi.org/10.1080/13603108.2021.1978578

Almasbekkyzy, A., Abdikerim, D., Nabi, D., Abdallah, Y. O., & Shehab, E. (2021, April). Digital maturity and readiness model for multiple-case of Kazakhstan large companies. *2021 IEEE International Conference on Smart Information Systems and Technologies* (SIST), 1-7. Doi: 10.1109/SIST50301.2021.9465912

Alsufyani, N., & Gill, A. Q. (2021). A review of digital maturity models from adaptive enterprise architecture perspective: Digital by design. *2021 IEEE 23rd Conference on Business Informatics (CBI)*, *1*, 121–130. Doi: http://hdl.handle.net/10453/157937

Aras, A., & Büyüközkan, G. (2023). Digital transformation journey guidance: A holistic digital maturity model based on a systematic literature review. *Systems*, *11*(4), 213.

Asdecker, B., & Felch, V. (2018). Development of an Industry 4.0 maturity model for the delivery process in supply chains. *Journal of Modelling in Management*, *13*(4), 840-883. Doi: http://dx.doi.org/10.1108/JM2-03-2018-0042

Aslanova, I. V., & Kulichkina, A. I. (2020). Digital maturity: Definition and model. *2nd International Scientific and Practical Conference "Modern Management Trends and the Digital Economy: from Regional Development to Global Economic Growth" (MTDE 2020)* (443-449). Atlantis Press. Doi: 10.2991/aebmr.k.200502.073

Atanassov, K. T. (1986). Intuitionistic fuzzy sets. *Fuzzy Sets and Systems*, *20*(1), 87–96, Doi: http://dx.doi.org/10.1016/S0165-0114(86)80034-3

Ayyildiz, E., & Taskin, A. (2022). A novel spherical fuzzy AHP-VIKOR methodology to determine serving petrol station selection during COVID-19 lockdown: A pilot study for İstanbul. *Socio-Economic Planning Sciences, 83*, 101345. Doi: http://dx.doi.org/10.1016/j.seps.2022.101345

Azevedo, A., & Santiago, S. B. (2019). Design of an assessment Industry 4.0 maturity model: An application to manufacturing company, *Proceedings of the International*

Conference on Industrial Engineering and Operations Management Toronto (pp. 208-217). IEOM Society International.

Bandara, O., Vidanagamachchi, K., & Wickramarachchi, R. (2019). *A model for assessing maturity of Industry 4.0 in the banking sector*, International Conference on Industrial Engineering and Operations Management, Bangkok, Thailand.

Barry, A.S., Assoul, S., & Souissi, N. (2022). Benchmarking of digital maturity models according to the dimension component. *Proceedings of the 2nd International Conference on Innovative Research in Applied Science, Engineering and Technology* (pp. 1-8). IEEE.

Batz A., Oleśków-Szłapka J., Stachowiak A., Pawłowski G., & Maruszewska K. (2020). Identification of logistics 4.0 maturity levels in Polish companies—Framework of the model and preliminary research. In Grzybowska K., Awasthi A., & Sawhney R. (Eds.) *Sustainable Logistics and Production in Industry 4.0. EcoProduction (Environmental Issues in Logistics and Manufacturing)*. (pp. 161-175). Cham: Springer.

Bibby, L. & Dehe, B. (2018). Defining and assessing Industry 4.0 maturity levels – case of the defense sector. *Production Planning & Control*, *29*(12), 1030-1043. Doi: https://doi.org/10.1080/09537287.2018.1503355

Branco, I.C., Jesus, F. R., & Oliveria, T. (2019). Assessing Industry 4.0 readiness in manufacturing: Evidence for the European Union. *Computers in Industry*, 107, 22-32. Doi: https://doi.org/10.1016/j.compind.2019.01.007

Brozzi, R., D'Amico, R. D., Pasetti Monizza, G., Marcher, C., Riedl, M. & Matt, D. (2018). Design of self-assessment tools to measure Industry 4.0 readiness. A methodological approach for craftsmanship SMEs. In Chiabert P., Bouras A., Noël F., Ríos J. (Eds), *Product Lifecycle Management to Support Industry 4.0. PLM 2018. IFIP Advances in Information and Communication Technology*, Vol: 540. Cham: Springer. Doi: https://doi.org/10.1007/978-3-030-01614-2_52

Büyüközkan, G., & Güler, M. (2019). Analysis of companies' digital maturity by hesitant fuzzy linguistic MCDM methods. *Journal of Intelligent and Fuzzy Systems*, *38*(2), 1-14. Doi: http://dx.doi.org/10.3233/JIFS-179473

Castro H. F., Carvalho A. R. F., Leal F., & Gouveia H. (2020). Assessing Industry 4.0 readiness of Portuguese companies. In Almeida H., & Vasco J. (Eds), *Progress in Digital and Physical Manufacturing*: *Lecture Notes in Mechanical Engineering*. (pp. 57-64). Cham: Springer.

Cordes, A. K., & Musies, N. (2021). Accelerating the transformation? The impact of COVID-19 on the digital maturity of retail businesses. *IEEE 23rd Conference on Business Informatics (CBI)* Vol. 1 (pp. 102-110). IEEE.

De Carolis, A., Macchi, M., Negri, E. & Terzi, S. (2017). A maturity model for assessing the digital readiness of manufacturing companies. In Lödding H., Riedel R., Thoben KD., von Cieminski G., Kiritsis D. (Eds), *Advances in Production Management Systems. The Path to Intelligent, Collaborative and Sustainable Manufacturing*. *IFIP Advances in Information and Communication Technology*, Vol. 513. Springer, Cham.

Duleba, S., Kutlu Gündoğdu, F., & Moslem, S. (2021). Interval-valued spherical fuzzy analytic hierarchy process method to evaluate public transportation development. *Informatica*, *32*(4), 661-686. Doi: http://dx.doi.org/10.15388/21-INFOR451

Duncan, R., Eden, R., Woods, L., Wong, I., & Sullivan, C. (2022). Synthesizing dimensions of digital maturity in hospitals: systematic review. *Journal of Medical Internet Research*, *24*(3), e32994.

Gajsek, B., Marolt, J., Rupnik, B., Lerher, T., & Sternad, M. (2019). Using maturity model and discrete event simulation for Industry 4.0 implementation. *International Journal of Simulation Modelling*, *3*, 488-489. Doi: https://doi.org/10.2507/IJSIMM18(3)489

Geissbauer, R., Vedsø, J., & Schrauf, S. (2016). A strategist's guide to Industry 4.0. *Strategy and Business*, 83, 148-163.

Gökalp, E., ¸Sener, U., & Eren, P. E. (2017). Development of an assessment model for Industry 4.0: Industry 4.0-MM. In Mas, A., Mesquida, A., O'Connor, R.V., Rout, T., Dorling, A. (Eds.), *Software Process Improvement and Capability Determination* (128–142). Cham, Switzerland: Springer International Publishing.

Goumeh, F., & Barforoush, A. A. (2021, March). A digital maturity model for digital banking revolution for Iranian banks. *26th International Computer Conference, Computer Society of Iran (CSICC)* (pp. 1-6). IEEE.

Gülseren, A., & Sağbaş A. (2019). Evaluation of digital transformation and digital maturity level in industry from Industry 4.0 perspective [in Turkish: Endüstri 4.0 Perspektifinde Sanayide Dijital Dönüşüm ve Dijital Olgunluk Seviyesinin Değerlendirilmesi]. *European Journal of Engineering and Applied Sciences*, *2*, 1-5, Doi: http://dergipark.gov.tr/EJEAS

Hamidi, S. R., Aziz, A. A., Shuhidan, S. M., Aziz A. A., & Mokhsin M. (2018). SMEs maturity model assessment of IR4.0 digital transformation. In Lokman A., Yamanaka T., Lévy P., Chen K., Koyama S. (Eds), *Proceedings of the 7th International Conference on Kansei Engineering and Emotion Research 2018. KEER 2018. Advances in Intelligent Systems and Computing*, (pp. 721-732). Vol 739. Singapore: Springer.

Hizam-Hanafiah, M., Soomro, M. A., & Abdullah, N.L. (2020). Industry 4.0 readiness models: A systematic literature review of model dimensions. *Information*, 11, 364.

Hongxiong, Y., & Xiaowen, X. (2022, February). Research on computer evaluation index system of digital maturity of automotive supply chain. *IEEE International Conference on Electrical Engineering, Big Data and Algorithms (EEBDA)* (pp. 442-446). IEEE.

Kiraz, A., Canpolat, O., Erkan, E. F., & Uygun, Ö. (2019). Assessing Industry 4.0 tendency with IMPULS criteria: A fuzzy cognitive map application [in Turkish: IMPULS kriterleri ile Endüstri 4.0 eğiliminin değerlendirilmesi: Bir bulanık bilişsel harita uygulaması]. *Academic Platform-Journal of Engineering and Science*, *7*(1), 14-23, Doi: https://doi.org/10.21541/apjes.332543

Klötzer, C., & Pflaum, A. (2017). Toward the development of a maturity model for digitalization within the manufacturing industry's supply chain. *Proceedings of the Hawaii International Conference on System Sciences*, Hawaii (pp. 4210–4219).

Kutlu Gündoğdu F, & Kahraman C. (2019). Spherical fuzzy sets and spherical fuzzy TOPSIS method. *Journal of Intelligent & Fuzzy Systems*, *36*(1), 337-52. Doi: http://dx.doi.org/10.3233/JIFS-181401

Kutlu Gündoğdu, F., & Kahraman, C. (2021). Hospital performance assessment using interval-valued spherical fuzzy analytic hierarchy process. *Decision Making with Spherical Fuzzy Sets: Theory and Applications*, 392, 349-373. Doi: http://dx.doi.org/10.1007/978-3-030-45461-6_15

Leyh, C., Schäffer, T., Bley, K. & Forstenhäusler, S. (2017). Assessing the IT and software landscapes of Industry 4.0 enterprises: The maturity model SIMMI 4.0. In Ziemba E. (Eds), *Information Technology for Management: New Ideas and Real Solutions. ISM 2016, AITM 2016. Lecture Notes in Business Information Processing*, Vol. 277. Cham: Springer.

Nahavandi, B., Homayounfar, M., & Daneshvar, A. (2023). A fuzzy Analytical Hierarchy Process for evaluation of knowledge management effectiveness in research centers. *International Journal of the Analytic Hierarchy Process*, *15*(1), 1-30.

Nick, G. A., Szaller, A., Bergman, J., & Várgedő, T. (2019). Industry 4.0 readiness in Hungary: Model, and the first results in connection to data application. IFAC-PapersOnLine, *52*(13), 289-294. Doi: http://dx.doi.org/10.1016/j.ifacol.2019.11.185

Özçelik, T. Ö., Erkollar, A. & Cebeci, H. İ. (2018, October). Industry 4.0 (digital) maturity level determination application for a manufacturing business [in Turkish: Bir İmalat İşletmesi için Endüstri 4.0 (Dijital) Olgunluk Seviyesi Belirleme Uygulaması]. *5th International Management Information Systems Conference,* Ankara, Turkey.

Oztemel, E., & Gursev, S. (2020). Literature review of Industry 4.0 and related technologies. *Journal of Intelligent Manufacturing, 31*, 127-182, Doi: http://dx.doi.org/10.1007/s10845-018-1433-8

Pacchini, A. P. T., Lucato, W. C., Facchini, F., & Mummolo, G. (2019). The degree of readiness for the implementation of Industry 4.0. *Computers in Industry*, 113, 103125. Doi: http://dx.doi.org/10.1016/j.compind.2019.103125

Poveda, C. A. (2023). Using multi-criteria decision-making to assess the importance of human capital in meeting the goals and objectives of sustainable development: An application of the Analytic Hierarchy Process. *International Journal of the Analytic Hierarchy Process, 15*(1), 1-31. Doi: https://doi.org/10.13033/ijahp.v15i1.1067

Rafeal, L. D., Jaione, G. E., Cristina, L., & Ibon, S. L. (2020). An Industry 4.0 maturity model for machine tool companies. *Technological Forecasting and Social Change*, 159, 120203. Doi: http://dx.doi.org/10.1016/j.techfore.2020.120203

Ramos, M. O., Silva, E. M., & Lima-Júnior, F. R. (2020). A fuzzy AHP approach to select suppliers in the Brazilian food supply chain. *Production*, 30, 1-16. Doi: http://dx.doi.org/10.1590/0103-6513.20200013

Rossmann, A. (2018). Digital maturity: Conceptualization and measurement Model. *Proceedings of the 39th International Conference on Information Systems (ICIS 2018)*, San Francisco, USA, (pp. 1–9).

Saaty, T.L. (1980). *The Analytic Hierarchy Process*. New York: McGraw Hill. International, Translated to Russian, Portuguese, and Chinese, Revised editions, Paperback (1996, 2000). Pittsburgh: RWS Publications

Salume, P. K., Barbosa, M. W., Pinto, M. R., & Sousa, P. R. (2021). Key dimensions of digital maturity: A study with retail sector companies in Brazil. *Revista de Administração Mackenzie*, *22*(6), 1–29. Doi:10.1590/1678-6971/eRAMD210071

Sarı, T. (2020). Development of an Industry 4.0 maturity model by Analytic Hierarchy Process: Case of food and beverage manufacturing sector. *Business and Management Studies: An International Journal*, *8*(3), 3526-3549. Doi: https://doi.org/10.15295/bmij.v8i3.1597

Schumacher, A., Erol, S. & Sihn, W. (2016). A maturity model for assessing INDUSTRY 4.0 readiness and maturity of manufacturing enterprises, *Procedia CIRP*, 52, 161-166. Doi: https://doi.org/10.1016/j.procir.2016.07.040

Smarandache, F. (2003). Definiton of neutrosophic logic-a generalization of the intuitionistic fuzzy logic. *EUSFLAT Conference* (pp. 141-146). https://doi.org/0.2139/ssrn.272158

Sriram, R. M. & Vinodh, S. (2020). Analysis of readiness factors for Industry 4.0 implementation in SMEs using COPRAS, *International Journal of Quality & Reliability Management*, *38*(5), 1178-1192. Doi: https://doi.org/10.1108/IJQRM-04-2020-0121

Stefan, L., Thom, W., Dominik, L., Dieter, K. & Bernd, K., (2018). Concept for an evolutionary maturity based Industry 4.0 migration model, *Procedia CIRP*, 72, 404-409. Doi: https://doi.org/10.1016/j.procir.2018.03.155

Stentoft, J., Wickstrom, K. A., Philipsen, K., & Haug, A. (2019), Drivers and barriers for Industry 4.0 readiness and practice: Empirical evidence from small and medium-sized manufacturers, *Production Planning and Control, 32*(10), 811-828. Doi: https://doi.org/10.1080/09537287.2020.1768318

Szejka, A. L., Rocha, T., Junior, O. C., & Freitas R. L. (2020). A preliminary discussion of the ACATECH 4.0 and AHP to measure enterprise maturity level index. *Transdisciplinary Engineering for Complex Socio-technical Systems – Real-life Applications*, *12*, 143-150. Doi: https://doi.org/10.32333/ATDE200071

Tavčar, J., Demšar, I. & Duhovnik, J. (2018). Engineering change management maturity assessment model with lean criteria for automotive supply chain. *Journal of Engineering Design*, *29*(4-5), 235-257. Doi: https://doi.org/10.1080/09544828.2018.1463513

Torra, V. (2010). Hesitant fuzzy sets. *International Journal of Intelligent Systems*, *25*(6), 529-539. Doi: https://doi.org/10.1002/int.20418

Ustaoğlu N. (2019). *A maturity model for digital transformation*, [Doctoral dissertation, Sabancı University, Thesis Number: 608242]. Sabancı University Research Database. https://research.sabanciuniv.edu/id/eprint/39704

Vogel-Heuser, B., & Hess, D. (2016). Guest editorial Industry 4.0–prerequisites and visions. *IEEE Transactions on Automation Science and Engineering*, *13*(2), 411-413. Doi: https://doi.org/10.1109/TASE.2016.2523639

Vrchota, J. & Pech, M. (2019). Readiness of enterprises in Czech Republic to implement Industry 4.0: Index of Industry 4.0. *Applied Sciences*, *9*(24), 5405. Doi: https://doi.org/10.3390/app9245405

Westerman, G., Tannou, M., Bonnet, D., Ferraris, P., & McAfee, A. (2012). The digital advantage: How digital leaders outperform their peers in every industry. *MIT Sloan Management and Capgemini Consulting, MA*, *2*, 2-23.

Yezhebay, A., Sengirova, V., Igali, D., Abdallah, Y. O., & Shehab, E. (2021, April). Digital maturity and readiness model for Kazakhstan SMEs. *IEEE International Conference on Smart Information Systems and Technologies (SIST)* (pp. 1-6).

Zadeh, L. A. (1996). Fuzzy sets. In Lotfi A Zadeh, George J. Klir, and Bo Yuan (Eds.) *Fuzzy sets, fuzzy logic, and fuzzy systems: selected papers* (pp. 394-432). World Scientific.

Zayat, W., Kilic, H. S., Yalcin, A. S., Zaim, S., & Delen, D. (2023). Application of MADM methods in Industry 4.0: A literature review. *Computers & Industrial Engineering*, *177*, 109075. Doi: https://doi.org/10.1016/j.cie.2023.109075