

## Article

# Implementing a Novel Use of Multicriteria Decision Analysis to Select IIoT Platforms for Smart Manufacturing

Roberto Contreras-Masse<sup>1,2,†,‡,\*</sup>, Alberto Ochoa-Zezzatti<sup>1,‡</sup>, Vicente García<sup>1,‡</sup>, Luis Pérez-Dominguez<sup>1,‡</sup> and Mayra Elizondo<sup>3,‡</sup>

<sup>1</sup> Universidad Autónoma de Ciudad Juárez (UACJ), Mexico

<sup>2</sup> Instituto Tecnológico de Ciudad Juárez (ITCJ), Mexico

<sup>3</sup> Universidad Nacional Autónoma de México (UNAM), Mexico

\* Correspondence: rcontreras@itcj.edu.mx;

† Current address: Av. Tecnológico No. 1340 Fracc. El Crucero C.P. 32500 Ciudad Juárez, Chih. México

‡ These authors contributed equally to this work.

**Abstract:** Industry 4.0 is having a great impact in all smart efforts. This is not a single product, but is composed of several technologies, being one of them Industrial Internet of Things (IIoT). Currently, there are very varied implementation options offered by several companies, and this imposes a new challenge to companies that want to implement IoT in their processes. This challenge suggests to use multi-criteria analysis to make a repeatable and justified decision, requiring a set of alternatives and criteria. This paper proposes a new methodology and comprehensive criteria to help organizations to take an educated decision by applying multi-criteria analysis. Here, we suggest a new original use of PROMETHEE-II with full example from weight calculation up to IoT platform selection, showing this methodology as an effective study for other organizations interested to select an IoT platform. The criteria proposed outstands from previous work by including not only technical aspects, but economic and social criteria, providing a full view of the problem analyzed. A case of study was used to prove this proposed methodology.

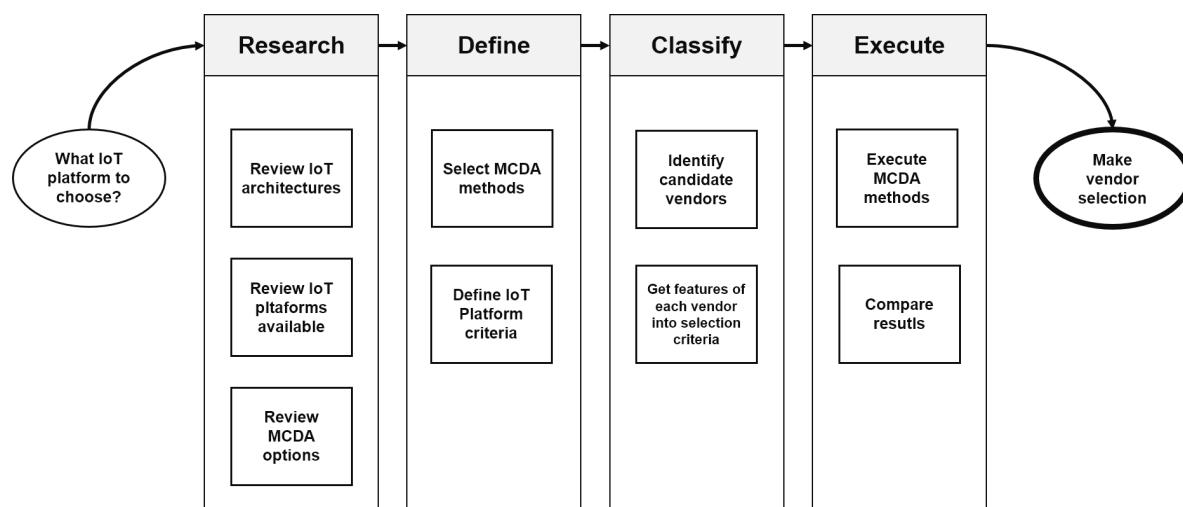
**Keywords:** IIoT; Platform Selection; Multi criteria analysis; MCDA; AHP; PROMETHEE-II; Cloud; Methodology

## 1. Introduction

Industry 4.0 is having high impact in all industries. This is not a unique product, but is composed of several technologies. Boston Consulting Group has defined nine technological pillars for Industry 4.0: cloud, additive manufacturing, simulation, big data and analysis, autonomous robots, augmented reality, integration of horizontal and vertical systems, cybersecurity and industrial internet of things (IIOT) [1]. IIOT has been used not only in the manufacturing industry, but has expanded to other industries such as health, travel and transportation, energy, gas and oil, etc. This is one of the main reasons that IIOT is known as the Internet of Things (IoT) [2]. IIoT is a key intelligent factor that allows factories to act intelligently. By adding sensors and actuators to objects, the object becomes intelligent because it can interact with people, other objects, generate data, generate transactions and react to environmental data [3,4]. Cities do not ignore this trend, since there is a plan to turn cities into smart cities in certain countries [5].

The decision processes that companies must follow should be supported by methods that consider pros and cons of plural points of view that affect the decision process. Researchers and practitioners have developed over time the techniques that today are part of the domain of Multiple Criteria Decision

Analysis (MCDA) which, very simplistically, requires three basic elements: a finite set of actions or alternatives, at least two criteria and at least one decision-making [6]. The MCDA has been the object of study and nowadays there are a lot of methods for decision making in disciplines such as waste management, industrial engineering, strategies, manufacturing, even natural resource management and environmental impact [7]. The purpose of this manuscript is precisely to propose a method of MCDA with the corresponding criteria for the selection of an IIoT platform, which can serve as a starting point to companies and individuals embarked on implementation projects of Industry 4.0. Our conceptual model to solve the problem is shown in Figure 1.



**Figure 1.** Conceptual model to select IIoT platforms

### 1.1. Literature Review

Industrial Internet of Things (IIoT) continues to evolve. Due to the intrinsic complexity, it is good practice to look at architectural references. IIoT have five main requirements in general basis [8]: 1) Enable communication and connectivity between devices and data processing; 2) Establish a mechanism to manage devices, including tasks such as adding or deleting devices, updating software and configurations; 3) Gather all the data produced by the devices and then analyze them to provide a meaningful perspective to the companies or users; 4) Facilitate scalability to handle the increased flow of "data pipes" (hereinafter referred to as data pipelines) and the flow of data, and handle an increasing number of devices; 5) Protect the data by adding the necessary functions to provide privacy and trust between the devices and the users. Table 1 shows the summary of the various multi-layer architectures found in the literature.

**Table 1.** IIoT Architectures

Num.	Layers	References
2	Devices and Communication	[9]
3	Devices, Communication and Application	[10–12]
4	Devices, Communication, Transport and Application	[9,12–16]
5	Devices, Local processing, Communication, Transport and Applications	[12]
7	Business, Management, Communication, Processing, Acquisition, User interaction and Security	[15,17]
8	Physical devices, Communication, Edge or Fog processing, Data storage, Applications, Collaboration and process, Security	[18]

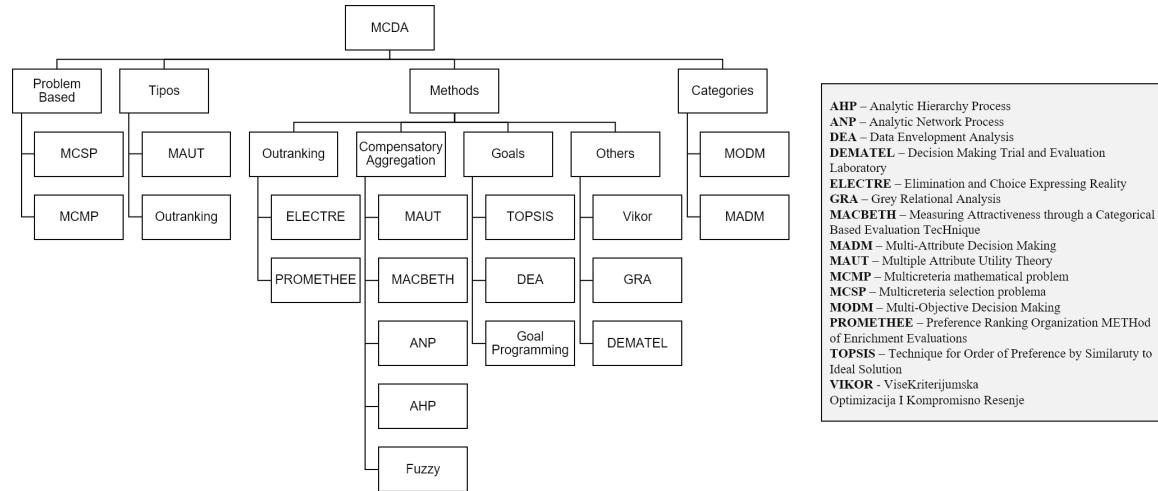
Technical architecture provides an extreme value to users because it can be implemented with different products. Therefore, it is understandable that several companies offer IIoT platforms that can

be useful for our architectures. Commercial providers aim to flexible options offered, and consumers are responsible for using each component in the best way they consider. The main commercial players identified are, in alphabetical order: Amazon Web Services, Bosch IoT Suite, Google Cloud Platform, IBM Blue Mix (now Watson IoT), Microsoft Azure IoT and Oracle Integrated Cloud [19]. The leading players identified in 2014 by Gartner Group were AWS and Microsoft, but in 2018 Google enters the leaders quadrant. IBM, for its commercial relevance is considered, although it has become a niche player, along with Oracle. Although Bosch IoT does not appear in the panorama detected by Gartner, we include it for being used in several industries. Each of these suppliers has similar characteristics among them but have different value propositions.

### 1.1.1. MCDA as a tool to select IIoT Platform

Making a decision introduce problems to individuals. One of the problems is the integration of heterogeneous data and the uncertainty factor surrounding a decision, and the criteria that usually conflict with each other [7,20]. To carry out a MCDA process, a series of tasks is proposed, based on the three generic steps suggested by [21]: i) identify the objective or goal, ii) select the criteria, parameters, factors, attributes, iii) selection of alternatives, iv) association of attributes with the criteria, v) selection of weight methods to represent the importance of each criterion, and vi) the method of aggregation. [21] included a step that is left out of these proposed tasks, but which should be considered in the discussion before executing the selected action. This step is to understand and compare the preferences of the person making the decision.

The MCDA can be classified according to the basis of the problem, by type, by category or by the methods used to make the analysis. Figure 2 shows a taxonomy adapted from [22]; the methods included in this taxonomy are not exhaustive. The MCDA is a collection of systematic methodologies for comparisons, classification and selection of multiple alternatives, each one with multiple attributes and is dependent on an evaluation matrix. Generally it used to detect and quantify the decisions and considerations from interested parties (stakeholders) about various monetary factors and non-monetary factors to compare alternative course of action [7,22]. The major division that exists in MCDA lies in the category of methodologies. First group considers discrete values with a limited number of known alternatives that involve some compensation or trade-off. This group is called Multiple Attributes Decision Making (MADM). The other group is the Multiple Objectives Decision Making (MODM) and its variable decision values are within a continuous domain with infinite or very numerous options that satisfy the restrictions, preferences or priorities [20]. Also, there is another classification according to the way of adding criteria and it is divided into the American school, which aggregates into a single criterion, and into the European or French school that uses outranking methods. It can be considered a mixture of both schools and they are indirect approaches, such as the Peer Criteria Comparison methods (PCCA) [23].



**Figure 2.** Taxonomy of MCDA (Adapted from [22])

### 1.1.2. Use of MCDA to select IIoT platforms or technology platforms - Related work

When finding the available alternatives of the market, a new question will arise to find the method that helps to select the appropriate option. To answer this last question, a review of the literature is made looking for: a) MCDA methods applied to the selection of IIoT platforms and b) knowing the criteria taken into account.

In the literature there is little information on the subject in recent years. Table 2 shows the summary of the work found. The selected methods are focused on AHP, TOPSIS and Fuzzy logic in AHP and TOPSIS. The outranking methods were not implemented, but were considered as an option or for future work by some authors [24,25]. The selection of an IIoT platform is not dominated by a single criterion, nor is there a single alternative. [26] considered AWS, Azure, Bosch, IBM Watson and Google Cloud within their options, which coincide with some of the alternatives considered in this manuscript. Therefore, it is interesting to review the criteria they included for MCDA, as summarized in Table 2.

**Table 2.** MCDA Related work to select technology

Yr.	Application	MCDA	Criteria	Ref.
2019	IoT Challenges	AHP, ANP	Communication, Technology, Privacy and security, Legal regulations, Culture	[27]
2018	Cloud service for IoT	FAHP, FTOPSIS	Availability, Privacy, Capacity, Speed, Cost	[28]
2018	Platform IoT	Fuzzy	Security, Device management, Integration level, Processing level, Database functionality, Data collection protocols, Visualization, Analytics variety	[26]
2018	IaaS	TOPSIS	Cost, Computing required, Storage capacity, Operating system	[25]
2018	Distributed IoT Databases	AHP	Usability, Prtability, Support	[29]
2017	IoT Device	AHP	Energy consumption, Implementation time, Difficulty of implementation, Cost, Clock device	[24]
2017	IoT Platform	AHP	Energy, Cost, Computing speed, Data memory, Program memory, device weight	[30]
2013	Ranking cloud services	AHP	Responsibility, Agility, Service assurance, Cost, Performance, Security and privacy, Usability	[31]

Criteria found in literature are purely technical with some hints of economy, and can be found as part of the characteristics of IoT architecture [32]. But when implementing an IIoT platform, non-technical aspects should also be considered. As the platform to be considered has its foundation in the cloud, it is valid to review the criteria included in previous MCDA exercises to select a cloud provider, looking for non-technical aspects.

The criteria for selecting a cloud proposed in the CSMIC Framework v 2.1 of 2014 <sup>1</sup> as Index of Measure of Service (SMI) include topics of interest to the organization, financial and usability, together With the technical issues [31]. Some of these criteria can be included to complement the analysis having the technical point of view and the business point of view.

Finally, there is the question about which methods are suitable for this type of problems, noting that the previous work includes AHP, ANP, TOPSIS and Fuzzy Logic, but they leave aside for future research methods such as PROMETHEE and ELECTRE. There are many more methods available in MCDA scope. Following the decision tree to select an MCDA method written by [23], which considers 56 methods, the number of options can be easily reduced. In the case of selecting an IoT platform that has different criteria, the problem has the characteristics of classification or ranking, ordering the options from best to worst. This technique is useful in real life, since they are hardly conform and subject themselves to a single option, but they have to consider their primary option and another option as backup, assuming that the first option is not viable.

The candidate methods found are COMET, NAIADE II, EVAMIX, MAUT, MAVT, SAW, SMART, TOPSIS, UTA, VIKOR, Fuzzy SAW, Fuzzy TOPSIS, Fuzzy VIKOR, PROMETHEE I, PAMSSEM II, Fuzzy PROMETHEE II, AHP + TOPSIS, AHP + VIKOR, fuzzy AHP + TOPSIS, AHP + Fuzzy TOPSIS, Fuzzy ANP + Fuzzy TOPSIS, AHP, ANP, MACBETH, DEMATEL, REMBRANDT, Fuzzy AHP and Fuzzy ANP.

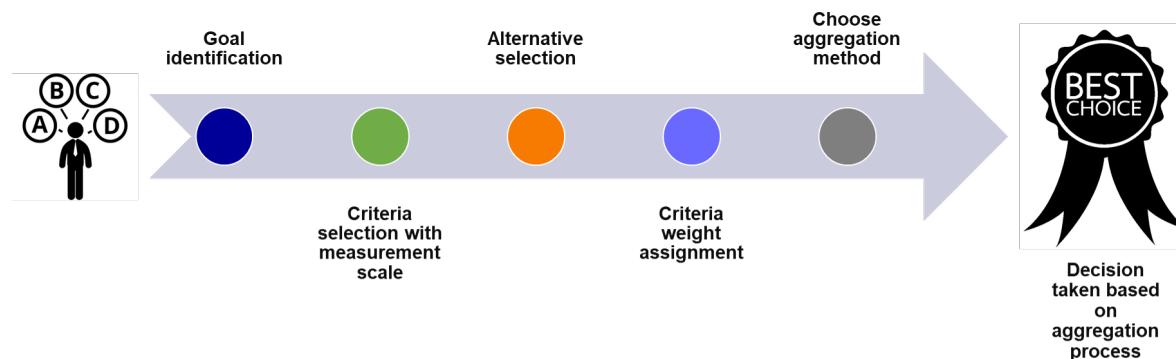
<sup>1</sup> Cloud Services Measurement Initiative Consortium (CSMIC) was created by Carnegie Mellon University to develop Service Measurement Index (SMI). it can be found at <https://spark.adobe.com/page/PN39b/>

Of the 29 methods suggested by the decision tree, those used in the literature are included for this type of problem. However, although it would be a very interesting exercise to compare the 29 methods with each other, it is beyond the scope of this article. We propose to use PROMETHEE II, which has not been used in previous works, but some authors have considered it for future work.

## 2. Materials and Methods

In our experience, companies that want to implement IIoT show great enthusiasm for the initiative, but on several occasions they have a misconception of what IoT entails. IoT concepts are technical and of great interest to engineers and systems architects, but the business factors, cost aspects, methods of payment, and commercial conditions, all of them are of great interest for senior management represented by the Chief Officers, referred often as CxO Level. In addition, the wide offer that exists in the market where suppliers have different prices and service schemes make it difficult to compare among each other, or at least difficult to do a linear comparison.

Our proposal identifies and suggests the criteria required for IIoT Platform selection for a MCDA exercise with PROMETHEE-II method, enabling organizations to compare results and make a well-founded decision. This work does not provide a universal and definitive solution, but rather, it proposes the methodology that any organization, be it small or large, can use to decide on the IIoT platform that best suits their circumstances and needs. Following the general MCDA process depicted in Figure 3, the decision objective is the selection of an IIoT platform.



**Figure 3.** Process for multiple criteria analysis

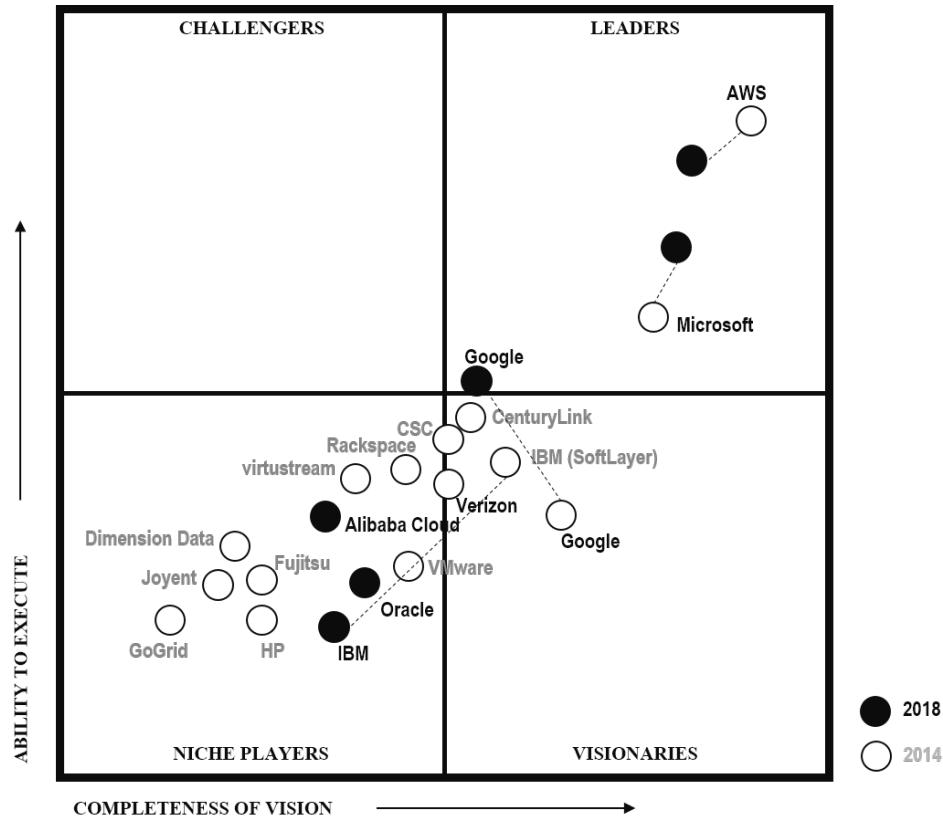
The selection of criteria must be consistent with the decision and each criterion must be independent of one another. Each criterion must also be measured on the same scale and applicable to all alternatives. The Table 3 summarizes the criteria to be used together with its definition. Criteria that are qualitative, i.e. based on expert judgement, can be measured by text to number scale. For calculating criteria weights, we propose to use Analytic Hierarchy Process and the Saaty scale [24,27]. Criteria that are quantitative should consider equal scenarios, such as the cost of data transmission, which for all alternatives should be calculated with the same number of devices, same message size and same number of messages per day.

The selected criteria are divided into three major areas of interest: technical, economic and social. This is a major enhancement over previous works found in the literature. To identify to what area each criterion belongs, we use a relationship matrix, where we identify if the criterion has a high, medium or low relationship with each of the areas. The selected criteria are also classified as quantitative and qualitative according to their nature, and are summarized in Table 3.

**Table 3.** Criteria for IIoT Platform selection process

Area	Criterion (Abbreviation)	Definition (Qualitative (Q) or Quantitative (C). All are maximization except when noted Minimization (min) )	Type
Technical (T)	Available region (TAr)	In cloud-based solutions, it is important to identify the regions where the provider is present and that are suited to the geographical situation of the industry.	C
	Managed Integration (TMI)	The platform has the ability to offer an integration engine with services and applications.	Q
	Communication Protocols (TCp)	IoT devices can communicate telemetry and receive messages with different protocols such as HTTP, MQTT, AMQP, CoAP, or even private.	C
	Security (TS)	The security of the platform must include security for the transmission, registration of devices, avoiding apocryphal devices, authentication and authorization, preferably from start to finish.	Q
	Device Management (TDm)	Devices that can be connected, device identification, device monitoring, send software updates to devices and specify alert conditions. The digital twin refers to the digital replica of the physical asset.	Q
	Display (TD)	It allows that the data and the behavior of the devices can be seen by humans. It is better if a native and customizable dashboard is offered to show the relevant data to each person.	Q
	Variety of Data Analytics (TAi)	The data collected must be analyzed in different ways. It is important to consider the data flow, real-time analysis, batch, and machine learning algorithms available on the platform.	Q
	Longevity in market (EM)	Years that the provider has in the market. It is expected that the reputation of a supplier will increase over the years.	Q
	Cost (EC)	Calculate the monthly cost (30 days average) for the devices that will be connected. Use constant message size and the frequency of constant message sending.	C(Min)
	Free Cost (EFc)	The providers offer a free amount of messages that are subtracted from the monthly consumption.	Q
Social (S)	Training Cost (ETc)	Providers can offer access to training with cost or free, and staff certification plans.	C(Min)
	Community support (SCs)	Informative resources about the platform, including the available documentation of the provider and external resources of the expert community (blogs, tutorials, discussion forums, etc.)	Q
	Available Resources (SHr)	Availability of human resources with expert knowledge in the platform.	Q
	Training (ST)	Providers offer training and certifications, which can be complicated to follow and hinder the learning curve. One measure may be the estimated time to complete the courses and certifications.	C

The existing alternatives for the IIoT platform considered in this paper appear in the literature, or are widely used in the industry and are recognized as market leaders of cloud providers, such Gartner's Magic Quadrant. Figure 4 shows how in 2014 there were 15 competitors, while in 2018 only six remained. However, it is easy to observe the leaders, dominated by AWS, Microsoft and the recently newcomer, Google. Thus, the alternatives included in this exercise are: AWS IoT Platform, Microsoft Azure IoT Platform and Google Cloud IoT Platform.

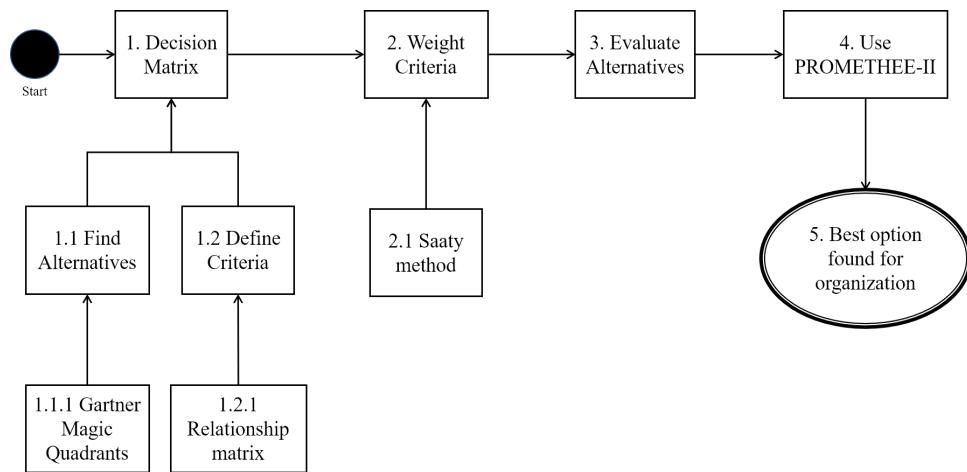


**Figure 4.** Gartner Cloud Providers Leaders Magic Quadrant 2014 vs 2018 (Adapted from [33,34], own creation)

Our proposal includes profiles of people who must participate in the expert judgement exercise, something that has not been found in literature. It is important that they are not only dedicated to technology in order to enrich the exercise. Table 5 lists the desirable profiles of people we suggest, who should be involved in a MCDA exercise as experts. It is important to note that not all roles must necessarily be participating, as these positions may vary between organizations

### 2.1. Methods

Our proposed methodology, shown in Figure 5, consists of several tasks in order to found the best alternative. The first task (Activity 1) is to define a decision matrix, taking in consideration sub tasks. It is required to find the alternatives available in the market (Activity 1.1). a good source of information is to rely in recognized entities such as Gartner Consulting (Activity 1.1.1); they perform studies to find who are the leaders, challengers, niche players and visionaries. Next, criteria is defined (Activity 1.2) supported by elaborating a relationship matrix (Activity 1.2.1). Defined criteria has been proposed in Table 3. It consists of fourteen items available, named  $C_i$ , where  $i = 1, 2, \dots, n$ , and  $n = 14$ , arranged in 3 main areas, supported by decision matrix shown in Figure 6.

**Figure 5.** Methodology proposed to select IIoT Platform

	Available Regions	Available Resources	Communication Protocols	Community Support	Cost	Device Management	Display	Free Cost	Longevity in Market	Managed Integration	Security	Training Available	Training cost	Variety of Data Analytics
Technical	H	L	H	M	L	H	H	M	L	H	H	M	L	H
Economic	L	M	L	M	H	L	L	H	H	L	L	L	H	L
Social	L	H	L	H	L	L	L	M	L	L	H	L	L	

**Figure 6.** Relationship matrix to find the criteria and area belonging

The resulting decision matrix will have 14 criteria with 3 alternatives is shown in table 4, as we are considering as feasible alternatives only the leaders from Fig. 4.

**Table 4.** Our resulting decision matrix (activity 1)

Alternative	Criterion $C_1$	Criterion $C_2$	...	Criterion $C_{14}$
AWS ( $S_1$ )				
Azure ( $S_2$ )				
GCP ( $S_3$ )				

**Table 5.** Roles involved in IIoT Platform selection

Role	Description	Interest
CIO	<b>Chief Information Officer</b> In terms usually is, it is the most important person responsible for technology in any company. Their tasks range from buying IT equipment to directing the workforce to the use of technology.	T, E, S
CTO	<b>Chief Technology Officer</b> The technology director reports to the CIO, which means that it acts as support for IoT projects. That said, in larger organizations, the work may be too much for just one person, so the CTO has this responsibility.	T
CInO	<b>Chief Innovation Officer</b> This role is of recent creation and is the one that can counteract the wild instinct oriented to sales of the business units of a company and design an organizational environment more favourable to innovation.	T, S
CSO	<b>Chief Security Officer</b> He is the main responsible for the information security program of an organization and should be consulted before any deployment of technology.	T
COO	<b>Chief Operations Officer</b> Oversees the business operations of an organization and work to create an operations strategy and communicate it to employees. He is very involved in the day to day of the company and will be one of the main impacted in an IoT project.	E
CMO	<b>Chief Marketing Officer</b> The technology and the business aspects of the company are converging. This convergence of technology and marketing reflects the need for the traditional Commercial Director to adapt to a digital world and, therefore, participates in any IoT project in which they are working, to express their opinion as to obtain commercial benefit for the company.	E
CFO	<b>Chief Financial Officer</b> In all the projects of the company, there must be the support of the Finance Director, who controls the economic resources of the company. In an IoT project, he is interested in the investment required, and especially in the return of investment to exercise.	E
HRO	<b>Human Resources Officer</b> It is the person who needs to know if the necessary skills to the project exist in the market, how easy it is to obtain them and the sources where they can be obtained. Among his responsibilities are the personnel development plans and the recruitment of human resources.	S
BUL	<b>Business Unit Leaders</b> The deputy directors and managers who report within each hierarchy are key personnel that can provide good opinions and issue a more tactical than strategic judgement. By being more focused on specific projects, their knowledge and sensitivity also becomes specific, giving value to expert judgements.	T, E, S

Then, Activity 2 start, where experts will need to grade each criterion in pairwise fashion, using Saaty scale [35] (Activity 2.1) for pairwise comparison (Table 6) to assign a level of importance of  $C_i$  over  $C_j$ . Expert's answers are recorded in a square matrix  $x = [n \times n]$ . Each element  $x_{ij}$  will have a numeric value translated from Saaty scale and, as it is pairwise, the reciprocal  $x_{ji} = 1/x_{ij}$  when  $i \neq j$ ; when  $i = j$ , then  $x_{ij} = 1$ . In other words,  $x_{ij}$  corresponds to the importance of  $C_i$  over  $C_j$ .

**Table 6.** Saaty scale for pairwise comparison (Adapted from [35])

Intensity of Importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favor one element over another
5	Strong importance	Experience and judgement strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another, its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values	Importance between above and below value

When designing the tool to grab expert's answers, consider the number of pairwise comparisons required. These can be easily calculated by

$$NumComparisons = \frac{n^2 - n}{2} \quad (1)$$

After having recorded all answers, it is required to calculate weights  $w$ , for each  $C_i$ . To proceed, first the matrix values need to be normalized by obtaining the sum of each column and then dividing each cell by the sum of its corresponding column.

From this normalized matrix, criteria weights  $w$  are obtained by the sum on each row element  $\sum_{i=1}^n x_{ij}$ , when  $j = 1, 2, \dots, n$ . However, it is important to verify if weights found are trustworthy and can be applied later. This is achieved by calculating the Consistency Ratio ( $CR$ ).  $CR$  will measure how consistent the judgements are relative to large sample of pure random judgements, known as Random Index ( $RI$ ). When  $CR < 0.1$ , then the weights are acceptable. In the case  $CR > 0.1$ , it indicates the judgements are untrustworthy because they are closer to random distribution and the exercise must be repeated. random distribution, also known as Saaty random consistency index, is well documented by Saaty [35] and widely used in literature. As a reference, Table 7 shows values for  $RI$ , based on number of criteria [36].

$CR$  is found by

$$CR = \frac{CI}{RI} \quad (2)$$

where  $CI$  is Concistency Index and  $RI$  is the Random Index.  $CI$  is calculated as

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (3)$$

It is required to multiply each value for its corresponding criteria weight and then sum each row to obtain a weighted sum value ( $WSM$ ). Then, each of this weighted sum values is divided by the corresponding criteria weight ( $CW$ ). The result is a new column with  $\lambda_i = \frac{WSM_i}{CW_i}$  values.

To calculate  $\lambda_{max}$ , just sum of the results of each  $\lambda$  and divide it by number of rows in the matrix

$$\lambda_{max} = \frac{\sum_{i=1}^n (\lambda_i)}{\text{num of rows}} \quad (4)$$

**Table 7.** Random Index [36]

N	RI
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51
12	1.48
13	1.56
14	1.57
15	1.59

If  $CR < 0.1$ , then calculated weights are accepted (trustworthy) and expert can proceed to grade each alternative  $S_k$  for each  $C_i$ . We propose qualitative criterion to use qualitative conversion, from 1 to 5. Each word from low, below low, average, good, excellent has a corresponding value, in this case {1, 2,3,4,5}.

Activity 3 consist on evaluate the alternatives using the decision matrix with the weights found and validated. It is required to define criterion goal. They can be Maximize (also known as direct criteria, or beneficial criteria), or Minimize (also known as indirect criteria or non beneficial criteria). This goal setting is important as it will define the normalization method in Activity 4.

Quantitative criterion just need to enter the value as it is found. For qualitative criterion, expert enters a perception of the criterion, that in turn will be translated into a numeric value. We propose to use a 1 to 5 values, as shown in Table 8.

**Table 8.** Perception to value

Perception	Value
Excellent	5
Good	4
Average	3
Below Average	2
Low	1

After all decision matrix is evaluated, it can be applied PROMETHEE-II method. PROMETHEE-II stands for Preference Ranking Organization Method for Enrichment Evaluations. Version I is just a partial ranking, reason enough not to use it in our methodology, while version II is a full ranking. PROMETHEE-II is an extensive documented method, and reader can find information about this method in [37,38].

Finally, all alternatives are ranked and it can be obtained the best option for the organization (Activity 5).

### 3. Results

Calculating weights, consistency and selecting the best alternative can be difficult to follow. It is better to show an example. In our work, we follow our proposed methodology to obtain the best option to select an IIoT platform calculating the weighted criteria with the three platform vendors located in leader quadrant from Gartner's magic quadrant (Fig. 4). Those are: AWS, Azure and GCP.

### 3.1. Weight Criteria Calculation

The first step in our methodology says to calculate the weights required for platform selection. In order to achieve this, there are two things to do: 1) Weight calculation coming from experts judgement (participants came from Table 5) and 2) Validate consistency.

Each expert must answer how important is  $criterion_i$  over  $criterion_j$ . Using Saaty scale [35] for pairwise comparison (Table 6) experts can express the importance between two criterion. In our proposed methodology, each expert consulted should answer  $[(14^2) - 14]/2 = 91$  comparisons, as there are 14 criteria. This is 91 items.

By following criteria abbreviations proposed in table 3, and having recorded expert's judgement for each pairwise comparison, table 9 shows the matrix with answers given.

**Table 9.** Expert's judgement pairwise comparison recorded

	TAr	TMi	TCp	TS	TDm	D	TAi	EM	EC	EFc	ETc	SCs	SHr	ST
<b>TAr</b>	<b>1</b>	$1/2$	$1/2$	$1/5$	$1/2$	$1/5$	$1/2$	2	$1/2$	1	$1/2$	$1/2$	$1/2$	$1/2$
<b>TMi</b>	2	<b>1</b>	1	1	1	1	1	5	1	3	3	5	1	3
<b>TCp</b>	2	1	<b>1</b>	1	3	1	1	5	1	3	5	5	3	5
<b>TS</b>	5	1	1	<b>1</b>	1	5	5	2	1	5	3	5	5	5
<b>TDm</b>	2	1	$1/3$	1	<b>1</b>	3	3	3	1	3	3	2	1	1
<b>D</b>	5	1	1	$1/5$	$1/3$	<b>1</b>	1	3	1	3	4	3	2	3
<b>TAi</b>	2	1	1	$1/5$	$1/3$	1	<b>1</b>	3	1	2	1	2	1	2
<b>EM</b>	$1/2$	$1/5$	$1/5$	$1/2$	$1/3$	$1/3$	$1/3$	<b>1</b>	$1/2$	1	$1/3$	$1/3$	$1/3$	$1/3$
<b>EC</b>	2	1	1	1	1	1	1	2	<b>1</b>	1	2	2	2	3
<b>EFc</b>	1	$1/3$	$1/3$	$1/5$	$1/3$	$1/3$	$1/2$	1	1	<b>1</b>	$1/2$	$1/3$	$1/2$	$1/3$
<b>ETc</b>	2	$1/3$	$1/5$	$1/3$	$1/3$	$1/55$	1	3	$1/2$	2	<b>1</b>	1	$1/2$	1
<b>SCs</b>	2	$1/5$	$1/5$	$1/5$	$1/2$	$1/3$	$1/2$	3	$1/2$	3	1	<b>1</b>	1	1
<b>SHr</b>	2	1	$1/3$	$1/5$	1	$1/2$	1	3	$1/2$	2	2	1	<b>1</b>	1
<b>ST</b>	2	$1/3$	$1/5$	$1/5$	1	$1/3$	$1/2$	3	$1/3$	3	1	1	1	<b>1</b>
$\sum x_{ij}$	30.5	9.9	8.3	7.23	11.67	15.283	17.33	39	10.83	33	27.33	29.167	19.83	27.167

We need to obtain the sum of each column. The sum of each column will be used to normalize Table 9 resulting in Table 10.

**Table 10.** Normalized matrix

	TAr	TMi	TCp	TS	TDm	TD	TAi	EM	EC	EFc	ETc	SCs	SHr	ST
<b>TAr</b>	0.033	0.051	0.060	0.028	0.043	0.013	0.029	0.051	0.046	0.030	0.018	0.017	0.025	0.018
<b>TMi</b>	0.066	0.101	0.120	0.138	0.086	0.065	0.058	0.128	0.092	0.091	0.110	0.171	0.050	0.110
<b>TCp</b>	0.066	0.101	0.120	0.138	0.257	0.065	0.058	0.128	0.092	0.091	0.183	0.171	0.151	0.184
<b>TS</b>	0.164	0.101	0.120	0.138	0.086	0.327	0.288	0.051	0.092	0.152	0.110	0.171	0.252	0.184
<b>TDm</b>	0.066	0.101	0.040	0.138	0.086	0.196	0.173	0.077	0.092	0.091	0.110	0.069	0.050	0.037
<b>TD</b>	0.164	0.101	0.120	0.028	0.029	0.065	0.058	0.077	0.092	0.091	0.146	0.103	0.101	0.110
<b>TAi</b>	0.066	0.101	0.120	0.028	0.029	0.065	0.058	0.077	0.092	0.061	0.037	0.069	0.050	0.074
<b>EM</b>	0.016	0.020	0.024	0.069	0.029	0.022	0.019	0.026	0.046	0.030	0.012	0.011	0.017	0.012
<b>EC</b>	0.066	0.101	0.120	0.138	0.086	0.065	0.058	0.051	0.092	0.030	0.073	0.069	0.101	0.110
<b>EFc</b>	0.033	0.034	0.040	0.028	0.029	0.022	0.029	0.026	0.092	0.030	0.018	0.011	0.025	0.012
<b>ETc</b>	0.066	0.034	0.024	0.046	0.029	0.016	0.058	0.077	0.046	0.061	0.037	0.034	0.025	0.037
<b>SCs</b>	0.066	0.020	0.024	0.028	0.043	0.022	0.029	0.077	0.046	0.091	0.037	0.034	0.050	0.037
<b>SHr</b>	0.066	0.101	0.040	0.028	0.086	0.033	0.058	0.077	0.046	0.061	0.073	0.034	0.050	0.037
<b>ST</b>	0.066	0.034	0.024	0.028	0.086	0.022	0.029	0.077	0.031	0.091	0.037	0.034	0.050	0.037

**Table 11.** Weights  $w_i$  calculated

Criterion $C_i$	Weight Calculated $w_i$
<b>TAr</b>	0.033054398
<b>TMi</b>	0.099114871
<b>TCp</b>	0.129047676
<b>TS</b>	0.159817455
<b>TDm</b>	0.094698157
<b>TD</b>	0.091812783
<b>TAi</b>	0.066103106
<b>EM</b>	0.025301927
<b>EC</b>	0.082932622
<b>EFc</b>	0.030639156
<b>ETc</b>	0.042044181
<b>SCs</b>	0.043080184
<b>SHr</b>	0.056348976
<b>ST</b>	0.046004508

To determine if weights are trustworthy, we calculated Consistency Index and Consistency ratio. Table 13 shows the values obtained when calculating  $WVS$ , the ratio of each  $\frac{WVS}{w_i}$ ,  $\lambda_{max}$  and equation 5 shows Consistency Index  $CI$  calculation.

**Table 12.** Computed weighted values

	TAr	TMi	TCp	TS	TDm	TD	TAi	EM	EC	EFc	ETc	SCs	SHr	ST
<b>TAr</b>	0.033	0.050	0.065	0.032	0.047	0.018	0.033	0.051	0.041	0.031	0.021	0.022	0.028	0.023
<b>TMi</b>	0.066	0.099	0.129	0.160	0.095	0.092	0.066	0.127	0.083	0.092	0.126	0.215	0.056	0.138
<b>TCp</b>	0.066	0.099	0.129	0.160	0.284	0.092	0.066	0.127	0.083	0.092	0.210	0.215	0.169	0.230
<b>TS</b>	0.165	0.099	0.129	0.160	0.095	0.459	0.331	0.051	0.083	0.153	0.126	0.215	0.282	0.230
<b>TDm</b>	0.066	0.099	0.043	0.160	0.095	0.275	0.198	0.076	0.083	0.092	0.126	0.086	0.056	0.046
<b>TD</b>	0.165	0.099	0.129	0.032	0.032	0.092	0.066	0.076	0.083	0.092	0.168	0.129	0.113	0.138
<b>TAi</b>	0.066	0.099	0.129	0.032	0.032	0.092	0.066	0.076	0.083	0.061	0.042	0.086	0.056	0.092
<b>EM</b>	0.017	0.020	0.026	0.080	0.032	0.031	0.022	0.025	0.041	0.031	0.014	0.014	0.019	0.015
<b>EC</b>	0.066	0.099	0.129	0.160	0.095	0.092	0.066	0.051	0.083	0.031	0.084	0.086	0.113	0.138
<b>EFc</b>	0.033	0.033	0.043	0.032	0.032	0.031	0.033	0.025	0.083	0.031	0.021	0.014	0.028	0.015
<b>ETc</b>	0.066	0.033	0.026	0.053	0.032	0.023	0.066	0.076	0.041	0.061	0.042	0.043	0.028	0.046
<b>SCs</b>	0.066	0.020	0.026	0.032	0.047	0.031	0.033	0.076	0.041	0.092	0.042	0.043	0.056	0.046
<b>SHr</b>	0.066	0.099	0.043	0.032	0.095	0.046	0.066	0.076	0.041	0.061	0.084	0.043	0.056	0.046
<b>ST</b>	0.066	0.033	0.026	0.032	0.095	0.031	0.033	0.076	0.028	0.092	0.042	0.043	0.056	0.046

**Table 13.** Computed consistency

Criterion $C_i$	Weight value $\sum$ (WVS)	Ratio $WVS/w_i$
<b>TAr</b>	0.494310596	14.95445755
<b>TMi</b>	1.543958531	15.57746603
<b>TCp</b>	2.022150174	15.66979151
<b>TS</b>	2.577562734	16.12816779
<b>TDm</b>	1.501905104	15.85991904
<b>TD</b>	1.413764592	15.39834154
<b>TAi</b>	1.012396031	15.31540793
<b>EM</b>	0.386173129	15.26259755
<b>EC</b>	1.291838682	15.57696654
<b>EFc</b>	0.454059119	14.81956987
<b>ETc</b>	0.636805226	15.14609676
<b>SCs</b>	0.651477099	15.12243086
<b>SHr</b>	0.855083138	15.17477683
<b>ST</b>	0.69821939	15.17719502
$\lambda_{max} = 15.37023$		

Consistency Index in our experiment is calculated as

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{15.37023 - 14}{(14 - 1)} = 0.105402 \quad (5)$$

Using the random index for  $N = 14$  from Table 7, Consistency ratio is computed as

$$CR = \frac{CI}{RI(n)} = \frac{0.105402}{1.59} = 0.06671 \quad (6)$$

As  $CR < 0.1$ , the weights for each criterion are consistent and trustworthy, therefore, they are accepted to use in our decision process.

### 3.2. IIoT Platform Selection

Among the three cloud platform vendors considered for this excercise: AWS, Azure and Google Cloud Platform (GCP), listed in alphabetical order. Each vendor brings IoT capacity, different services and price schema not directly comparable among vendors. Each organization must have their goals, and will answer the weight criteria process differently, so it is not possible to determine which vendor is better than other in an absolute fashion. For that reason, this scenario is a good fit for our methodology.

Each alternative (let's call them  $S_i$ ) need to be graded on each of the criterion proposed. It is convenient to have it on a table, with criteria identified (in this case we use abbreviations suggested in our methodology) and specify if criterion is cualitative, i.e. requires a numeric value contained in criterion domain, or it is qualitative and requires to convert the appreciation of expert grading into a pre-established numeric value, as shown in table 14.

**Table 14.** Pre-define values for qualitative labels

Qualitative label	Pre-defined value
Low	1
Below Avg	2
Average	3
Good	4
Excellent	5

For criterion "Available regions (TAr), AWS has 22 available regions worldwide<sup>2</sup>, Azure offers 55 regions<sup>3</sup> and GCP offers 21<sup>4</sup>. Criterion Communication ports (TCp), AWS offers three options (HTTP, Websockets, MQTT), Azure offers four (HTTP, AMQP, MQTT, Websockets), and GCP offers two (HTTP, MQTT). Criterion Cost (EC) is the most cumbersome to compare and calculate. AWS uses a mix schema to estimate IoT costs. Azure is based on messages, and GCP has a traffic consumption schema. As it can be seen, this is not comparable directly, so we estimated costs based on a same scenario for all three vendors.

The scenario consist of 1,000 devices, sending a message of 8Kb with a rate of 2 messages per minute. All estimations are per month. Our compared estimations using each vendor calculator are summarized on table 15.

**Table 15.** Cost estimations by vendor

AWS	Azure	GCP
\$ 3.46 Connectivity	2,880 messages/device	675,000 MB/month
\$86.40 of messaging	2,880,000 msg/day	\$0.0045/MB
\$36.00 device shadow	S1 node provides 400,00	
\$ 4.32 rules triggered	msg/day	
\$ 8.64 rules actions	unlimited access	
	Need 8 X S1 nodes	
Total Cost: \$138.32	Total Cost: \$180.00	Total Cost: \$3,037.50

Training cost (ETc) takes in consideration the cost of certification, being AWS \$150.00, Azure \$165.00 and GCP \$200.00 (at the time of writing this paper). The rest of the criteria are evaluated from a qualitative form. In the Table 16, contains the grades provided and  $Max(x_{ij})$  and  $Min(x_{ij})$ . In order to save space, we use  $S_1$  as AWS,  $S_2$  as Azure, and  $S_3$  as GCP.

**Table 16.** Graded alternatives

$S_i$	TAr	TMi	TCp	TS	TDm	TD	TAi	EM	EC	EFc	ETc	SCs	SHr	ST
$S_1$ AWS	22	4	3	5	3	4	5	5	138.82	3	150	4	5	4
$S_2$ Azure	55	5	4	4	4	5	5	4	182.53	5	165	5	5	3
$S_3$ GCP	21	3	3	3	3	5	4	3	3037.5	4	200	3	3	3
$Max(x_{ij})$	55	5	4	5	4	5	5	5	3037.5	5	200	5	5	4
$Min(x_{ij})$	21	3	3	3	3	4	4	3	138.82	3	150	3	3	3

To Normalize the table, we need to consider if we are maximizing (Eq. ??) or minimizing (Eq. ??). The resulting normalized matrix is on Table 17. As a courtesy to the reader, we exemplify the operation using the first cell of the matrix. The operation executed to normalize values is

$$\frac{X_{1,1} - Min(x_{ij})}{Max(x_{ij}) - Min(x_{ij})} = \frac{22 - 21}{55 - 21} = 0.023$$

<sup>2</sup> <https://aws.amazon.com/about-aws/global-infrastructure/?p=ngi&loc=1>

<sup>3</sup> <https://azure.microsoft.com/en-us/global-infrastructure/regions/>

<sup>4</sup> <https://cloud.google.com/about/locations/>

**Table 17.** Normalized table

$S_i$	TAr	TMi	TCp	TS	TDm	TD	TAi	EM	EC	EFc	ETc	SCs	SHr	ST
$S_1$	0.029	0.5	0	1	0	0	1	1	1	0	1	0.5	1	1
$S_2$	1	1	1	0.5	1	1	1	0.5	0.985	1	0.7	1	1	0
$S_3$	0	0	0	0	0	1	0	0	0	0.5	0	0	0	0

Next step is to calculate differences from normalized table 17 using a pairwise comparison as shown in table 18. The sample operation is

$$S_1 - S_2 = (0.029 - 1) = -0.971$$

**Table 18.** Calculated differences from normalized matrix

$S_a - S_b$	TAr	TMi	TCp	TS	TDm	TD	TAi	EM	EC	EFc	ETc	SCs	SHr	ST
$S_1 - S_2$	-0.971	-0.5	-1	0.5	-1	-1	0	0.5	0.015	-1	0.3	-0.5	0	1
$S_1 - S_3$	0.029	0.5	0	1	0	-1	1	1	1	-0.5	1	0.5	1	1
$S_2 - S_1$	0.971	0.5	1	-0.5	1	1	0	-0.5	-0.015	1	-0.3	0.5	0	-1
$S_2 - S_3$	1	1	1	0.5	1	0	1	0.5	0.985	0.5	0.7	1	1	0
$S_3 - S_1$	-0.029	-0.5	0	-1	0	1	-1	-1	-1	0.5	-1	-0.5	-1	-1
$S_3 - S_2$	-1	-1	-1	-0.5	-1	0	-1	-0.5	-0.985	-0.5	-0.7	-1	-1	0

Now, to calculate preference function values we use eq. ??, resulting in table 19. The operation is

$$P_i(a, b) \leq 0 \text{ then } P_i(a, b) = 0; -0.971 \leq 0 \text{ then } = 0$$

**Table 19.** Preference function computations results

$S_a - S_b$	TAr	TMi	TCp	TS	TDm	TD	TAi	EM	EC	EFc	ETc	SCs	SHr	ST
$S_1 - S_2$	0	0	0	0.5	0	0	0	0.5	0.0151	0	0.3	0	0	1
$S_1 - S_3$	0.023	0.5	0	1	0	0	1	1	1	0	1	0.5	1	1
$S_2 - S_1$	0.971	0.5	1	0	1	1	0	0	0	1	0	0.5	0	0
$S_2 - S_3$	1	1	1	0.5	1	0	1	0.5	0.985	0.5	0.7	1	1	0
$S_3 - S_1$	0	0	0	0	0	1	0	0	0	0.5	0	0	0	0
$S_3 - S_2$	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Next, we calculate the weighted preferences, using preference function and weights found (Table 11). Each cell has the value  $wP_i(a, b)$  and results are in Table 20 by doing

$$w_i P_i(a, b) = 0.033 \times 0 = 0$$

**Table 20.** Weighted preferences

	TAr	TMi	TCp	TS	TDm	TD	TAi	EM	EC	EFc	ETc	SCs	SHr	ST
$w_i$	0.033	0.099	0.129	0.160	0.095	0.092	0.066	0.025	0.083	0.031	0.042	0.043	0.056	0.046
$S_1 - S_2$	0.000	0.000	0.000	0.080	0.000	0.000	0.000	0.013	0.001	0.000	0.013	0.000	0.000	0.046
$S_1 - S_3$	0.001	0.050	0.000	0.160	0.000	0.000	0.066	0.025	0.083	0.000	0.042	0.022	0.056	0.046
$S_2 - S_1$	0.032	0.050	0.129	0.000	0.095	0.092	0.000	0.000	0.000	0.031	0.000	0.022	0.000	0.000
$S_2 - S_3$	0.033	0.099	0.129	0.080	0.095	0.000	0.066	0.013	0.082	0.015	0.029	0.043	0.056	0.000
$S_3 - S_1$	0.000	0.000	0.000	0.000	0.000	0.092	0.000	0.000	0.000	0.015	0.000	0.000	0.000	0.000
$S_3 - S_2$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

The aggregated preference is shown in Table 21.

**Table 21.** Aggregated preference

$S_q - S_b$	$\pi(a, b)$
$S_1 - S_2$	0.152428017
$S_1 - S_3$	0.55062249
$S_2 - S_1$	0.44937751
$S_2 - S_3$	0.740439621
$S_3 - S_1$	0.107132361
$S_3 - S_2$	0

Next, using the aggregated preference values, we calculate the entering and leaving flows. Table 22 has the arranged values; right-most column contains the leaving flow ( $\varphi^+$ ) and bottom row shows the entering flow ( $\varphi^-$ ).

**Table 22.** Entering and leaving flows

	AWS	Azure	GCP	$\varphi^+$
<b>AWS</b>		0.152428017	0.55062249	0.351525254
<b>Azure</b>	0.44937751		0.740439621	0.594908565
<b>GCP</b>	0.107132361	0		0.053566181
$\varphi^-$	0.278254935	0.076214009	0.645531056	

Leaving and entering flow are calculated using eq. ?? and ???. Our operations are

$$\varphi^+ = \frac{1}{n-1} \sum_{b=1}^n \pi(a, b) = \frac{(0.152428017 + 0.55062249)}{3-1} = 0.351525254$$

$$\varphi^- = \frac{1}{n-1} \sum_{b=1}^n \pi(b, a) = \frac{(0.44937751 + 0.107132361)}{3-1} = 0.278254935$$

As we are using PROMETHEE-II, we need to calculate net flow  $\Phi$ . The best way to do it is to build another table with each alternative and its corresponding leaving and entering flows. Add the column for net flow ( $\Phi = \varphi^+ - \varphi^-$ ) and order the net flows from highest to lowest to rank all alternatives available. Table 23 shows the results.

**Table 23.** Ranking of alternatives

	Leaving flow $\varphi^+$	Entering flow $\varphi^-$	Net Flow $\Phi$	Rank
AWS	0.351525254	0.278254935	0.073270318	2
Azure	0.594908565	0.076214009	0.518694557	1
GCP	0.053566181	0.645531056	-0.591964875	3

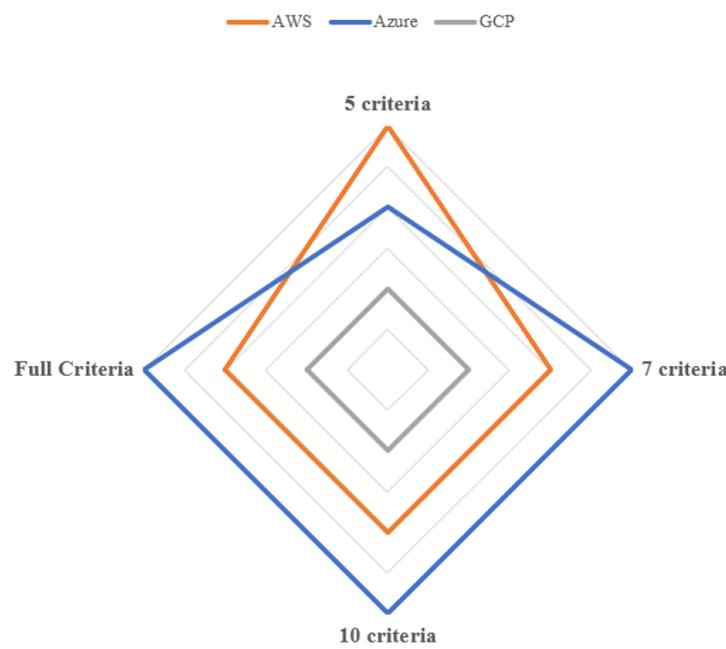
#### 4. Discussion

The methodology proposed to find the best alternative within a decision matrix, using all criteria, and applied to an example, finds the best solution. However, as part of this research, we decided to execute two validations. The first one is using the proposed methodology with criteria subsets. The second consist on run the full criteria (14 elements) with three different methods: TOPSIS, which its use has been reported in literature for similar problems, MOORA and Dimensional Analysis (DA), using same alternatives and values in decision matrix.

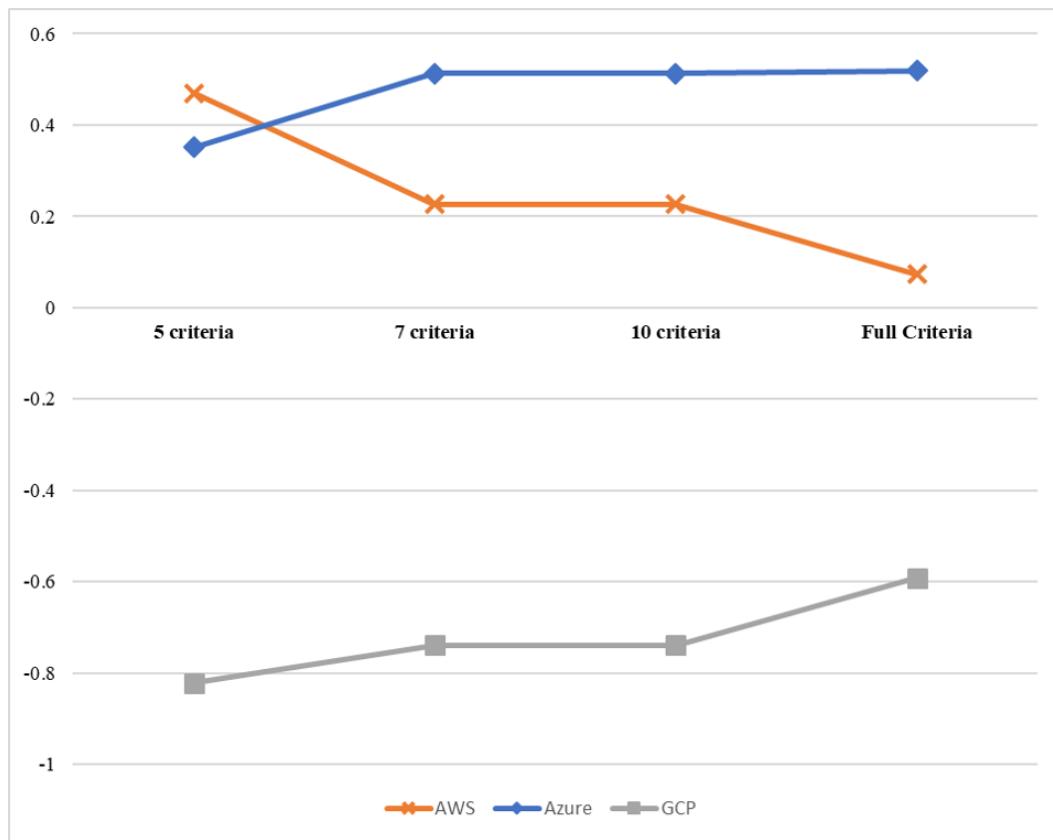
Our proposed methodology with criteria subsets shows a good consistency in the alternative selected, except when we used five criteria. When use seven or ten criteria, the result is exactly the same, as shown in Table 24 and Fig. 7.

**Table 24.** Ranking with our proposed methodology with criteria subsets (1 is highest)

	5 criteria	7 criteria	10 criteria	Full Criteria (14)
AWS	1	2	2	2
Azure	2	1	1	1
GCP	3	3	3	3

**Figure 7.** Comparison of results using different criteria subsets with same methodology

Also, we found there is a change of index values when adding criteria. Fig. 8 depict how alternative AWS lowers when adding criteria, and alternative GCP increases. It can be observed also how alternative Azure remains not only as the best alternative, but also consistent in the index value.

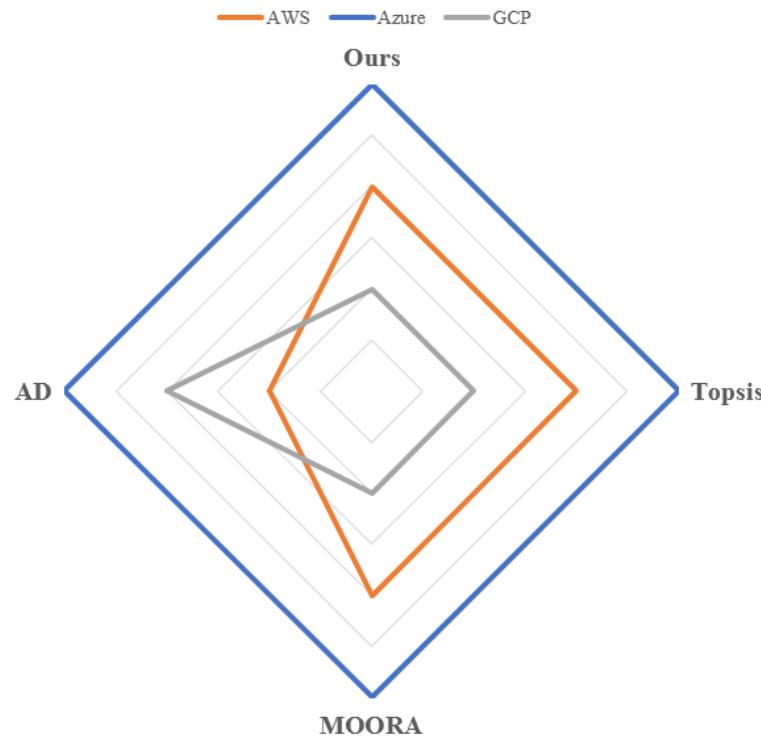


**Figure 8.** Comaprison of resulting indexes in proposed methodology

Now, comparing TOPSIS, MOORA and DA against our proposed methodology, the results are consistent, as all algorithms selected the same alternative with same number of criteria considered. Table 25 and Fig. 9 shows all three other methods selected the same alternative as our methodology.

**Table 25.** Proposed methodology validation with three more algorithms using full criteria

	Ours	TOPSIS	MOORA	AD
AWS	2	2	2	3
Azure	1	1	1	1
GCP	3	3	3	2



**Figure 9.** Comparing different methodologies against our proposed methodology

Because TOPSIS has been used in similar problems, we decided to do an additional comparison. By running TOPSIS against the same criteria subsets, we can observe the selected alternative is the same for all cases, as shown in Table 26.

**Table 26.** Ranking with our proposed methodology with criteria subsets (1 is highest)

	5 criteria	7 criteria	10 criteria	Full Criteria (14)
AWS	1	2	2	2
Azure	2	1	1	1
GCP	3	3	3	3

## 5. Conclusions

As technology in IIoT and cloud advance, there will be new options available in the market for the organizations. Also, there are aspects that are relevant, not only technical, but economical and social. The three alternatives evaluated for this paper are aligned to leaders identified by Gartner up to 2018, however, it doesn't assure they will be the only ones in the near, mid or long term.

The criteria proposed follows and adapt for today's vision. People must have double deep abilities, that is technical and business. That is one of the reasons to add to technical criteria the angles of economics and social view. Both of them have been left off in literature and daily practice. Our contribution to industry provides these two missing aspects.

Cost is one of the most difficult and confusing comparisons, if there is not a good scenario to run against each price schema. However, as it is shown on Table 11, cost is not the main driver to take a decision in IIoT. Security has the highest weight and this is understandable as organization's IIoT implementations and solutions will transmit sensitive data. Communication protocols is the second most important criterion, and the reasoning behind is the flexibility required for different sensors available in the market. Device management and display are very close in importance, which is logic as organizations need to deploy from tenths to thousands of devices for a solution, and having a dashboard to locate and get information about devices is important.

Of economic and social criteria, the most significant are cost and available resources, respectively; longevity in the market was the least important criterion. This can be read as organizations may be open to experiment and learn with newcomers.

It is the best to have different experts from different background or responsibility within the organization. The roles suggested in this methodology (Table 5) covers a large part of main organization areas. We decided to include not only the IT department, but operations, financial, human resources, and business unit leaders. This proves to be aligned with the criteria suggested. By inviting to participate to different roles, the weighting criteria becomes more accurate, therefore, the selection process will be better. We do not suggest to have a single expert to provide opinion on criteria weighting. As people may have different understanding or could be biased towards a specific criteria, having more than one expert is preferred, and our proposed set of roles provide the options to select the experts.

Use of Saaty scale and method to evaluate criteria importance was proven to be effective. However, we discover the validation of opinions is even more important, in order to provide a trustworthy weights for the selection criteria. In our experiment, consistency ratio was 0.06, which is acceptable and allows to continue with the process. Organizations must use this kind of validations when choosing what would be more important over other criteria.

As it was discovered in the literature review (Table 2), most work related to cloud and IoT has focused on AHP and TOPSIS. But selecting an IIoT platform cannot have a single alternative winner, it is better to have all alternatives ranked. Our experience states in some cases, the vendor selected cannot deliver or does not meet other organization's requirements such as terms, legal contracts, conditions, or timing. When this happens, it would be a waste of time to redo the whole MCDA process again. That is why PROMETHEE-II proven to be effective as it can rank from top to bottom the alternatives available. In our exercise, Azure was the first option, followed by AWS and GCP.

It is important to notice, PROMETHEE-II and our methodology will not say which platform or technology is better, from an absolute standpoint, but which platform or technology is better suited for the organization based on the weights and grades provided by experts within the organization.

The paper demonstrated that our proposed methodology is effective to find the best alternative to select an IIoT platform vendor as it has been performed consistent with five, seven and ten criteria subsets, as well as comparing results against other methods. Also, it contributes to the field of IIoT as it provides a novel method to solve the problem many organizations are or will face at any time. Combining Saaty weight method and PROMETHEE-II, decision makers have a good tool to perform the selection. However, if it is limited to the technical aspects, the result may be biased and miss important aspects of the market. For example, if the technology is very good, the platform is the most complete and least expensive, but there are not engineers or developers available, or training classes cost a fortune, implementing this platform will be a difficult and expensive project, with hidden costs not detected since inception. That is the reason and justification to include economic and social aspects in the criteria, as our methodology proposes.

IIoT platform selection should not be left to IT departments or CIO or CTO. Doing that will miss the point of view of other important leaders that will use, maintain or benefit from selected platform. Chief Operation Officer, leaders from business units, interdisciplinary teams, and even human resources and finance should participate in the MCDA process, as they bring ideas and considerations that sometimes are ignored unintentionally. Our proposed methodology provides a suggested list of key persons to participate, something that was not found in the literature, and is very valuable for the decision process.

As a side discovery, Comparing price schemas among vendors is not an easy task. We saw very useful to have a common scenario to run against the price schemas. To build a common scenario it is required to have a close to reality idea of usage, number of devices, message size, and frequency of communication. Trying to compare price schemas without this scenario could lead to a miss information entered in the grading matrix of PROMETHEE-II part (Table 16).

The process of doing calculation and operations is laborious, due to the nature of algorithms used in our methodology proposed. This inspires us to continue the future work enhancing the methodology, creating a software to facilitate the computation. Another key aspect is the importance grading from Saaty's process. Filling the matrix with reciprocals values, could lead to human error easily. This also highlight as part of our future work to develop a graphical user interface that experts can use in a friendly fashion to enter the importance between criteria and fully automate our methodology when multiple experts participate in the process.

**Author Contributions:** All the authors jointly contributed to the finalization of the paper: R.C. defined the criteria proposed and provide the MCDA options; A.O. supervised the overall process and provide resources; M.E. directed the method of ranking; L.P. reviewed R.C. development of methodology; V.G. critically reviewed the concept and design of the paper. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding

**Conflicts of Interest:** The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

## Abbreviations

The following abbreviations are used in this manuscript:

IoT	Internet of Things
IIoT	Industrial Internet of Things
MQTT	Message Queue Telemetry Transport
HTTP	Hypertext Transfer Protocol
AMQP	Advanced Message Queuing Protocol
S1	Type of Azure IoT Hub
AWS	Amazon Web Services
GCP	Google Cloud Platform
MCDA	Multiple Criteria Decision Analysis

## References

1. Rüßmann, M.; Lorenz, M.; Gerbert, P.; Waldner, M.; Justus, J.; Engel, P.; Harnisch, M. Industry 4.0: The future of productivity and growth in manufacturing industries. *Boston Consulting Group* **2015**, *9*, 54–89.
2. Hatzivasilis, G.; Fysarakis, K.; Soultatos, O.; Askokylakis, I.; Papaefstathiou, I.; Demetriou, G. The Industrial Internet of Things as an enabler for a Circular Economy Hy-LP: A novel IIoT protocol, evaluated on a wind park's SDN/NFV-enabled 5G industrial network **2018**. doi:10.1016/j.comcom.2018.02.007.
3. Höller, J.; Tsatsis, V.; Mulligan, C.; Karnouskos, S.; Avesand, S.; Boyle, D. IoT Architecture – State of the Art. In *From Machine-To-Machine to the Internet of Things*; 2014. doi:10.1016/B978-0-12-407684-6.00006-1.
4. Lanotte, R.; Merro, M. A semantic theory of the Internet of Things. *Information and Computation* **2018**, *259*, 72–101. doi:10.1016/j.ic.2018.01.001.
5. Rathore, M.M.; Ahmad, A.; Paul, A.; Rho, S. Urban planning and building smart cities based on the Internet of Things using Big Data analytics. *Computer Networks* **2016**, *101*, 63–80. doi:10.1016/j.comnet.2015.12.023.
6. Figueira, J.; Greco, S.; Ehrgott, M. *Multiple criteria decision analysis: state of the art surveys*; Vol. 78, Springer Science & Business Media, 2005.
7. Huang, I.B.; Keisler, J.; Linkov, I. Multi-criteria decision analysis in environmental sciences: ten years of applications and trends. *Science of the total environment* **2011**, *409*, 3578–3594.
8. Weyrich, M.; Ebert, C. Reference architectures for the internet of things. *IEEE Software* **2016**, pp. 112–116.
9. Vasilomanolakis, E.; Daubert, J.; Luthra, M.; Gazis, V.; Wiesmaier, A.; Kikiras, P. On the Security and Privacy of Internet of Things Architectures and Systems. Proceedings - 2015 International Workshop on Secure Internet of Things, SIoT 2015, 2016. doi:10.1109/SIoT.2015.9.
10. Gironés, T.; Canovas Solbes, J.; Parra-Boronat, A. An Integrated IoT Architecture for Smart Metering. *IEEE Communications Magazine* **2016**, *54*, 50–57. doi:10.1109/MCOM.2016.1600647CM.
11. Krishnamurthy, R.; Cecil, J.; Perera, D. IMECE2017-72293 AN INTERNET OF THINGS (IOT) BASED FRAMEWORKS FOR COLLABORATIVE MANUFACTURING. Technical report, 2017.

12. Ray, P.P. A survey on Internet of Things architectures **2018**. doi:10.1016/j.jksuci.2016.10.003.
13. Ferreira, H.G.C.; Dias Canedo, E.; De Sousa, R.T. IoT architecture to enable intercommunication through REST API and UPnP using IP, ZigBee and arduino. International Conference on Wireless and Mobile Computing, Networking and Communications, 2013. doi:10.1109/WiMOB.2013.6673340.
14. Gazis, V.; Goertz, M.; Huber, M.; Leonardi, A.; Mathioudakis, K.; Wiesmaier, A.; Zeiger, F. Short paper: IoT: Challenges, projects, architectures. 2015 18th International Conference on Intelligence in Next Generation Networks. IEEE, 2015, pp. 145–147.
15. Firdous, F.; Mohd Umair, M.; Alikhan Siddiqui, D.; Mohd Umair, A. 512 Ms IoT Based Home Automation System over the Cloud. Technical report, 2018.
16. Nitti, M.; Pilloni, V.; Giusto, D.; Popescu, V. IoT Architecture for a sustainable tourism application in a smart city environment. *Mobile Information Systems* **2017**. doi:10.1155/2017/9201640.
17. Contreras-Castillo, J.; Zeadally, S.; Guerrero Ibáñez, J.A. A seven-layered model architecture for Internet of Vehicles. *Journal of Information and Telecommunication* **2017**. doi:10.1080/24751839.2017.1295601.
18. Rahimi, H.; Zibaeenejad, A.; Safavi, A.A. A Novel IoT Architecture based on 5G-IoT and Next Generation Technologies. Technical report, 2018.
19. Dumitru, R.L. IoT Platforms: Analysis for Building Projects. *Informatica Economica* **2017**. doi:10.12948/issn14531305/21.2.2017.04.
20. Zanakis, S.H.; Solomon, A.; Wishart, N.; Dubliss, S. Multi-attribute decision making: a simulation comparison of select methods. *European journal of operational research* **1998**, 107, 507–529.
21. Henig, M.I.; Buchanan, J.T. Solving MCDM problems: Process concepts. *Journal of Multi-Criteria Decision Analysis* **1996**, 5, 3–21.
22. Whaiduzzaman, M.; Gani, A.; Anuar, N.B.; Shiraz, M.; Haque, M.N.; Haque, I.T. Cloud service selection using multicriteria decision analysis. *The Scientific World Journal* **2014**, 2014.
23. Watrobski, J.; Jankowski, J.; Pawel, Z.; Karczmarczyk, A.; Ziolo, M. Generalised framework for multi-criteria method selection. *Omega* **2018**.
24. Silva, E.M.; Jardim-Goncalves, R. Multi-criteria analysis and decision methodology for the selection of internet-of-things hardware platforms. Doctoral Conference on Computing, Electrical and Industrial Systems. Springer, 2017, pp. 111–121.
25. Soltani, S.; Martin, P.; Elgazzar, K. A hybrid approach to automatic IaaS service selection. *Journal of Cloud Computing* **2018**, 7, 12. doi:10.1186/s13677-018-0113-8.
26. Kondratenko, Y.; Kondratenko, G.; Sidenko, I. Multi-criteria decision making for selecting a rational IoT platform. 2018 IEEE 9th International Conference on Dependable Systems, Services and Technologies (DESSERT). IEEE, 2018, pp. 147–152.
27. Uslu, B.; Eren, T.; Gür, S.; Özcan, E. Evaluation of the Difficulties in the Internet of Things (IoT) with Multi-Criteria Decision-Making. *Processes* **2019**, 7, 164.
28. Singla, C.; Mahajan, N.; Kaushal, S.; Verma, A.; Sangaiah, A.K. Modelling and Analysis of Multi-objective Service Selection Scheme in IoT-Cloud Environment. In *Cognitive Computing for Big Data Systems Over IoT*; Springer, 2018; pp. 63–77.
29. Alelaiwi, A. Evaluating distributed IoT databases for edge/cloud platforms using the analytic hierarchy process. *Journal of Parallel and Distributed Computing* **2019**, 124, 41–46.
30. Silva, E.M.; Agostinho, C.; Jardim-Goncalves, R. A multi-criteria decision model for the selection of a more suitable Internet-of-Things device. 2017 International Conference on Engineering, Technology and Innovation (ICE/ITMC). IEEE, 2017, pp. 1268–1276.
31. Garg, S.K.; Versteeg, S.; Buyya, R. A framework for ranking of cloud computing services. *Future Generation Computer Systems* **2013**, 29, 1012–1023.
32. Guth, J.; Breitenbacher, U.; Falkenthal, M.; Leymann, F.; Reinfurt, L. Comparison of IoT platform architectures: A field study based on a reference architecture. 2016 Cloudification of the Internet of Things, CIoT 2016, 2017. doi:10.1109/CIoT.2016.7872918.
33. Google Cloud Platform breaks into leader category in Gartner's Magic Quadrant. <https://www.zdnet.com/article/google-cloud-platform-breaks-into-leader-category-in-gartners-magic-quadrant/>. Accessed: 2020-01-28.
34. Amazon and Microsoft top Gartner's IaaS Magic Quadrant. <https://www.zdnet.com/article/amazon-and-microsoft-top-gartners-iaas-magic-quadrant/>. Accessed: 2020-01-28.

35. Saaty, T.L. Decision making with the analytic hierarchy process. *International journal of services sciences* **2008**, *1*, 83–98.
36. Setiawan, A.; Sediyono, E.; Moekoe, D.A. Application of AHP method in determining priorities of conversion of unusedland to food land in Minahasa Tenggara. *International Journal of Computer Applications* **2014**, *89*.
37. Vulević, T.; Dragović, N. Multi-criteria decision analysis for sub-watersheds ranking via the PROMETHEE method. *International Soil and Water Conservation Research* **2017**, *5*, 50–55.
38. Brans, J.P.; De Smet, Y. PROMETHEE methods. In *Multiple criteria decision analysis*; Springer, 2016; pp. 187–219.