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Selection of IoT Platform with Multi-Criteria Analysis: Defining Criteria and Experts to Interview

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Abstract. Industry 4.0 is having a great impact in all industries. This is not a unique product, but is composed of several technologies. IoT is a key intelligent factor that allows factories to act intelligently. By adding sensors and actuators to the objects, the object becomes intelligent because it can interact with people, other objects, generate data, generate transactions and react to the environment data. 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. The decision processes that companies must follow should not be free will or by hunches, since this contradicts a methodology and would make the decision process unrepeatable and unjustifiable. Decisions must be supported by methods that consider pros and cons of plural points of view that affect the decision process. With a wide range of IoT platforms, which are not directly comparable to each other, it seems that Multi-Criteria Decision Analysis (MCDA) can be useful to help companies make a decision on what platform to implement, depending on the circumstances prevailing in each company at the time to make the choice. This article shows the complexity of selecting an IoT platform and provides the key decision criteria that must be taken into account when evaluating IoT Platforms alternatives.

Keywords: IoT, platform selection, multi criteria analysis, MCDA, AHP, PROMETHEE.

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) [22]. 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) [11]. IoT 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 [13,17]. Cities do not ignore this trend, since there is a plan to turn cities into smart cities in certain countries [20].

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 [5]. 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 [14].The purpose of this manuscript is precisely to propose a method of MCDA with the corresponding criteria for the selection of an IoT 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.

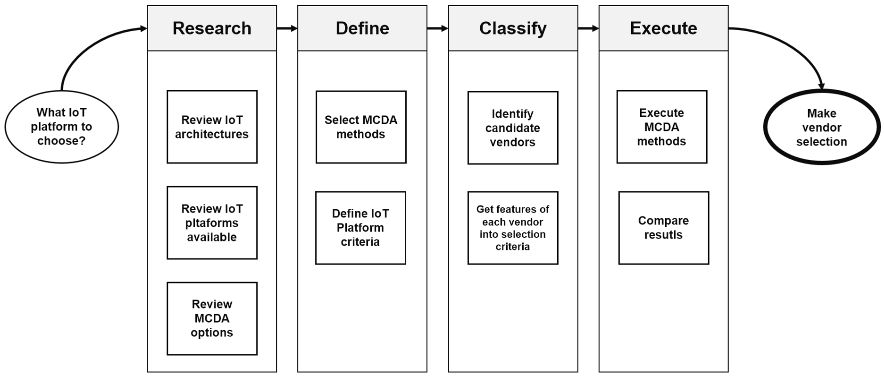

Fig. 1. Conceptual model to select IoT platforms.

This work is organized by sections. Section 2 shows the complexity to compare commercial IoT platforms, including a quick view of the different architectures found in the literature. Section 3 establishes the MCDA reference framework and the methods considered for the selection of platforms, taking into account similar efforts reported in the literature. Section 4 proposes the characteristics to be considered for MCDA. Finally, section 5 discusses the future work to be done and what MCDA methods could fit this kind of decision problem.

2 IoT Architectures and Commercial Platforms

Internet of Things (IoT) continues to evolve. Due to the instrinsic complexity, it is good practice to look at architectural references. IoT have five main requirements in general basis [30]: 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. Technical architecture provides an extreme value to users because it can be

Table 1. IoT Architectures.

Num.	Layers	References
2	Devices and Communication	[28]
3	Devices, Communication and Application	[9,16,21]
4	Devices, Communication, Transport and Application	[4,8,6,18,21,28]
5	Devices, Local processing, Communication, Transport and Applications	[21]
7	Business, Management, Communication, Processing, Acquisition, User interaction and Security	[2,6]
8	Physical devices, Communication, Edge or Fog processing, Data storage, Applications, Collaboration and process, Security	[19]

implemented with different products. Therefore, it is understandable that several companies offer IoT 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 [3]. 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 and have differentiated within their offer.

3 MCDA as a Tool for Selection of IoT 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 [14,32]. To carry out a MCDA process, a series of tasks is proposed, based on the three generic steps suggested by [12]: 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. [12] 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 [31]; 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 [14,31]. 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 [32]. 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) [29].

3.1 Use of MCDA for Selection of IoT 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 IoT 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

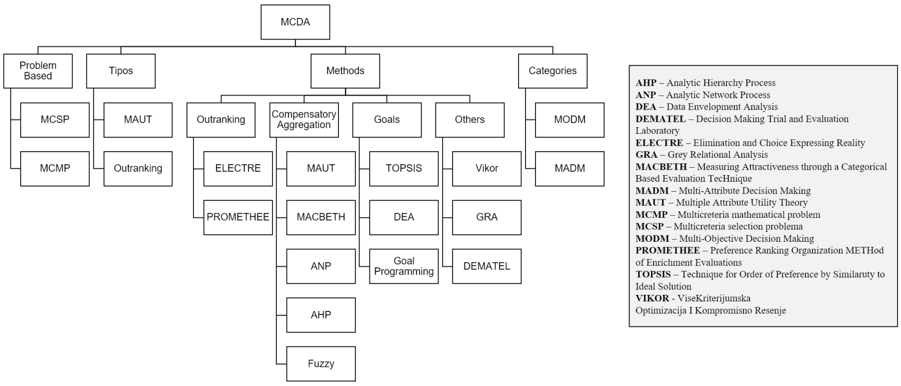

Fig. 2. Taxonomy of MCDA (Adapted from [31]).

some authors [24,26]. The selection of an IoT platform is not dominated by a single criterion, nor is there a single alternative. [15] 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.

Criteria found in literature are purely technical with some hints of economy, and can be found as part of the characteristics of IoT architecture [10]. But when implementing an IoT 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 [3] as Index of Measure of Service (SMI) include topics of interest to the organization, financial and usability, together With the technical issues [7]. 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. In the MCDA universe there are many more methods available. Following the decision tree to select an MCDA method written by [29], 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

[3] 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/`

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	[25]
2018	Platform IoT	Fuzzy	Security, Device management, Integration level, Processing level, Database functionality, Data collection protocols, Visualization, Analytics variety	[15]
2018	IaaS	TOPSIS	Cost, Computing required, Storage capacity, Operating system	[26]
2018	Distributed IoT Databases	AHP	Usability, Prtability, Support	[1]
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	[23]
2013	Ranking cloud services	AHP	Responsibility, Agility, Service assurance, Cost, Performance, Security and privacy, Usability	[7]

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 II, 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.

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. As the AHP method has been used regularly we suggest to take it as one of the two methods proposed. The other selected method is PRMOETHEE II, which has not been used in previous works, but some authors have considered it for future work.

4 Proposed Criteria and Roles to Participate

In our experience, companies that want to implement IoT 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 IoT Platform selection for a MCDA exercise with at least two different methods, 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 company, be it small or large, can use to decide on the IoT 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 IoT platform.

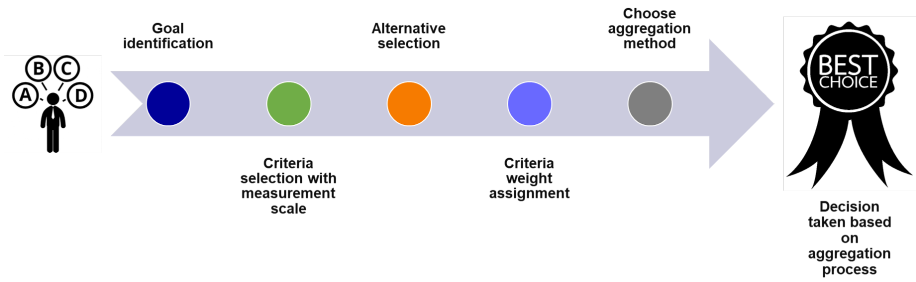

Fig. 3. Conceptual model to select IoT platforms.

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 with 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 difference over previous works found in the literature. The selected criteria are also classified as quantitative and qualitative according to their nature, and are summarized in Table **??**.

The existing alternatives for the IoT platform considered in this paper appear in the literature or are widely used in the industry and are recognized as market leaders, in addition to the author's experience with various global suppliers. Thus, the alternatives included in this exercise are: AWS IoT Platform, Microsoft

Azure IoT Platform, Bosch IoT Suite, IBM Watson IoT Platform, Google Cloud IoT Platform, GE Predix IoT Platform, Thingworx (PTC), and SAP Cloud IoT.

Our proposal includes profiles of people who must participate in the expert judgement exercise. 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 who should be involved in a MCDA exercise as experts.

5 Conclusion and Future Work

Selecting an IoT Platform is not an easy task, as it has been found in literature the vast amount of different architectures, vendors and approaches. This work concentrated to find the criteria and labor roles to take a decision on what platform to use.

As a first conclusion, we found MCDA has been used effectively in technological decisions, very close to what we were looking for, but not exactly the problem we faced. AHP and TOPSIS were MCDA methods employed in the past, with good results. However, outranking methods such as PROMETHEE have not been used, but few authors considered it for future work. This opens the opportunity for us to explore these methods in future work. In addition to this, PRMOETHEE I and II are accepted MCDA methods for ranking options, as it was found in literature.

Second, our research suggests the criteria found in previous work are technical oriented, with few criteria considering other business areas, such as economic ones. Most authors that included these kind of criteria, mainly considered cost, which is important but not the only one. Our work is different and provides a more comprehensive criteria, with updated technical aspects based on literature and technical experience; our economic aspects include prestige and market longevity, cost of training, and free tier bonus (offered by most of vendors to compete against others). Another important contribution from our work is the inclusion of social criteria, important for an organization to cover human resources skills. We recommend to consider three main social criteria: Level of Support found in the community, facility to find human resources available in market, and available training programs, offered by vendor, private entities or universities.

As IoT and technology is now part of core business, experts should not come only from IT department, but from different areas of organization. This is our third conclusion, as we suggest the CxO levels that should be considered to provide preferences and expert judgment. One important role is Business Unit Leader, as it deals with daily problems, customers, clients, and details that may not be visible to CxO level.

Our future work will consist to create the mechanism to gather experts' judgment information in a simple and efficient way, and test it against two MCDA methods. One of them will be AHP, widely used in literature, and it could be used as a control method. The second method to use will be PROMETHEE II, as it is a complete outranking method. Also, comparison of those two methods will help to find effectiveness of methods. Our future work is also considering test our methodology in a large organization and publish our findings.

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