IoT Ecosystems Design: A Multi-Method, Multi-Criteria Assessment Methodology

Edgar M. Silva, Ricardo Jardim-Goncalves

***Abstract*—This paper proposes a methodology to assist decision-makers on the selection of a more proper device' system for a specific task. A versatile methodology providing mechanisms for an assessment based on Multi-Criteria with the capacity to apply different Decision Methods, taking also into consideration criteria' constraints defined by stakeholder's. Decision-makers are able to perform a better reasoning and more aware analysis of diverse (e.g.: hardware architecture, communication protocols) and very often contradicting criteria, such as energy consumption versus computation speed. This is addressed using a model-driven based approach, which gives support for a high openness to the use of different as well as new, even user-defined decision methods, including criteria and respective constraints through their formal specification. Proposing an Assessment Methodology with Multi-Methods, Multi-Criteria, Multi-Constraints this work tries to answer to "*which methods could be applied or develop to assist in devices (i.e. IoT Systems) assessment*" showing that a more conscious/aware, accurate selection of the more suitable device system(s) can be made, and consequently improve IoT Ecosystems design.**

***Index Terms*—Internet-of-Things, IoT Assessment, Model-Driven, Multi-Method, Multi-Criteria Decision.**

I. INTRODUCTION

THE Internet-of-Things (IoT), considered as Internet first real evolution, has become immensely important to society due to revolutionary business models with the potential to radically improve Human life [1]. IoT Ecosystems rely on key components to sense the environment, act, and to giving people a different perspective of what surrounds them. These components are devices, embedded systems with specific hardware characteristics (Resource-Constrained) and applications code, firmware to execute the expected task.

Based on definitions from [2], [3], stating that a system is "group of items forming a unified whole", a "set of computer equipment and programs used together for a particular purpose", from now on devices, embedded systems will be addressed as ***IoT Systems***.

To respond to a highly dynamic, novel business models and consequently a new variety of applications and services tacking advantage of IoT characteristics, manufacturers are providing a wide set of possible alternatives (IoT Systems), based on a constant evolution of micro-electronic technologies but also in new software, execution architectures [4].

However, there is no consensus of crucial questions like what are the best practices for developing projects for IoT, how to select the best architecture, which communications protocols are the most suitable, etc. To facilitate and increase effectiveness during the design of IoT Deployments, stakeholders must be able to verify IoT Systems based on all characteristics that these systems have to offer. Either on hardware components specification, application language, memory usage, or if it is available based on energy consumption profiles.

In these sense, this work focus on the capability to agilely respond to a very dynamic market offer of IoT Systems, in a way that the design phase of IoT Ecosystems can be enhanced. To answer to "*Which methods could be applied or develop to assist in IoT Systems assessment?*" it is proposed an Assessment Methodology to evaluate IoT Systems based on a Model-Driven approach to formally describe these systems and stakeholders judgement. The proposed methodology is able to analyse problems with Multi-Criteria, Multi-Constraints and apply different decision-making methods (Multi-Methods).

Next section briefly discusses the issues surrounding the IoT, focusing particularly on methods that formally describe all IoT Systems (devices) characteristics and how decision-making has being applying to IoT. Section III describes the proposed methodology to analyse IoT Systems to enhance the decision quality during the design of IoT Ecosystems regarding the more suitable IoT System for a certain task. Section IV presents the procedure to apply the assessment constraints defined by the stakeholders followed by a description of a more than 83 million combinations applied regarding criteria qualification weights. Section V describes a scenario obtain from [4] and compares, verifies the results. Section VI reports over the proposed contributions and presents a discussion regarding the results. Section VII concludes this paper.

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II. INTERNET-OF-THINGS (IOT)

IoT is referred as the new stage, evolution of Internet [5]. It is a highly heterogeneous environment, formed by objects, systems, applications and people that communicate, share information to achieve common goals in different business areas and applications. IoT represent different things depending on the actors involved, which by its own create different notions of what is "IoT value", from social, economic, and technical perspectives. Three point of views that "are neither clear-cut nor mutually exclusive" [6].

The creation of IoT deployments brings concerns regarding cyber-security, enhance even more with the constant increase of cyber-attacks to IoT systems. Consequently, new cyber security measures and methods are needed to reduce the cyber risk in IoT [7]. Reliability of an IoT Ecosystem also depends on its capacity to respond to cyber-attacks. The incapacity to do so has an economic impact, which needs to be assessed at design phase. Banks, insurance companies are incapable to effectively and efficiently assess the cyber risk in IoT, making it impossible to put a price on it [8], [9]. Today's assessment approaches are based on a complete comprehension of data, systems and assets.

Risk assessment is a challenging issue in IoT due to the lack of capability to completely identify real vulnerabilities and threats (systems knowledge is constrained and systems are very dynamic). Consequently, new assessment methods, methodologies are needed based on new risk metrics, validation methods, standardized IoT databases, and new risk vectors (e.g.: International IoT Asset Classification; and key IoT Cyber Risk Factors) [7]–[9].

Many are the issues, challenges yet to be solved to transform IoT potential in a real, consistent, widely-used technology within society. Namely, scalability, energy consumption, standards, architectures, big data, privacy, security, trust and real time-based solutions [10]–[12].

Furthermore, stakeholders have been facing the difficulty to reach a consensus regarding the best practices for IoT projects. Combining or fulfil several requirements is not an easy task to researchers, domain practitioners and engineers [4]. Many are the features/criteria (e.g.: cost, communication capabilities) with direct impact in the global view of the project (i.e. IoT Ecosystem), but there are also others (e.g.: energy consumption, computation capabilities) that influence the performance of an application running in an IoT device (i.e. IoT System).

Structured information over IoT Ecosystems or IoT Systems, play a very important role for the development of automatic assessment tools, by providing concrete descriptions of the assets (i.e. systems features) involved with direct influence on the system performance.

A. Internet-of-Things: Model-Driven Definition

A common approach to tackle systems complexity has being the use of model-driven techniques, stakeholders are using models to clearly express domain concepts, defining critical systems development stages [13]. In the next two sub-sections is presented model-driven approaches to define two levels of the IoT. First, from a global perspective, IoT Ecosystems are defined in terms of behaviour, functional point of view. Followed by a formal specification of an IoT device (IoT System), considering three views: hardware, software and energy profile.

1) IoT Ecosystems: System and systems-of-systems have been defined in terms of requirements, behaviours, processes, etc. Standardisation alliances/organisations have propose standards with support for syntactic and semantic interoperability, for example OMG' Systems Modelling Language (SysML) [14], OGC' Sensor Model Language (SensorML) [15] and W3C' Semantic Sensor Network (SSN) [16].

Focus on requirements specification, structure and behaviour, SysML was designed as a modelling language to describe engineering systems, interoperable with other engineering tools, using interoperability standards such OMG XMI 2 and ISO 10303 STEP AP233. SensorML is used to describe sensors functional models with the capability to represent components as processes, physical (e.g. detectors, actuators) as well as non-physical (e.g. mathematical operations or functions). It uses models and a XML encoding to describe processes. Sensors and sensor systems are defined using geometric, dynamic, and observational characteristics. SSN is an extension to SensorML, an ontology that provides means to add semantic annotations to sensors and services, allowing in this way data to be organised, managed and consequently be queried by different systems and understood.

2) IoT Systems (Devices): With literature focus on describing functional and interactions within an IoT Ecosystem, the authors in [11] presented a model-based specification to formally describe all components, characteristics, features that a device has to offer.

The authors state that a device is actually an ***IoT System*** described by two core parts and a third one if available. The two mandatory parts are: ***Hardware*** and ***Software*** (Application code); while the third part is an ***Energy Profile*** (a description of the consumed energy). The defined ***IoT System*** concept, accordingly to the authors, relays on the fact that a system is "a set of computer equipment and programs used together for a particular purpose" [3].

Fig. 1 depicts a high-level view of IoT System specification accordingly with [11]. An IoT System is by its nature a Resource-Constrained System (RCS), a device that has small size, low-power operations, limited processing and storage capabilities, and that often runs on batteries. The authors presented a Model-Driven approach to describe an IoT System — Resource-Constrained System Meta-Model (RCSM) (Fig. 1). In the figure is also possible to see the relations with other models, core parts, that enables a formal description of these imperative pieces (IoT Systems) in a complete and conscious form (***HardwareModel***, ***SoftwareModel*** and ***EnergyProfile***).

The representation of IoT System hardware characteristics was achieved by a single specification model (identified in Fig. 1 as RCSH — Resource-Constrained System Hardware), that is comprehensive enough to embrace hardware platforms diversity — Platform Independent. The proposed specification describes a device as a set of *Modules/Components* that can be of the following types: *Processing Unit*; *Machine-to-Machine*

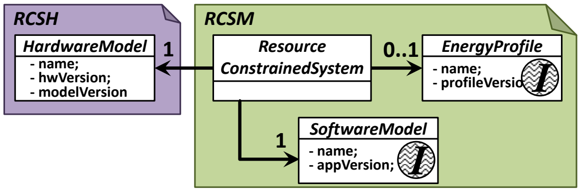


Fig. 1: High-Level View of IoT System Specification (adapted from [11]).

or *Human-to-Machine* Interfaces; *Memory*; *Security*; *Sensing Unit*; *Power Supply*; or *Actuator*. Feature values are specified using two types of properties (aggregation or single property), unit type and property domain definition. For simplicity the classes, from RCSH model, to instantiate modules/components and its respective properties were hidden in Fig. 1, as well as the links to instantiate properties for ***SoftwareModel*** and ***EnergyProfile*** (to more detail please see [11]).

In the software languages and energy information cases, is not possible to specify a single Meta-Model. Programs follow specific rules of the software languages in which they are written from. With energy information the scenario is similarly, there are different forms to represent, simulate energy consumption. Consequently, a different approach was proposed. Classes ***SoftwareModel*** and ***EnergyProfile*** are in fact interface classes, allowing instantiation of different software languages and energy profile models. In this sense, the proposed IoT System description is not bound to a restricted, pre-established specification models for these two last parts. Nevertheless, software and energy specification models have to respect two rules. Properties definition must follow the same specification used in the hardware case, and the model main class has to inherit from the corresponding interface (e.g. ***SoftwareModel***).

Fig. 1 and Fig. 2 use the following terminology: ’**0..1**’ — none or one; ’**0..***’ — none or more; ’**1**’ — only one; ’**1..***’ — at least one; and ’**2..***’ — two or more. For example, in Fig. 1, the class “*ResourceConstrainedSystem*” can reference/include an “*EnergyProfile*” or not.

B. Decision-Making in IoT

IoT is an umbrella term for a wide range of technologies, applications and services domains. With this comes a vast number of possibilities (e.g. communication protocols, hardware platforms, applications performance, etc.) that putted together create an infinity number of possible solutions. Next are addressed some examples of decision-making in IoT scope.

The authors in [17] focus on ensure an appropriate selection of the manufacturing processes that need to be improved, updated with IoT technologies. Processes stages were analysed for IoT application based on five criteria: reliability, security, business, mobility and heterogeneity. The selection of the more suitable part of the process to have implemented IoT technologies was obtained by applying the Analytic Hierarchy Process (AHP) method [18].

Two sub-classes derive from Multi-Criteria Decision-Making (MCDM) problems. One focus on choosing a solution from a finite, explicitly known number of alternatives, and another focus on cases where alternatives are not known, infinite or not countable [19]. AHP is a well-known MCDM method for the case where alternatives are known.

In wireless communications, poses the problem of selecting which technologies best serves the IoT network scenario. The publication [20] addresses the decision-making regarding wireless communication technologies (e.g. Wi-Fi, Z-Wave, Bluetooth, ZigBee, NFC, etc.) considering four criteria as the most important: reliability, dependability, safety and security. The authors used a MCDM ideal point method, applying two metrics (Euclidean and Hamming) to compute the distance between the considered technologies. In [21], the same authors extended their work with application of new methods, namely coagulation methods (linear, max-min, multiplicative), and a new metric (Chebyshev) in the ideal point method. Wireless technologies were maintained, but new criteria were selected, compared: data rate; frequency range; technology definition; number of nodes; action range; and energy efficiency.

Another scope is security of IoT services. In [22], authors combine MCDM fuzzy methods to assess different aspects and requirements during the architecture and service implementations, to assist on decision-making regarding the allocation of security assets and resources. They combine the Analytic Network Process (a generalisation of AHP; problems are modelled as networks instead of decomposed into a hierarchy) with a decision-making trial and evaluation laboratory (DEMATEL) technique (analyse criteria’ cause and effect interrelationship).

In [23], the authors present the problem of selecting an IoT platform using MCDM during the design phase of IoT. Facing the common problem of a wide offer, in this case of IoT platforms (AWS, Kaa, IBM Watson, Microsoft Azure and Bosh IoT Suite), it is proposed two MCDM approaches for weight coefficients calculation. The approaches follow a linear convolution and a multiplicative convolution, both considering criteria weight and preference value. In [24], they extended the work using a soft computing approach (Mamdani-type fuzzy logic inference engine), also to analyse IoT platforms. The selection results were compared with the ones obtained from the previous method.

Engineers when building a sensor network for any IoT deployment face a wide diversity of available devices (IoT Systems). The authors in [11], to address the analysis of ***IoT Systems*** (devices), presented a specification model to describe criteria, criterion constraints, ranking outcome and includes the possibility to reference/use more than one de-

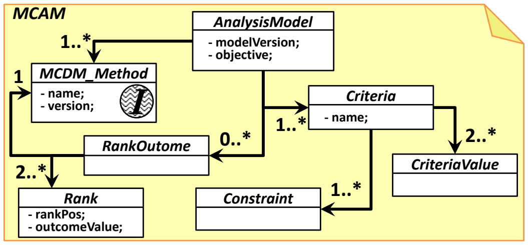


Fig. 2: High-Level View of MCAM Specification (adapted from [11]).

cision method. The proposed Multi-Criteria Analysis Model (MCAM), with a high-level view depicted in Fig. 2, enables the description of two types of criteria (qualitative and quantitative), and constraints are of three types: ***Availability*** ("*Must Have*" and "*Cannot Have*"); ***Condition*** ("*Less Than*", "*Equal*" and "*Greater Than*"); and ***Optimisation*** ("*Minimisation*" and "*Maximisation*"). The use, inclusion of a decision method must follow one rule: the main class object of the decision method model must inherit from class "*MCDM_Method*". Criteria values are specified using two types of properties (aggregation or single property), unit type and property domain definition.

The decision making examples given above indicate the used of different MCDM methods. In [17], authors applied the AHP method, in [20] was used a MCDM ideal point method, the Analytic Network Process (ANP) method was used in [22], a linear and multiplicative convolution methods were applied in [23], and the authors in [11] presented a model approach to include different, even new MCDM methods for the selection of a proper IoT System.

However, in [25], [26] is argue that the decision methods more commonly used are *AHP*, *ELECTRE* [27] and *PROMETHEE* [28], while in [29], [30] is included *TOPSIS* to this group of MCDM methods.

III. MULTI-METHOD, MULTI-CRITERIA ASSESSMENT

In a world with a diversity of possible solutions (IoT Systems) with an even higher number of features (e.g. best architecture, which communications protocols are the most suitable, etc.), engineers are facing the difficulty to choose in a conscious way, the more suitable solution on how to implement and/or improve a certain task.

Therefore, and to answer to the question "*Which methods could be applied or develop to assist in IoT System assessment*" presented in Section I, addressing the analysis of IoT Systems, next is proposed an assessment methodology with a disruptive approach from one-two methods' application, by enabling the use of different, even new MCDM methods, including constraints definition and stakeholders opinion.

A. *Diversity of Available MCDM Methods*

As shown, MCDM methodologies have being applied in IoT independently of the area (e.g.: security, communications, platforms, etc.). Approaches go from very specific (e.g.: looking for a wireless communication protocol) to very high level (e.g.: select an IoT platform).

The diversity of MCDM methods makes it very difficult, if not impossible to describe all methods in a single, unique mathematical procedure. However, it is possible to describe what is needed as input to apply a MCDM method and how the outcome, result form should be. In this sense, using high-level IDEF-0 [31] "black box" view, Fig. 3 depicts the procedure to compute, apply a generic MCDM method. The procedure activity detail is described by the specification of inputs, outputs, control, and mechanisms.

Input consists in an *Assessment Table*, i.e. the solutions-criteria cluster. Literature review in Section II-B shown that MCDM methods for problems with a finite and known number of alternatives perform their analysis based on three aspects: information regarding solutions and their features, and in stakeholders judgement. Stakeholder's judgement is part of the control definition, that with the application of the indicated mechanisms the output is calculated.

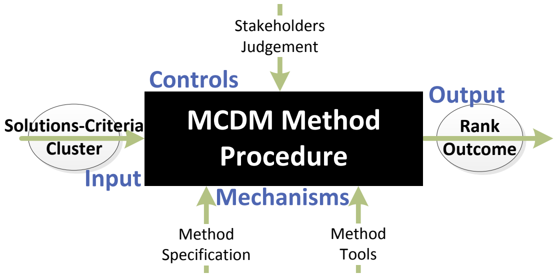


Fig. 3: MCDM Method: Procedure Activity Detail.

Controls are related with stakeholder's judgement. MCDM methods in some way need the decision maker judgement. For example in the AHP method it is used to establish criterion priority, in PROMETHEE case is used to select the preference functions, and in ELECTRE is used to select different thresholds.

Mechanisms are normally what or who that executes the process. With the information provided by the input and definitions by the controls, it is necessary to apply tools to compute the method outcome. Following a model-driven approach, specification models are provided to describe the method.

Output, the system output is the rank outcome, a result from the application of MCDM method procedure.

B. *Multi-Method, Multi-Criteria Assessment Methodology*

Fig. 4 depicts the Multi-Method, Multi-Criteria Assessment Methodology to analyse IoT Systems, to assist in IoT Ecosystem design. By describing each individual problem, objective from the IoT Ecosystem, which will be solve, executed by a certain device (IoT System), the proposed assessment methodology provides, suggests the more suitable IoT System to execute that specific task.

The proposed assessment methodology is a 4-step process: 1) criteria and possible solutions selection, definition; 2) enforcement of a first-level of assessment constraints; 3) ranking solutions based on a MCDM method; and finally 4) the application of a second-level of assessment constraints. This work is an improvement, extension to the work presented in [4] which only contemplated the use of AHP method (mandatory aspect), a single application level of the assessment constraints, and solutions and respective features were provided by hand (no use of IoT Systems formalisation and automatisms to load such information).

1) Criteria & Possible Solutions: Accordingly with the problem, objective defined, stakeholders (users, developers, researchers, etc.) select the solutions, i.e. IoT Systems, and criteria. These *Solutions* (IoT Systems) are represented by set S_{Set} in (1), where the number of alternatives is a finite number $n \in \mathbb{N}$. The set of features/criteria, called C_{Set} , is defined as in (1), with a m size, $m \in \mathbb{N}$. IoT Systems and respective

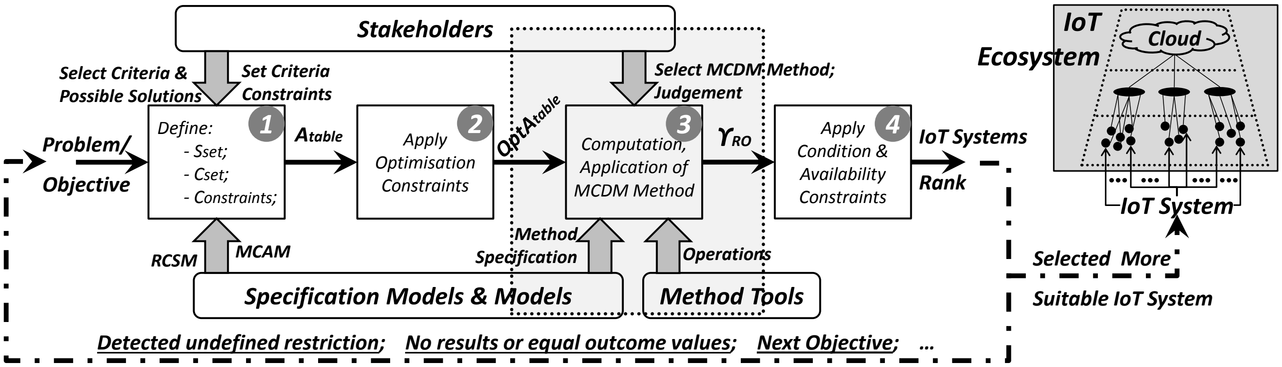


Fig. 4: IoT Ecosystem Design: A Multi-Method, Multi-Criteria Assessment Methodology.

criteria are well described by RCSM specification models, with the selected criteria and constraints defined by MCAM specification model. This makes data clear and accessible for stakeholders. Furthermore, IoT Systems have a vast number of features, although stakeholders may or may not consider all of them as important for the scenario, problem in hand, during the creation of C_{Set}.

$$\begin{aligned} S_{Set} &= \{s_1,\, s_2,\, ...,\, s_n\}\,;\, n \in \mathbb{N} \\ C_{Set} &= \{c_1,\, c_2,\, ...,\, c_m\}\,;\, m \in \mathbb{N} \end{aligned} \tag{1}$$

Each instantiation of class *Criteria* (see Fig. 2) is a criterion c_j , i.e. an element of C_{Set}. In the solutions case, the instantiation of class *ResourceConstraintSystem* (see Fig. 1) selected by stakeholders gives origin to Solutions set S_{Set}.

With possible solutions and criteria sets defined is possible to create an ***Assessment Table***, A_{table}. This follows a common principle seen in MCDM methods, and therefore applied to describe the solutions-criteria cluster in the form of a matrix (which also benefits mathematical operations). The ***Assessment Table***, A_{table}, given by (2), is a ***n-by-m*** matrix. Rows represent the contemplated solutions and the columns the assessment features. The element $v_{i,j}$ presents the value for IoT System *i* of the criterion *j*.

$$A_{table} = \begin{bmatrix} v_{1,1} & v_{1,2} & \cdots & v_{1,m} \\ v_{2,1} & v_{2,2} & \cdots & v_{2,m} \\ \vdots & \vdots & \ddots & \vdots \\ v_{n,1} & v_{n,2} & \cdots & v_{n,m} \end{bmatrix} = (v_{i,j}) \in \mathbb{R}^{n \times m} \tag{2}$$

From the work presented in [11] (see Section II-B) is defined the ***Assessment Constraints*** set, AC_{set}, defined in (3), which is formed by three subsets of constraints. This division occurs due to two factors. First the eliminative nature of constraints (automatically exclude solutions) of type *Availability* and *Condition*. Second, *Optimization* constraints have a direct influence on the MCDM methods, since these are built to rank solutions from criteria high values to the lower ones, and which is why the two constraints subsets are applied at different steps of the proposed methodology (as explained later). In this sense, it is defined ***no-eliminative assessment constraints set***, AC_{Opt}, and ***eliminative assessment constraints sets***, AC_{Cod} and AC_{Ava}.

$$\begin{gathered} AC_{Opt} = \{MIN,\, MAX\}; \\ AC_{Cod} = \{LessThan,\, Equal,\, GreaterThan\}; \\ AC_{Ava} = \{MustHave,\, CannotHave\}; \\ AC_{set} = AC_{Opt} \cup AC_{Cod} \cup AC_{Ava} \end{gathered} \tag{3}$$

The stakeholder's judgement has an important role since it is their considerations that specify the rules over the criteria (settling the constraints) which express formally what has to be analysed and in which way, to achieve the objective. The constraints that each criterion has to respect are obtained from the instantiation of MCAM, enabling the proposed methodology to assess all criteria accordingly to decision maker objective.

2) First-Level of Assessment Constraints: As mentioned, constraints are divided in two type of sets, *no-eliminative* and *eliminative*, and are applied at different stages of the IoT Systems assessment methodology. The first assessment constraints applied are the ***no-eliminative evaluation constraints***, AC_{Opt}. Application of *Optimization* constraints to the solutions-criteria cluster is made by using the assessment constraints function (see Fig. 6 in Section IV) which results in $OptA_{table}$, a ***n-by-m*** matrix, as described in (4). Rows continue to represent the contemplated solutions and the columns the assessment features, similar to A_{table} in (2). The value ***p*** identifies the number of constraints applied to criterion ***j***. The ***maxV*** argument is determine by (5).

$$\begin{gathered} \Phi_{i,j} = \prod_{k=1}^{p} ProcessAC(v_{i,j},\, Constraint_k,\, maxV,\, 0)\,; \\ OptA_{table} = (\,\Phi_{i,j}\,)\,; \\ Constraint_k \in AC_{Opt}\,; \\ p \in \mathbb{N} \end{gathered} \tag{4}$$

The main difference between matrix A_{table} and $OptA_{table}$ is that the second contemplates the application of *Optimization* constraints, which is highly important if stakeholders desire any criterion minimisation analysis.

$$maxV = max\{v_{1,j},\, v_{2,j},\, ...,\, v_{n,j}\} \tag{5}$$

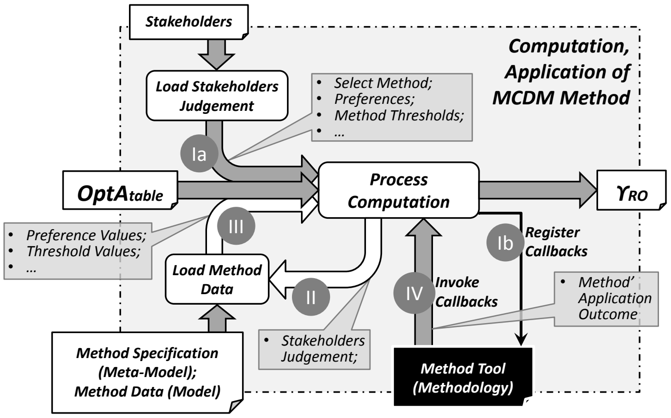


Fig. 5: Process to Apply a MCDM Method.

3) Application of a MCDM Method: This step addresses the diversity of available MCDM methods, by proposing a process to implement the system presented in Fig. 3. An inside view of this process is depicted in Fig. 5, in which the presented approach reduces the black box (unknown procedure) to only the MCDM method computation (*Method Tool*), by using Model-Based modules/components to load the method parameters, enabling stakeholders to apply their preferences.

The process starts with two operations: stakeholders' intervention (***Ia***) on selecting MCDM method and its options; and the register of callback functions (***Ib***) for load of Solutions-Criteria values, method options and return of ranking outcome.

By selecting the MCDM method, its options are made available to stakeholders. In AHP case for example, preference values (level of importance of criterion ***a*** over criterion ***b***) are requested, as well as consistency threshold. Or in ELECTRE case, it is requested to stakeholders to select criteria weight values, and threshold values for discordance and concordance levels. The request of such information is accomplished by loading the respective specification model of the MCDM method. This reasoning, stakeholders' judgement, is then introduced in MCDM method model (***II***). Generated a valid MCDM method model it is made available (***III***) to be used by the *Method Tool*.

Computation of MCDM method provided by *Method Tool* module is identified as "black box", an unknown procedure due to the MCDM methods' distinct processes. However, based on a formal specification of the method, third-party actors can built and provide a package to execute the mathematical operations. Information, details of solutions features, *Solutions-Criteria Cluster* — $OptA_{table}$, has a known form and widely adopted. Stakeholders' opinions are described in a formal way — MCDM method specification model (Meta-Model). The expected outcome, the solutions ranking form is also known — Υ_{RO}. Information accessible through the use of callback functions (***IV***).

Although, a rule must be respected by the method execution tool, i.e. it must provide means to register callback functions which are used as access points to get data and to return the ranking outcome.

The proposed methodology specifies the ranking outcome provided by the selected MCDM method, ***MCDM Rank Outcome*** — Υ_{RO}, a ***n-by-1*** matrix as given in (6). Rows continue to represent each contemplated solution and the column reports the rank outcome values. The element $RO_{i,1}$ presents the MCDM method rank outcome value for IoT System ***i***.

$$\Upsilon_{RO} = \left[RO_1,\, RO_2,\, \ldots,\, RO_n\right]^T = (RO_{i,1}) \in \mathbb{R}^{n\times 1} \quad (6)$$

4) Second-Level of Assessment Constraints: Known the result from the selected MCDM method is time to apply the two types of assessment constraints left, the ***eliminative assessment constraints***, AC_{Cod} and AC_{Ava}. The enforcement of assessment constraints of type *Condition*, AC_{Cod}, results in a ***n-by-1*** binary matrix, $Eval_{Cod}$, given by (7). The ***Th*** argument is the threshold value for constraint ***k*** in criterion ***j***, value that is retrieved from the instantiation of MCAM.

$$\begin{gathered}\Theta_i = \prod_{j=1}^{m}\sum_{k=1}^{p} ProcessAC(v_{i,j},\, Constraint_k,\, 0,\, Th)\,; \\ Constraint_k \in\, AC_{Cod}\,; \\ p,\in \mathbb{N}\,; \\ (\,Eval_{Cod}\,)_{i,1} = \begin{cases} 1, & \textbf{if } \Theta_i > 0 \\ 0, & \textbf{otherwise}. \end{cases}\end{gathered} \quad (7)$$

The enforcement of the ***assessment constraints*** of type Availability, AC_{Ava}, also results in a ***n-by-1*** binary matrix, $Eval_{Ava}$, and is given by (8).

$$\begin{gathered}(\,Eval_{Ava}\,)_{i,1} = \\ \prod_{j=1}^{m}\sum_{k=1}^{p} ProcessAC(v_{i,j},\, Constraint_k,\, 0,\, 0)\,; \\ Constraint_k \in\, AC_{Ava}; \\ p,\in\, \mathbb{N}\end{gathered} \quad (8)$$

The binary outcome from matrices $Eval_{Cod}$ and $Eval_{Ava}$ state if a solution is considered valid according to stakeholders' *eliminative* constraints. The ***final solutions ranking***, $(\,IoT_{Systems}\,)_{Rank}$, is given by (9). Where $(\,S_{Value}\,)_{i,1}$ is the Multi-Criteria Assessment outcome value for the solution ***i*** (IoT System ***i***). The highest $(\,S_{Value}\,)_{i,1}$ identifies the more suitable solution, according to the proposed methodology.

$$\begin{aligned}(\,IoT_{Systems}\,)_{Rank} &= \Upsilon_{RO} \odot Eval_{Cod} \odot Eval_{Ava} \\ &= \begin{bmatrix}(\,S_{Value}\,)_1 \\ (\,S_{Value}\,)_2 \\ \vdots \\ (\,S_{Value}\,)_n\end{bmatrix} \\ &= (\,(\,S_{Value}\,)_{i,1}\,) \in \mathbb{R}^{n\times 1}\end{aligned} \quad (9)$$

The proposed methodology works in a close loop for two main reasons: unsatisfactory result or new computation. A not satisfactory assessment outcome can occur in the case of applied constraints excluded all solutions, detected an undefined restriction (e.g. limit a criterion value), no results (all solutions eliminated) or equal outcome values for all or top qualified solutions. A normal scenario is to design a IoT Ecosystem with several IoT Systems which leads to a constant application of the methodology by changing the purpose, objective.

To determine the impact that the constraints enforce in the solutions, a procedure (applied in Step 2 and 4) was developed to execute this task and it is presented in Fig. 6. This function, ***ProcessAC***, which processes the assessment constraints has four input arguments and returns a value of type double. The first argument, ***CriterionV***, is the ***jth*** criterion value of solution ***i***. ***ConstraintType*** is an assessment constraint type, i.e. is one of the AC_{set} elements. The ***maxV*** argument is determine by (5), and the last argument, a ***Threshold***, is a value used in constraints of ***Condition*** type (value obtain from MCAM).

```
Function ProcessAC (CriterionV, ConstraintType, maxV, Threshold)
    If ConstraintType is of type MAX then
        Return CriterionV;
    Else if ConstraintType is of type MIN then
        Return maxV - CriterionV;
    Else if ConstraintType is of type MustHave then
        If CriterionV different from 0 then
            Return 1.0;
    Else if ConstraintType is of type CannotHave then
        If CriterionV equal to 0 then
            Return 1.0;
    Else if ConstraintType is of type LessThan then
        If CriterionV is less than Threshold then
            Return 1.0;
    Else if ConstraintType is of type GreatThan then
        If CriterionV is greater than Threshold then
            Return 1.0;
    Else if ConstraintType is of type Equal then
        If CriterionV is equal to Threshold
            Return 1.0;
    Return 0.0;
End Function.
```

Fig. 6: Procedure to Process Assessment Constraints.

Assessment Constraints of type ***Condition*** ("*Less Than*", "*Equal*" and "*Greater Than*") presented in [4] use ***threshold*** values to define, restrict value sets for criteria. For example, stipulate a max cost (α) for a final solution. The MCAM specification uses a *double* type variable for definition of threshold in quantitative and *string* for qualitative criteria.

IV. IoT SYSTEMS ASSESSMENT: INDUSTRIAL SCENARIO

The work presented in [4] evaluated a set of six solutions (IoT Systems) by analysis of five criteria. The objective consisted in select a type of device to be placed in metalworking machines of a metal-modelling line to control scrap and good pieces. Data retrieved was used to perform a better schedule of deliveries, next metal-modelling task, and request of raw materials.

Solutions, criteria and constraints sets are defined in (11). The considered solutions were: s_1) Arduino Uno + CAN Shield; s_2) Arduino Uno + new design CAN board; s_3) Arduino DUE + CAN Shield; s_4) Arduino DUE + new design CAN board; s_5) ATMEGA328P board + CAN Shield; and s_6) ATMEGA328P board + new design CAN board. Arduinos and CAN Board were bought off-the-shelf, while the other boards were design and built specifically for the case. Regarding criteria, it was identified: c_1) energy (milli-Watts); c_2) duration (Days' Work); c_3) implementation (Difficulty); c_4) cost (Euros); and c_5) clock speed (MHz). The Assessment Table, A_{Table}, for the scenario presented is given by (10), where $v_{i,j}$ is value for solution i, criterion j. Criteria' preference levels considered in [4] are presented in Table I. Threshold values used were: 8.1 for c_2 constraint; and $hard$ for c_3 constraint.

$$A_{table} = \begin{bmatrix} 127.5 & 1 & Easy & 46.2 & 16 \\ 127.5 & 5 & Med.-Hard & 30.2 & 16 \\ 372.9 & 1 & Easy & 61.87 & 84 \\ 372.9 & 5 & Medium & 43.57 & 84 \\ 100 & 5 & Medium & 28.1 & 20 \\ 100 & 10 & Hard & 12.1 & 20 \end{bmatrix} = (v_{i,j}) \in \mathbb{R}^{6\times 5} \tag{10}$$

The solutions ranking obtain in [4] with respective outcome values was: 1) S_1 with 0.844; 2) S_3 with 0.822; 3) S_5 with 0.797 ; 4) S_2 with 0.774; 5) S_4 with 0.771; 6) S_6 with 0.361. Remind that this was computed based on data provided directly by users in a single MCDM method (AHP) methodology.

$$\begin{gathered} S_{Set} = \{s_1,\, s_2,\, s_3,\, s_4,\, s_5,\, s_6\}\,;\; n = 6; \\ C_{Set} = \{c_1,\, c_2,\, c_3,\, c_4,\, c_5\}\,;\; m = 5; \\ Constraint_{c1} = \{MIN\}\,; \\ Constraint_{c2} = \{MIN,\, LessThan\}\,; \\ Constraint_{c3} = \{MIN,\, LessThan\}\,; \\ Constraint_{c4} = \{MIN\}\,; \\ Constraint_{c5} = \{MAX\}\,; \end{gathered} \tag{11}$$

TABLE I: Criteria' Preference Levels used in [4].

	c_1	c_2	c_3	c_4	c_5
c_1	1	1/3	1/3	1/3	2
c_2	3	1	1	1	4
c_3	3	1	1	1	4
c_4	3	1	1	1	4
c_5	1/2	1/4	1/4	1/4	1

V. RESULTS

The constraints definition (*'min', 'max', 'lessThan', 'greaterThan', 'equal', 'mustHave' and 'cannotHave'*) are directly related with criteria values, which makes it impossible to cover all possibilities. Also, stakeholders have different perspectives of which criterion is more important, and its importance also depends on the scenario being addressed, i.e. settle a relation between criteria is also a difficult task. This second point is handle in AHP method with Saaty 1-9 scale (9 for highly important and 1 for equal importance) [18]. PROMETHEE uses different functions and another example is ELECTRE with concordance and discordance thresholds (directly related to criteria values).

Since AHP presents a limited criteria qualification method, it was computed all possibilities up to 4 criteria which the results are presented in Table II. To determine the correctness of each combination it was computed the AHP method

TABLE II: AHP: Possible Combination of Criteria' Priorities.

	3 Criteria:	4 Criteria:
Valid:	1.087 $[\approx 22,13\%]$	749.873 $[\approx 3,11\%]$
Invalid:	3.826 $[\approx 77,87\%]$	23.387.696 $[\approx 96.89\%]$
Total:	4.913	24.137.569

Consistency Ratio, ***CR*** (see (12)), and considered valid each combination with a $CR \leq 10\%$. CR values higher than 10% states that exists serious inconsistencies in the judgement made (attribution of importance values to each criterion). In (12), λ_{max} stands for the maximum value from the ***eigenvector*** of criteria preference levels table, and m the number of criteria. The ***Random Consistency Index***, ***RI***, as the name implies, is a random value, built from exhaustive tests, where the number of criteria varies. One example is the work presented in [32], from which the ***RI*** value for a number of four criteria is 0.9.

$$CR = \frac{\lambda_{max}-m}{RI\times(m-1)} \qquad (12)$$

The results presented are limited in the number of criteria due to computational issues. A 5 criteria analysis will present a total of more than 201×10^{12} possible combinations (estimated to take 2,5 to 3 years using a dedicated personal computer — i7 processor; 16GB of memory; 512 GB high-speed SSD). One criterion' analysis is a non-Multi-Criteria problem, and for two criteria, all 17 possibilities are valid ($CR = 0\%$).

Next the proposed Multi-Method, Multi-Criteria Assessment Methodology, presented in Fig. 4, is applied using the same solutions set as described in (11). Although, due to computation issues afore mentioned, it was only considered 4 criteria (energy; duration; implementation and cost). Criteria c_5), clock speed, respective constraints and preference levels were not contemplated. Recalculating solutions ranking, the outcome values are: 1) S_1 with 0.215; 2) S_5 with 0.174; 3) S_3 with 0.163; 4) S_2 with 0.146; 5) S_4 with 0.12; 6) S_6 with 0. A change between 2nd and 3rd place, i.e. S_5 is now considered as second choice. Solutions will be evaluated now with all possible criteria preference combinations.

Analysing the methodology process presented in Fig. 4, results of step *1)* and *2)* are exact the same (no change of solutions, criteria and constraints) for all combinations. Although, changing the stakeholders judgement (computing all possible and valid criteria' preference levels for 4 criteria) results in different outcomes (Υ_{RO}) in step *3).*

With all valid combinations computed was possible to develop a script that generates the respective AHP models. The specification model used for AHP Multi-Criteria Method was presented in [11]. An instantiation example of an AHP model is presented in Fig. 7. Figure depicts preference values for criterion *energy* (c_1), highlighting the relation with criterion *cost* (c_4). In this case, criterion c_4 ('*..assessmentCriteria.3*') is considered three times more important than c_1 ('*..assessmentCriteria.0*').

All AHP models generated correspond to step ***II*** and ***III*** of the process presented in Fig. 5.

Table III reports the outcome for five of the solutions considered, by application of the more than 749 thousand possible combinations just for criteria preference weight. Solution s_6 is not represented in the table since it place always sixth (749.873 times) due to an eliminative assessment constraint. The results shows, reinforces the outcome obtain in [4]. The solution, s_1, is ranked in first place $\approx 70,4\%$ of the times, dividing this place only with solution s_5.

TABLE III: Application of All Possible and Valid Criteria' Preference Levels.

	s_1	s_2	s_3	s_4	s_5
1^{o} Place	527.701	0	0	0	222.172
2^{o} Place	91.467	130.705	235.117	0	292.584
3^{o} Place	130.705	310.041	74.010	0	235.117
4^{o} Place	0	216.933	247.549	285.391	0
5^{o} Place	0	92.154	193.197	464.482	0

VI. CONTRIBUTIONS & DISCUSSION

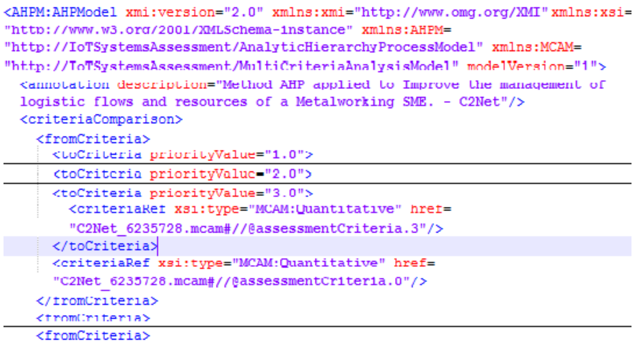
New embedded systems are provided everyday by manufacturers, and many are the features/criteria that influence the overall performance of an IoT System, which makes the IoT Systems selection a decision very difficult for stakeholders (e.g. engineers, developers, end-users, etc.) [4].

This paper contributes with a novel assessment methodology for the study and evaluation of IoT System solutions (device) to be used during the design of IoT Ecosystems to improve, assist decision-makers (engineers, developers, owners, etc.) on the selection of a more suitable IoT System for a certain task.

The proposed methodology is an extension to the work presented in [4], by providing new mechanisms for a more versatile assessment. Mechanisms that include traceability (using model representations) to the solutions, criteria and constraints used, as well as traceability to the applied MCDM methods. Also, mechanisms with the capability to apply different decision methods for the same objective and the possibility to use other MCDM methods not considered at this point.

The MCDM methods used in the works presented in Section II-B are examples of methods that can be used by the proposed methodology, with the advantage of include criteria constraints, traceability (register options made), and direct comparison with other methods.

Decision makers can apply optimisation functions (best or worse based on criteria value), availability restrictions (must or cannot have a certain feature) or set data range for criteria



```
<AHPM:AHPModel xmi:version="2.0" xmlns:xmi="http://www.omg.org/XMI" xmlns:xsi=
"http://www.w3.org/2001/XMLSchema-instance" xmlns:AHPM=
"http://IoTSystemsAssessment/AnalyticHierarchyProcessModel" xmlns:MCAM=
"http://IoTSystemsAssessment/MultiCriteriaAnalysisModel" modelVersion="1">
  <annotation description="Method AHP applied to Improve the management of
  logistic flows and resources of a Metalworking SME. - C2Net"/>
  <criteriaComparison>
    <fromCriteria>
      <toCriteria priorityValue="1.0">
      <toCriteria priorityValue="2.0">
      <toCriteria priorityValue="3.0">
        <criteriaRef xsi:type="MCAM:Quantitative" href=
        "C2Net_6235728.mcam#//@assessmentCriteria.3"/>
      </toCriteria>
      <criteriaRef xsi:type="MCAM:Quantitative" href=
      "C2Net_6235728.mcam#//@assessmentCriteria.0"/>
    </fromCriteria>
    <fromCriteria>
    <fromCriteria>
```

Fig. 7: AHP Model Instantiation: one of AHP Models used.

for which a solution is acceptable, to tackle the inadequacy of the MCDM methods to define specific constraints/restrictions.

Selection of criteria changes with each scenario, stakeholder judgement and objective, as well as the number of criteria involved in the assessment. With large number of criteria is very common to neglect the existence of dependencies between criteria. The scenario presented in Section IV is possible to observe that criteria c_2 and c_3 (day's work and difficulty) have a certain relation. Criteria dependencies can influence negatively the final ranking result. AHP is an example of a MCDM method that allows the modelling of criteria interdependencies. With MCDM methods that not present methods to model criteria interactions and dependencies the proposed methodology can tackle this by analyse of any kind of proportional relation between criteria, or use criteria meaning analyses using for example ontologies. Criteria dependencies should be verified before applying the proposed methodology.

Disadvantages from the known MCDM methods are not solve and are projected to the proposed methodology, however the openness to accept new, different MCDM methods allows stakeholders to decide which is best not only for them but also for each particular application case. Besides, with the model-driven nature of the methodology, already existing MCDM methods can be improved, and changes applied.

Stakeholders' decision/selection upon the more suitable MCDM method to use with the proposed methodology can depend mainly on the scenario/problem (e.g.: number of criteria, possible solution, etc.) but also the stakeholders' knowledge on possible MCDM methods. For instance the AHP method is commonly applied to problems with conflicting criteria, and its capability to check inconsistencies in stakeholders' judgement is a plus. PROMETHEE on the other hand needs less input from decision makers. The most important is preference function selection, which can turn out to be difficult for inexperienced users. The ELECTRE can handle data with high uncertainty, and more indicated in cases where the stakeholders are not capable of give rational information. Although, select concordance and discordance conditions can be difficult. It is also more suitable in cases with several solutions and not so many criteria [25]–[30].

An important aspect is validation of the Multi-Method, Multi-Criteria Assessment Methodology for IoT Ecosystems Design. The industrial scenario presented is very practical and concrete example were the proposed methodology helps the stakeholders in their decision. For this case, validation was achieved by checking the compliance of technical and stakeholders requirements (objective, criteria, constraints) with final results. Solution ranking obtain through exhaustive tests was verified with the defined acceptance.

VII. CONCLUSIONS

This paper proposed an Assessment Methodology enabling the application of different MCDM methods, based on well-defined criteria and respective constraints by taking benefit from the specification models (MCAM and RCSM) presented in [11]. The methodology enables stakeholders to access which IoT System is more suitable for each specific task during a design phase of an IoT Ecosystem. This work contributes to the current State-of-the-Art advance by providing means to use different constraints types besides the normal minimisation and maximisation evaluation seen in the common MCDM methods, but also defines mechanisms to combine this new approach with available MCDM methods, as well as its indiscriminate use. As future work it is foreseen the analysis of IoT Systems with other MCDM methods, by providing respective specification models (Meta-Models) and tools to execute their operations.

With inclusion of other MCDM methods another feature will be added to the proposed methodology, a module to to analyse in real-time the problem to be solve and provide some guidance to stakeholders on the more indicated MCDM. The recommendation will be based on the literature.

Validation should also be improved with the inclusion of more MCDM methods. For now it is accomplished by requirements validation, verification if the final solution meets the specification and use of traceability features provided by the use of a model-based approach. It is foreseen the analysis of the tests deviation, by changing preference weights, constraints or considered criteria, and continue to evaluate that the objective specification is meet. Traceability feature plays a very important role in this. Separately validate each procedure to verify that the proposed methodology as a whole will meet its specification and its reliability and consistency.

Although, the proposed methodology purpose is not to compare to then highlight the better MCDM method, but to use the different methods available to assist and improve the final stakeholders' decision.

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REFERENCES

[1] D. Evans, "The internet of things: How the next evolution of the internet is changing everything," CISCO Internet Business Solutions Group (IBSG), White Paper, 4 2011, available from: http://www.cisco.com/web/about/ac79/docs/innov/IoT_IBSG_0411FINAL.pdf.

[2] Merriam-Webster, "system," Merriam-webster, An Encyclopaedia Britannica, 2019, retrieved June 4, 2019. https://www.merriam-webster.com/dictionary/system.

[3] system. Cambridge Dictionary. [Online]. Available: https://dictionary.cambridge.org/dictionary/english/system

[4] E.M. Silva, C. Agostinho, and R. Jardim-Goncalves, "A multi-criteria decision model for the selection of a more suitable internet-of-things device," in *International Conference on Engineering, Technology and Innovation (ICE/ITMC)*, 6 2017, pp. 1268–1276.

[5] O. Vermesan and P. Friess, *Building the Hyperconnected Society: Internet of Things Research and Innovation Value Chains, Ecosystems and Markets*, ser. River Publishers Series in Communications. River Publishers, 6 2015, vol. 43.

[6] R. Nicolescu, M. Huth, P. Radanliev, and D. De Roure, "Mapping the values of iot," *J. of Inf. Technology*, vol. 33, no. 4, pp. 345–360, Dec 2018. [Online]. Available: https://doi.org/10.1057/s41265-018-0054-1

[7] P. Radanliev, D.C.D. Roure, R. Nicolescu, M. Huth, R.M. Montalvo, S. Cannady, and P. Burnap, "Future developments in cyber risk assessment for the internet of things," *Computers in Industry*, vol. 102, pp. 14 – 22, 2018. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0166361518301817

[8] P. Radanliev, D. De Roure, S. Cannady, R.M. Montalvo, R. Nicolescu, and M. Huth, "Economic impact of iot cyber risk - analysing past and present to predict the future developments in iot risk analysis and iot cyber insurance," in *Living in the Internet of Things: Cybersecurity of the IoT - 2018*, 3 2018, pp. 1–9.

[9] J.R.C. Nurse, P. Radanliev, S. Creese, and D. De Roure, "If you can't understand it, you can't properly assess it! the reality of assessing security risks in internet of things systems," in *Living in the Internet of Things: Cybersecurity of the IoT - 2018*, 3 2018, pp. 1–9.

[10] J.A. Stankovic, "Research directions for the internet of things," *Internet of Things Journal, IEEE*, vol. 1, no. 1, pp. 3–9, 2 2014.

[11] E.M. Silva and R. Jardim-Goncalves, "Cyber-physical systems: A multi-criteria assessment for internet-of-things (iot) systems," *Enterprise Information Systems*, pp. 1–20, 2019.

[12] M. Chernyshev, Z. Baig, O. Bello, and S. Zeadally, "Internet of things (iot): Research, simulators, and testbeds," *IEEE Internet of Things Journal*, vol. 5, no. 3, pp. 1637–1647, June 2018.

[13] J. Hutchinson, M. Rouncefield, and J. Whittle, "Model-driven engineering practices in industry," in *Proc. of the 33rd international conference on Software engineering*, ser. ICSE '11. ACM, 2011, pp. 633–642.

[14] J.A. Lane and T. Bohn, "Using sysml modeling to understand and evolve systems of systems," *Systems Eng.*, vol. 16, no. 1, pp. 87–98, 3 2013.

[15] OGC, "Sensor model language (sensorml)," Open Geospatial Consortium (OGC), 2 2014, retrieved June 7, 2019. https://www.opengeospatial.org/standards/sensorml.

[16] W3C, "Semantic sensor network xg final report," World Wide Web Consortium (W3C), 6 2011, retrieved June 26, 2019. https://www.w3.org/2005/Incubator/ssn/XGR-ssn-20110628/.

[17] L.F.C.S. Durão, M.M. Carvalho, S. Takey, P.A. Cauchick-Miguel, and E. Zancul, "Internet of things process selection: Ahp selection method," *The International Journal of Advanced Manufacturing Technology*, vol. 99, no. 9, pp. 2623–2634, 12 2018.

[18] T.L. Saaty, "A scaling method for priorities in hierarchical structures," *J. of Mathematical Psychology*, vol. 15, no. 3, pp. 234 – 281, 6 1977.

[19] M. Majumder, *Impact of Urbanization on Water Shortage in Face of Climatic Aberrations*, 1st ed., ser. SpringerBriefs in Water Science and Technology. Springer Singapore, 2015, no. 1.

[20] Y.P. Kondratenko, G.V. Kondratenko, and I.V. Sidenko, "Multi-criteria selection of the wireless communication technology for specialized iot network," in *ICTERI Workshops*, 2018.

[21] H. Krapivina, Y.P. Kondratenko, and G.V. Kondratenko, "Multi-criteria decision making approaches for choice of wireless communication technologies for iot-based systems," in *Proceedings of ICTERI 2019. Volume III: PhD Symposium co-located with 15th International Conference "ICT in Education, Research, and Industrial Applications 2019", Kherson, Ukraine, June 12 - 15*, 2019, pp. 73–82. [Online]. Available: http://ceur-ws.org/Vol-2403/paper9.pdf

[22] K.C. Park and D.H. Shin, "Security assessment framework for iot service," *Telecommunication Syst.*, vol. 64, no. 1, pp. 193–209, 1 2017.

[23] Y. Kondratenko, G. Kondratenko, and I. Sidenko, "Multi-criteria decision making for selecting a rational iot platform," in *2018 IEEE 9th International Conference on Dependable Systems, Services and Technologies (DESSERT)*, 5 2018, pp. 147–152.

[24] Y. Kondratenko, G. Kondratenko, and I. Sidenko, "Multi-criteria decision making and soft computing for the selection of specialized iot platform," in *Recent Developments in Data Science and Intelligent Analysis of Information*, O. Chertov, T. Mylovanov, Y. Kondratenko, J. Kacprzyk, V. Kreinovich, and V. Stefanuk, Eds. Cham: Springer International Publishing, 2019, pp. 71–80.

[25] A. Kolios, V. Mytilinou, E. Lozano-Minguez, and K. Salonitis, "A comparative study of multiple-criteria decision-making methods under stochastic inputs," *Energies*, vol. 9, no. 7, p. 566, 7 2016.

[26] D. Sabaei, J. Erkoyuncu, and R. Roy, "A review of multi-criteria decision making methods for enhanced maintenance delivery," *Procedia CIRP*, vol. 37, pp. 30 – 35, 8 2015.

[27] B. Roy, "The outranking approach and the foundations of electre methods," *Theory and Decision*, vol. 31, no. 1, pp. 49–73, 7 1991.

[28] J.P. Brans and P. Vincke, "Note-a preference ranking organisation method," *Management Science*, vol. 31, no. 6, pp. 647–656, 6 1985.

[29] M.E. José Figueira, Salvatore Greco, *Multiple Criteria Decision Analysis: State of the Art Surveys*, ser. Internat. Series in Operations Research & Manag. Sci., S. Greco, Ed. NY, USA: Springer, 2005, vol. 78, no. 1.

[30] M. Aruldoss, T.M. Lakshmi, and V.P. Venkatesan, "A survey on multi criteria decision making methods and its applications," *American Journal of Information Systems*, vol. 1, no. 1, pp. 31–43, 12 2013.

[31] KBSI, "Idef0 function modeling method," Knowledge Based Systems, Inc., 2019, accessed March 22, 2019. [Online]. Available: http://www.idef.com/idefo-function_modeling_method/

[32] H. Donegan and F. Dodd, "A note on saaty's random indexes," *Mathemat. and Comput. Modelling*, vol. 15, no. 10, pp. 135 – 137, 1 1991.

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