https://dx.doi.org/10.22161/ijaers.6.2.2 ISSN: 2349-6495(P) | 2456-1908(O)

SMM: A Maturity Model of Smart Cities Based on Sustainability Indicators of the ISO 37122

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***Abstract*— *Most indicators used for Smart Cities do not follow a pattern and/or are not able to be compared to each other In order to standardize the maturity evaluation of these cities, the present work aimed to propose a new framework to evaluate the maturity degree of a Smart City. The Sustainability Maturity Model (SMM) was inspired by CMMI maturity indices, by COBIT process controls and ISO 37122 indicators. Thus, the steps of the framework were developed, and a case study was carried out in a hypothetical city in order to validate it. As a result, it was observed that SMM allowed classifying the city by its maturity level based on the sustainability indicators of ISO 37122. This assessment can add value to a city aiming to become smart, and can serve as basis for applying new assessments and measuring the evolution of these environments.*

Keywords*— *Smart Cities, Maturity, ISO 37122, CMMI, COBIT.

I. INTRODUCTION

Technological advances easy the development of strategies and programs to improve the life quality of the population. The inclusion of ICTs in the management of cities can facilitate the decision-making process of managers, thus creating improvements in the infrastructure and services offered to citizens and can be used as a subsidy for the creation of Smart Cities [1].

Smart Cities can have several definitions and, among them, according to [2], are communities that seek to transform life and work effectively using Information Technology. Managers from various cities around the world say their cities are smart just because they have ICT-based initiatives, which is not correct. [3].

There are maturity models that allow us to measure the degree of smartness of a city. Creating a maturity pattern presupposes enlisting requirements, analyzing, and defining data that will be required to measure the intelligence level of a Smart City.

Most indicators used in cities do not follow a pattern and/or are not able to be compared to each other. In this sense, several standards have been developed in order to provide a set of indicators as a recommendation of what to measure and how it should be measured. However, the standards do not define a target threshold or numerical value for the indicators.

Thus, in order to standardize the maturity evaluation of a Smart City, this work aims to propose a *framework* to evaluate the maturity degree of a Smart City. For this, the maturity model that served as inspiration for the development of the proposed *framework* was the CMMI - *Capability Maturity Model* [18], along with COBIT project management [20], in addition to ISO 37122 [15], thus developing the *framework Sustainability Maturity Model - SMM* of analyzes of maturity.

The proposed methodology aims to determine the level of maturity of a Smart City, describing the best practices of control of the indicators described in ISO 37122 associated with COBIT and CMMI, thus contributing to the improvement of the maturity analysis of a smart city.

The relevance of this study lies in the attempt to contribute to filling the existing gap in the standardized evaluation of a Smart City, proposing a *framework* for assessing the maturity level of a city.

This article is organized into five sections, with this first one presenting the goal of the study and its relevance. In the second part, the theoretical framework is presented, followed by the materials and methods used to achieve the proposed goal. In the fourth section, the reader is presented with the analysis of the results found and, in the

https://dx.doi.org/10.22161/ijaers.6.2.2 ISSN: 2349-6495(P) | 2456-1908(O)

fifth and last section, the final considerations are presented as well as suggestions for future research.

II. THEORETICAL BACKGROUND

From the emergence of the concept of smart cities, various indices, indicators, and methods were created to measure potential and evaluate cities [1]. Researchers have proposed their models based on the indicators and/or domains they found most relevant to a smart city. Some of these models present levels that serve to measure and analyze the predisposition of a city that aims to become smart [2 - 16].

Even though the issue has already been revealed as a trend towards the solution of social problems, it is perceived that there is still a limited understanding of how smart solutions will help cities to evolve as safe and efficient urban spaces [1][3].

Linked to this is the fact that the same solution and/or standard does not always apply in the same way to more than one locality since each region has its specific characteristics. Therefore, in order to measure the performance of a city, the classification attribute must be decomposed into indicators [4], because in this way the city will be able to evaluate its performance based on its reality and, consequently, adopt the best solutions according to its own demands.

Given this context, there is great variety of classification indicators, since there are several perspectives on how cities can be classified, viewed and evaluated by different social actors (being them companies, academics, political leaders and the population in general), but most of the indicators used do not follow a pattern and are not comparable over time and with each other [22]. It is necessary to understand the way of measuring the indexes of a smart city in order to avoid dubious questions in the classification of maturity levels [23].

Salient that it is not the intention of this work to approach definitions for the terms intelligent models of maturity and cities since, in the present time, it has distinct definitions that they change as the vision of each author. The focus, in this case, is the approach and contextualization of an evaluation *framework* for measuring a smart city, since it was shown the need for a standardization of a model to measure such levels [1].

Even before the production of the *framework* itself, a survey of the Maturity Measurement Models was carried out, in order to illustrate the existing gap in the evaluation of smart cities. In this way, Table 1 was developed, which illustrates the models and their respective authors. During the study process of these models, it was verified that six of them have tangible maturity models to be used to evaluate a smart city; these works are marked with an "x" in the "Relevance" column in Table 1. The other models did not continue their solutions, either because of the level of complexity or they did not become public because they were from private agencies.

Table 1: Maturity Models

MODELS	AUTHORS	RELEVANCE
Model Based On Giffinger	Giffinger et al. (2007)	
MMT	Gamma, Alvaro, and Peixoto (2012)	
SCIP	Inteli (2012)	
IDC GOVER	Clarke (2013)	
SCMM	Meijeringa, Kern and Tobi (2014)	x
WEISS - evaluative readiness	Weiss (2016)	x
SC4A	Artieda (2017)	
ESC	Junkes (2017)	
WCCD	Wccd (2017)	x
RCSC	Connected Smart Cities (2017)	
NBR ISO 37120	Nbr ISO 37120 (2017)	x
ISO 37122	ISO (2017)	x
RBCIH	Rbcih (2018)	
Br-Scmm	Moraes (2018)	
IBMCCI	Guimarães (2018)	x

The CMMI model is a precursor when it refers to maturity. It is linked to maturity levels and processes, thus serving as references to other models. It was initially developed for companies, based on the need to have a maturity model that would serve as a reference for organizations, so that these could continually evolve their processes, consecutively, increasing the quality of their products and services, obtaining greater market acceptance [18].

CMMI has a perspective on the maturity capacity of software processes. It is divided into 5 levels of maturity that show, in turn, the degree of progress an organization has at a certain moment. In addition, it has as main objective to act as a guide for the improvement of the processes of the organization, considering for this activity such as the management of software development, deadlines and costs previously established [18] [19] [20].

COBIT was created by ISACA (Information Systems Audit and Control Association), and its main objective is to generate value for the company and its processes. Accepted internationally as a good practice of control over IT information, COBIT is used to implement governance and improve IT controls. COBIT works by applying a variety of information control practices, ranging from planning to monitoring results. Thus, in general, COBIT begins by establishing best practices in IT governance that are in line with the company's objectives. From there, a description of the processes occurs, including planning, execution, and monitoring of IT processes. The control objectives are also established, which should be specific to the needs of each company. Also, the control objectives are established, that must be specific for the necessities of each company. The evaluation of models and processes is also important to correct nonconformities and, in general, management can be helped with a guide to good practices that helps, for example, the delegation of tasks and the evaluation of the interaction between processes [20].

ISO 37122 - INDICATORS FOR SMART CITIES is the first standard of the body directed exclusively to Smart Cities. Cities that adopt ISO 37122 will have standardized definitions and methodologies for a set of key performance indicators as tools to become more sustainable and smarter [15]. The norm takes sustainability as its general principle, as it relates to the process of change for smart cities. It is designed to help cities guide and evaluate the performance management of municipal services and all service provision, as well as the life quality of the population. ISO 37122 covers 19 thematic areas in its scope: economy, finance, education, governance, telecommunication, transport, energy, environment and climate change, urban/local agriculture and food security, urban planning, wastewater, culture, health, housing, security, leisure, population / social conditions, and solid waste. The measurement of performance occurs through 75 indicators that are typified in the standard as general and its application requirements [15]. It should be noted that cities that use ISO 37122 as a reference must report at least 50% of the indicators of this standard.

III. MATERIAL AND METHODS

The *framework* proposed to evaluate the degree of maturity of an Intelligent City was inspired by the maturity model CMMI - COBIT and ISO 37122. CMMI was based on the levels of maturity to determine the levels of maturity degree of the *framework*. With COBIT, results were planned and monitored. Finally, with ISO 37122, the indicators reported in the standard were used.

The *framework*, named *Sustainability Maturity Model* - SMM, is composed of 5 steps, as can be seen in Fig 01.

Step 1 consists of evaluating, through a questionnaire based on the indicators of ISO 37122, the city to be analyzed. The goal of this step is to demonstrate the degree of compliance with the recommendations of ISO 37122 of a smart city - according to the existing domains (Economy, People, Governance, Mobility Environment, Life). [1][15].

In step 2, COBIT is applied, through the planning and monitoring of the results obtained in step 1, in addition to CMMI, to evaluate in which level of sustainability a city is within a scale ranging from 1 to 5, being: 1 - Initial, 2 - Managed, 3 - Defined, 4 - Quantitatively Managed and 5 - In Optimization. In level 1, the city does not have or does not carry out activities or actions in this dimension using technological resources or ICTs, and in 5 the city is in optimization [1].

Table 2: Level of maturity degree based on CMMI

LEVEL	DETAILING
1- Initial (10-20)%	At this level is the stage where cities start. This phase indicates that cities plan and shape the information systems they will use to integrate their smart solutions.
2- Managed (30-40)%	At this level, cities are called efficient, seeking innovation and pioneering information technology solutions, with a greater focus on supporting decision-making for both citizens and governments using data obtained in the various domains.
3- Defined (50-60)%	At this level is the phase where data is already collected and accessible to the population through information systems, where they properly operate and where the use of cloud computing systems is verified, being integrated into the form of services and available to both citizens as well as third parties.
4- Quantitatively Managed (70-80)%	At this level, cities are at a stage of integrated resources and available in the form of services for both citizens and applications. At this stage, the use of computing aims to be available everywhere.
5- In Optimization (90-100)%	At this level cities are classified as efficient, seeking innovation and becoming pioneers in technological solutions. At this stage, they contemplate the use of the data obtained in the various domains of the city.

In Table 2 it is possible to verify the description of the 5 levels of maturity inspired by CMMI. There it is shown the representation by stages, where it is proposed to improve the capacity of smart cities through the evolution of maturity levels. Each maturity level covers a set of

https://dx.doi.org/10.22161/ijaers.6.2.2 ISSN: 2349-6495(P) | 2456-1908(O)

areas that must be considered in order to achieve the desired level. For example, to achieve maturity level 3, all Indicators for domains related to level 1, level 2 and level 3 should be considered.
In this first moment, it was considered that all areas will possess the same level of importance and score, because, for the city to be considered smart is observed the need for harmony among all domains.
The results may range from 1 to 5; Initial; Managed; Defined; Quantitatively Managed; Optimization.
Step 3 consists of the data analysis, where all information obtained will be validated. Step 4 is where you get the results of the city being measured; it is where the information of the maturity level of the city is obtained. Finally, in step 5 all information used and obtained to designate the degree of maturity of the city are stored for comparability and possible standardization.
It should be noted that steps 1 through 3 are referred to as internal processes, while steps 4 and 5 are external processes.

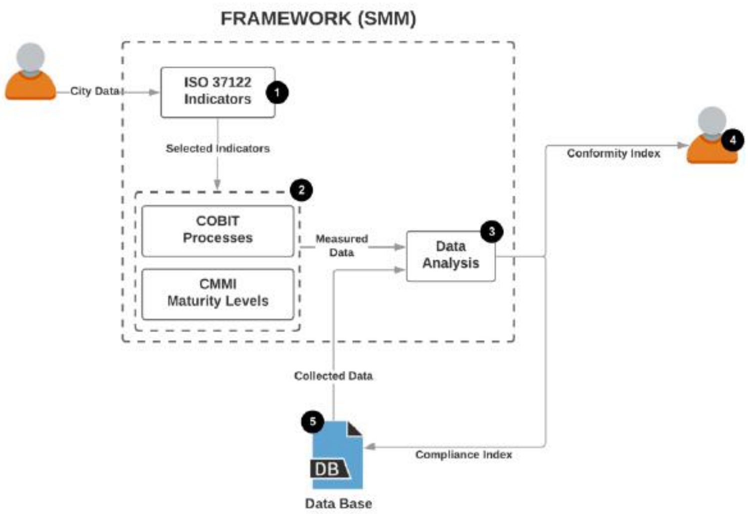

Fig. 01: SMM Framework - Sustainability Maturity Model

In order to validate the *Sustainability Maturity Model - SMM*, a case study was conducted in a hypothetical city. Initially, a questionnaire composed of six domains based on the six pillars of [3] was developed. Based on these six pillars, the nineteen thematic areas of ISO 37122 were associated and, from that point on, questions were asked corresponding to the 75 indicators based on ISO 37122.
In order to reach the research goal, a cut of the questionnaire was done, selecting 45 out of the 75 available indicators, since the norm recommends that cities that use ISO 37122 as a reference must inform at least 50% of the indicators. Table 2 shows the 45 indicators that were selected from the fields of Smart Economy, Smart People, Smart Governance, Smart Mobility, Environment, and Smart Life, as well as the answers obtained.

Table 3: General Indicators Questionnaire of ISO 37122

QUESTIONNAIRE				
Smart Economy				
1.1. Economy	**IND**	**V**	**F**	**P**
1.1.1. Are there local companies hired to provide municipal services with data and communication openly available?	1	x		1
1.1.2. Are there startups in your city?	2	x		1
1.1.3. Is there any workforce employed in Information and Communication Technologies (ICT) sector?	3	x		1
1.1.4. Is there workforce employed in the Education, Research and Development sectors?	4	x		1
1.2. Finances	**IND**	**V**	**F**	**P**
1.2.1. Is there a municipal budget for investments in innovation and smart city initiatives per year?	5	x		1
1.2.2. Is there an annual amount of tax charged from the sharing economy as a percentage of the total tax charged?	6	x		1
1.2.3. Is there any percentage of payments to the city that are electronically paid based on electronic invoices?	7	x		1
Smart People				
2.1. Education	**IND**	**V**	**F**	**P**
2.1.1. Are there databases through public libraries?	8	x		1
2.1.2. Is there in the city's population professional proficiency in one or more foreign languages?	9	x		1
2.1.3. Number of computers, laptops, tablets, or other digital learning devices available to elementary school students?	10	x		1
2.1.4. Number of computers, laptops, tablets, or other digital learning devices available to high school students?	11	x		1
2.1.5. Number of higher education institutions in Science, Technology, Engineering, and Mathematics?	12		x	0
Smart Governance				
3.1. Governance	**IND**	**V**	**F**	**P**
3.1.1. Annual number of accesses to the municipal portal of open data?	13	x		1
3.1.2. Is there a set of data offered in the municipal portal of open data?	14	x		1
3.1.3. Is there a set of municipal data available to the public?	15	x		1

https://dx.doi.org/10.22161/ijaers.6.2.2 ISSN: 2349-6495(P) | 2456-1908(O)

3.1.4. Is there accessible online city services?	16		x	0
3.1.5. Is there an average response time to relevant queries made through the non-emergency consultation system of the city (days)?	17		x	0
Smart Mobility				
4.1. Telecommunication	**IND**	**V**	**F**	**P**
4.1.1. Does the city's population have access to computers or other electronic devices with internet access in libraries and other public buildings?	18	x		1
4.1.2. Does the population of the city have access to broadband at sufficient speed?	19	x		1
4.1.3. Is there in the city area under a neutral/white zone / not covered by telecommunication connectivity?	20	x		1
4.1.4. Is there in the city area with Internet connectivity available to the public?	21	x		1
4.2. Transport	**IND**	**V**	**F**	**P**
4.2.1. Are there streets and paths covered by alerts and traffic information online in real time?	22	x		1
4.2.2. Is there use of transportation sharing by users in an economical way?	23	x		1
4.2.3. Are there low-emission vehicles registered in the city?	24	x		1
4.2.4. Are there bicycles available through sharing services?	25	x		1
4.2.5. Are there public transport lines equipped with real-time ICT-based system?	26	x		1
4.2.6. Is there a public transport network in the city covered by a unified payment system?	27		x	0
4.2.7. Are there public parking spaces equipped with electronic payment systems?	28		x	0
4.2.8. Are there public parking spaces equipped with real-time ICT-based availability systems?	29		x	0
4.2.9. Are there smart traffic lights?	30		x	0
4.2.10. Are there city areas mapped by real-time interactive street maps as a percentage of the total area of the city?	31		x	0
Smart Environment				
5.1. Energy	**IND**	**V**	**F**	**P**
5.1.1. Is there electrical and thermal energy (KWh) produced from wastewater treatment?	32		x	0
5.1.2. Is there electrical and thermal energy (KWh) produced from solid waste treatment?	33	x		1
5.1.3. Is there energy produced in the city using decentralized energy production systems?	34	x		1
5.1.4. In there in the city storage capacity of the power grid?	35	x		1
5.1.5. Is there public lighting power consumption?	36	x		1
5.1.6. Is there reformed public lighting?	37	x		1
5.1.7. Are there public buildings that need renovation?	38	x		1
5.2. Environment and Climatic Change	**IND**	**V**	**F**	**P**
5.2.1. Are there ecosystems mapped by remote sensing monitoring?	39	x		1
5.2.2. Is there annual monitoring of the remote sensing frequency of the ecosystem?	40	x		1
5.2.3. Are there buildings built or renovated in the last 5 years in accordance with the principles of green building?	41	x		1
5.2.4. Are there real-time ICT-based air quality monitoring stations?	42	x		1
Smart Living				
6.1. Culture	**IND**	**V**	**F**	**P**
6.1.1. Are there indicators on the number of book titles in the library?	43	x		1
6.1.2. Are there indicators on the number of eBook titles?	44	x		1
6.1.3. Are there any indicators on active library users?	45	x		0

IV. ANALYSIS, RESULTS, AND DISCUSSIONS

Following the development of *SMM* steps, as well as the application of the questionnaire, the results analysis was started. The present research made the combination between the standard and the methodology; from the application of the questionnaire cut, shown in Table 2, the result presented in Table 3 was obtained.

Table 3, presented in section III, illustrates the domains and thematic areas; questions were synthesized in numbers in the IND (indicators) column. Questions were answered as true or false, and column P represents the binary values 0 or 1, absent or present respectively, where the indicator that receives the assignment of truth is given the value 1 and the indicator that receives the assignment of false, it is given the value 0, according to Table 3.

Initially, to prevent losses and precision, the Boolean Algebra was used, that allows identifying with bigger easiness the number of requirements taken care of for each process and each sentence is treated as true or solely false, as Table 4. The sentence indicator "*Are there local companies hired to provide municipal services with data and communication openly available?*" was identified as a true sentence since the city met the indicator of ISO 37122. However, the sentence "*Number of higher education institutions in Science, Technology, Engineering, and Mathematics?*" was identified as a false sentence because the city does not meet the requirement.

Table 4: Values according to the nature of the sentence

	Indicator	V	F
1	There are local companies contracted to provide municipal services with data and communication openly available	x	
12	Number of higher education institutions in Science, Technology		x

Table 5 illustrates a test case, assuming a hypothetical city that met the results of Table 3 in the domains: economy, people, governance, mobility, environment, and life; it is the result of the case study. Of the 75 pointers, 45 had been raised, what it is equivalent 60% of the pointers of the norm since the proper norm praises that the cities that use ISO 37122 as a reference must inform at least 50% of the pointers.

Thus, the compiled result of Table 3 is presented, where, after registration and validation of the indicators (true/false), it becomes possible to follow the city's degree of evolution. It is possible to observe that, based on the example studied, of the 45 indicators surveyed, the city has 40 Contemplated Indicators, which corresponds to 53% of the 75 General Indicators of ISO 37122.

Table 5: Result, analysis, domains, and indicators

Percentage of Maturity Level	
Contemplated indicators	40
Total of Indicators	75
General Compliance Index	53%

The individual measurement by domain is also contemplated, according to Table 6, being possible to observe the number of indexes per domain. Smart Economy has 100% of its indicators marked as true. Smart people, in turn, have 80%, while Governance has 60%, Mobility 64%, Environment 60% and finally, Smart Life has 10% of its indicators marked. Now, Table 6 presents an association of the domains validated to its indicators, associated with its thematic areas.

Table 6: Domain Compliance Index

Domains	%
1. Smart Economy	100%
2. Smart People	80%
3. Smart Governance	60%
4. Smart Mobility	64%
5. Smart Environment	60%
6. Smart Living	10%

Fig. 2 graphically illustrates the spiral result of the maturity levels evaluated, obtained from the case study of the result of Table 5. This representation is ideal to verify the expansion or retraction of each of the domains through their indicators. It is possible to see each of the domains as well as the percentage related to their degree of maturity.

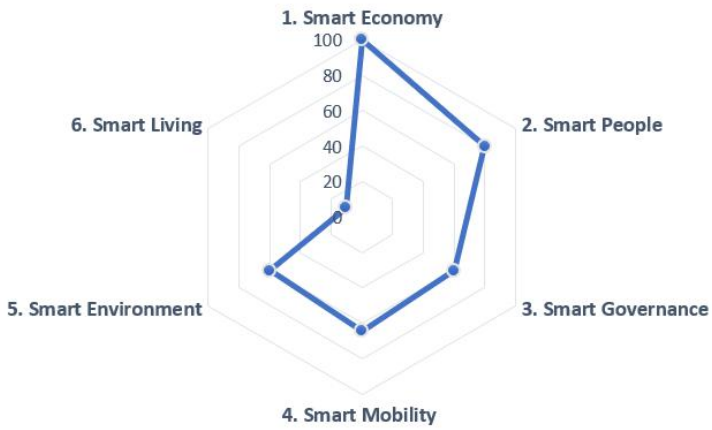

Fig 2: Maturity Analysis

Each domain, in turn, has a unique set of indicators. The calculations follow the methodology of [21]. However, in the present work, CMMI was used to measure the maturity level.

The hypothetical city, taken as a case study, illustrated in Fig. 2, obtained the result of 53% of maturity level; in this way, it is possible to associate the result found with the maturity degrees of CMMI. In the case in question, the city is at level 3; defined, since it is within the range of 50-60%, as it is possible to verify in Table 2.

After identifying the stage of the city, it is internally verified, with the management of the city, the next stage to be achieved and which competencies should be acquired in this process. This phase is important because it allows achieving success and, consequently, improvement in the quality of services [19].

V. CONCLUSION

The present study proposes a new *framework* to evaluate the degree of maturity of an Intelligent City, called *Sustainability Maturity Model* (SMM).

Several authors developed maturity models and alerted to the importance of investment in the development of a standard model and the importance of standardization of indicators that serve as a reference for the analysis of Smart Cities.

SMM development for smart cities maturity evaluation was based on ISO 37122 and inspired by the CMMI maturity model, as well as making use of COBIT processes.

From the application of SMM steps in a hypothetical city, it was possible to identify that the city is at maturity level 3, thus allowing managers to take measures to reach higher levels, as well as the data collected can be used for comparison with other cities using SMM. The proposed *framework* is a useful tool for any city, regardless of its size, its type, its origins, and its characteristics, since it also allows the study of each domain separately.

According to the established objective and the proposed methodology, SMM proved to be an important instrument for the evaluation of an intelligent city. It is possible, based on the analysis of its domains and indicators, to identify the level of maturity of the city to be analyzed.

With the absence of a diagnosis, actions can become disoriented, poorly prioritized, redundant, and not deliver the expected return. In this way, the application of SMM makes it possible to verify the diagnosis by domains, thus observing in which aspect the city undergoing study stands out, as well as its imbalances.

It is proven that the proposed objectives have been achieved and the results can serve as a basis for applying new assessments and evolution measurement of smart cities.

As future work prospects, we intend to use artificial intelligence techniques to consolidate the General Conformity Index.

ACKNOWLEDGEMENTS

[1]Santana thanks FAPESB (Foundation of Support to Research of the State of Bahia) (Grant BOL0691/2018).

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