Smart Cities Evaluations through SMM Framework - Sustainability Maturity Model

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Abstract

The insertion of Communication and Information Technologies (ICT's) in the scope of city management can facilitate managers' decision making, thus creating improvements in the infrastructure and services offered to citizens and can serve as a subsidy to the creation of Intelligent Cities. To assess the level of maturity of an intelligent city, this article aims to propose and apply a new framework, because most of the models used do not follow a standard and/or are not able to be compared with each other. Named SMM - Sustainability Maturity Model, it was inspired by the CMMI maturity indexes, the COBIT process controls, and used ISO 37122 indicators, thus serving as statistical measurement of ISO indicators, adapted to the CMMI maturity model and COBIT best management practices. In this way, the stages of the framework were developed, and a case study was conducted in the cities of São Paulo, Rio de Janeiro, and Salvador to validate it. As a result, it was observed that the SMM allowed classifying the cities by their level of maturity. Such measurement and comparison of maturity level were considered for the Intelligent Economy Domain of 3 of the 4 largest Brazilian cities in population. This evaluation adds value to the city that wishes to become intelligent, thus being able to serve as a basis for the application of new evaluations and measurement of the evolution of these environments.

Keywords— Smart Cities, SMM, Maturity, ISO 37122, CMMI, COBIT

1 Introduction

Definitions of Smart Cities may vary from one author to another. One of them states they are communities that seek to transform life and work effectively using Information Technology. Managers from various locations around the world claim that their cities are smart just because they have ICT-based initiatives, which is not correct (GIFFINGER et al., 2007).

With the emergence of the concept of smart cities, several indexes and indicators were created to measure the potential of cities, as well as neighborhoods and small towns, to develop maturity models to classify these locations. The term "smart city" is not used uniformly, ranging from cities with high ICT use to cities whose education or intelligence of their inhabitants is recognized (WEISS, 2016).

Smart cities can build innovative solutions for urban centers. They identify the priority characteristics of management by local government to find ways to increase the potential and solutions to the problems of the population (LEMOS, 2016).

These cities can use their resources, solving the demands of their inhabitants without wasting money, and with high creative potential. Thus, innovations in the management of municipal governments can be a differential in Public Administration intelligently and assertively, allowing to face problems faced by the population (WEISS, 2016).

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Several standards and/or models have been developed that 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 standardized metric to measure at what level of maturity cities intend to become smart (GAMA, ALVARO, and PEIXOTO, 2012).

In this sense, this research aims to verify the applicability of the Sustainability Maturity Model (SMM), developed by Santana et al. (2019).

The SMM model was developed to propose a framework to evaluate the degree of maturity of an Intelligent City. The maturity models that served as inspiration for the development of SMM were the Capability Maturity Model (CMMI), together with the management of COBIT, added to the ISO 37122 standards (SANTANA et al., 2019).

This research is justified by the attempt to evaluate the applicability of SMM in metropolises such as Salvador, Rio de Janeiro, and São Paulo, observing the degree of maturity and confronting it with what is disclosed by their respective managers. The relevance of this study rests in an attempt to contribute to filling the existing gap in a standardized evaluation of a Smart City.

This article is organized into five sections, being in this first one presented the objective of the work and its relevance. In the 2nd section, the theoretical reference is presented, giving theoretical support to the research. The 3rd section presents the methodological path used to achieve the proposed objective. In the 4th section, the analysis of the results found is presented. Finally, in the 5th and last section, the conclusion and/or final considerations are presented, as well as suggestions for future research.

2. Background

From the concept emergence of smart cities, several indexes, indicators, and measurement models were created to evaluate them (SANTANA; NUNES; SANTOS, 2018). Researchers proposed their models based on the indicators and/or domains they found most relevant for a smart city. Some of these models have levels that serve to measure, analyze, and graduate the level of intelligence of a city (SANTANA et al., 2019). The models found do not always apply in the same way to more than one location, since each region has its specific characteristics and these do not contemplate them in their entirety (JUNKES, 2016).

Faced with this context, there is a wide variety of classification indicators, as there are various perspectives on how cities can be classified, seen, and evaluated by different social actors. However, most of the models used do not follow a pattern and are not comparable over time and with each other (GUIMARÃES, 2018). To illustrate the gap existing in the evaluation of Smart Cities, Box 01 presents the models found in research and their respective limitations.

Model	Models' limitations
Giffinger et al. (2007)	First to be carried out with Smart Cities focused on medium-sized cities and stereotyped as ranking.
SCMM (Smart City Maturity Model)	The strength of this model is the gradual evolution and readiness of technology. Limited understanding of the model and its simplicity are pointed out as limitations.
BR-SCMM (Brazilian Model)	Applicable in a more interesting way to cities that are starting the development process to become smart. Limitation: the need for data, simplicity, and the fact that the model is still under development.
WCCD Certification Model	It is based on a universal standard (ISO), allowing comparison between cities already certified. The model's limitation is the complex and restricted data collection and the complexity of the analysis.
MMT Model (Technological Maturity)	As a strong point, it has a maturity scale of five levels. As a limitation, it is based on only three facts, being people, business, and technology; the model is still in development.
IDC Model(GOVER)	As a relevant point of this model is the gradual evolution between the five levels and, as a limitation, it is still in development.
SC4A Model (SMART CITY FOR ALL)	A positive point in this model is identified as the gradual five-level scale, the focus on accessibility and inclusion of information technology, and the fact that the model is still under development.
Modelo RCSC (Ranking Connected Smart City)	The strong point of this model is the existence of annual awards for cities that are positively evaluated by it, in addition to the gradual and quantitative analysis. As a limitation, we have complex evaluation and applicability.
Modelo ESC (European Smart Cities)	In this model, the positive point is the possibility of obtaining indicators on top of the 27 applicability domains, and as a limitation, its complex applicability, being able to make the comparison of up to three cities.

Modelo SCIP (Smart City Index Portugal)	Five positive points of this model stand out: the comparison of performance between municipalities; having five domains; using scale variation from 0 to 10; revealing the cities with the most inherent characteristics of a smart city and having a global comparative analysis. Limitation: the fact that it is still under development.
RBCIH Model (Brazilian Network of Intelligent and Human Cities)	This model is based on the possibility of exchanging experience between cities, this being a positive point, besides aiming to create a seal for classifying a smart city. As a limitation, it uses the indicators of ISO 37120, which are not suitable for smart cities.
NBR ISO 37120 Model	The standard has several strong points, highlighting the fact that it is an international standard that serves as a reference for standardization and normalization. As a negative point, this standard is not specifically designed for smart cities.
ISO 37122 Model (Indicators for Smart Cities)	ISO 37122 will help cities implement Smart Cities policies to provide better services to citizens.
WEISS Model (Readiness Assessment Model)	This model is focused exclusively on ICT perspectives. The fact that its applicability is complex stands out as a limitation.
IBMCCI Model	In the development of this model little would be added, since several authors have already formulated their classification and evaluation models.

Table 1: Smart City Assessment Models

3 Methods

Due to the need to establish a standard model to measure the level of intelligence for cities that have different characteristics and are at different points of maturity, Santana et al., (2019) proposed the SMM framework - Sustainability Maturity Model. According to the authors, SMM was inspired for its development by CMMI (PAULK, 1993), together with the management of COBIT (ISACA, 2012), added to the ISO 37122 standards (SANTANA; NUNES; SANTOS, 2018).

According to Paulk (1993), the CMMI model is a forerunner when it comes to maturity, linked to maturity levels and processes and thus serving as a reference for other models. The COBIT, developed by Information Systems Audit and Control Association (ISACA), has as main objective to generate value for the managerial processes of an organization (ISACA, 2012). ISO 37122 - Indicators for Smart Cities, is the first standard of the agency directed exclusively to Smart Cities. Cities adopting ISO 37122 will have standardized definitions and methodologies for a set of key performance indicators as tools to become more sustainable and smart. With ISO 37122, the indicators informed in the standard were used, which in total include 75, which are indicated for smart cities. ISO 37122 is divided into 19 thematic areas and uses 6 domains: Smart Economy, Smart People, Smart Governance, Smart Mobility, Smart Environment, and Smart Life (ISO, 2017).

The SMM Framework is composed of 5 stages, as can be seen in Figure 1. This way, it is necessary to collect data from the external environment, passing through the application of ISO 37122 through the Maturity Test, data analysis, identification of the maturity level of the city inspired by CMMI, until reaching the process analysis of the information obtained inspired by COBIT, and/or the archiving of the whole process in a database for further consultation, comparability, and knowledge of those interested. Each step will be described as follows.

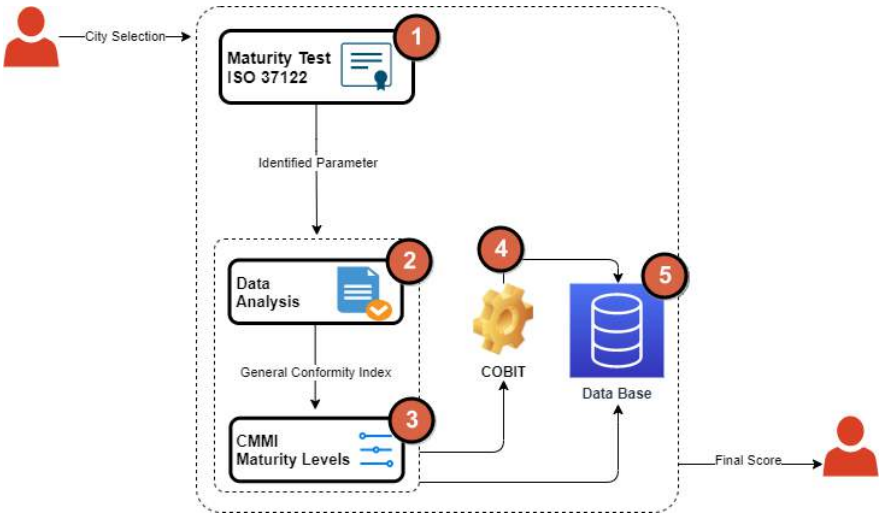

Figure 1: SMM - Sustainability Maturity Model Framing

Maturity Test:

Step 1 consists of applying the Maturity Test, formulated based on ISO 37122 and CMMI, and consisting of three steps: 1) choose the domains or subdomains to be evaluated; 2) calculate, based on ISO 37122, the indicators of the selected domains; 3) verify the scale of parameter evaluation of each indicator, developed from the level of the degree of maturity, based on the CMMI, in which it is possible to identify if the indicator was fully met (AT - Fully Met), partially met (AP - Partially Met), or not met (NA - Not Met).

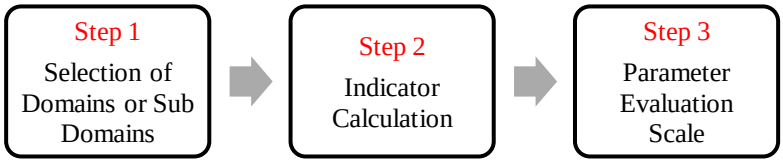

Figure 2: Step processes

Data Analysis:

The second step consists of the Data Analysis, supported by the equations proposed in Table 2. After selecting and obtaining the indexes of the domains, the components that will define the classification index of smart cities, one reaches a point of formulation of the SMM that implies an aggregation of the calculated indexes for each dimension, consisting of the analysis of data. For the validation phase, of the data complying with what is determined by ISO 37122 for the calculation of each indicator, the data collection strategy was used in the main open public data media, the data were collected from various databases made available by public bodies and organizations, municipalities of national industrial property institutes, regulatory agencies, national telecommunications agency, among others.

The indexes are extremely important tools for improving communication, as they seek to simplify the information on complex phenomena so that its understanding is clear to all types of audiences and thus can guide decision making.

Often the composition of the index can give different weights for its components, which can be questioned as subjectivity since depending on the weights assigned to each component, the result of the index can vary a lot.

1. General Compliance Index (ICG) - **Equation (1)**	
$$ICG = \frac{\sum_{k=1}^{p} ICD_k \times PD_k}{\sum_{k=1}^{p} PD_k}$$	The General Conformity Index (ICG) is the index that will indicate the level of maturity that the city is in the global aspect, since for its calculation it involves all indicators. It is the weighted average multiplying the ICD (Domain Compliance Index) by the PD (Domain Weight) divided by the sum of the PD, where k = 1, 2, 3 ... p where p is the total of Domains. Ranging from 0 to 100%, its formula is defined by equation (1).
2 - PD = DOMAIN WEIGHT - **Equation (2)**	
$$PD = \sum_{j=1}^{m} PSD_m$$	Where PD (Weight of Domains) is the sum of PSD (Weight of Sub-domains) represented by equation (2).
3. Domain Compliance Index (ICD) - **Equation (3)**	
$$ICD = \frac{\sum_{j=1}^{m} IMSD_j \times PSD_j}{\sum_{j=1}^{m} PSD_j}$$	The Domain Conformity Index (ICD) is the index that will indicate the level of maturity that the city is in the domain selected for analysis, for its calculation the indicators of the specific domain are selected. It is a weighted average which is calculated by multiplying the IMSD (Subdomain Maturity Index) by the PSD (Subdomain Weight) divided by the sum of the PSD having j = 1, 2, 3 ... m, being the total subdomains, varying 0 to 100% and its formula is defined by equation (3).
4. Sub-domain Maturity Index (IMSD) - **Equation (4)**	
$$IMSD = \frac{\sum_{i=1}^{n} EAP_i \times RI_i}{TTI \times EAP[TA]}$$	The Subdomain Maturity Index (IMSD) is the index that will indicate the level of maturity that the city is in the subdomain selected for analysis, for its calculation the indicators of the specific subdomain are selected. It is the sum of the product between the EAP and IR, where EAP is the Scale of the Parameter Evaluation (0 = NA (Not Answered), 1 = PA (Partly Answered) and 2 = TA (Fully Answered)) and IR is the Result

	of Indicators, divided by the TTI (Total ISO Indicators in the Subdomain) multiplied by the EAP [TA] (Fully Answered Scale of the Parameter Evaluation) having i = 1, 2, 3 ... n, being the total of indicators of each subdomain . Defined by equation (4).

Table 2: Equations developed for Step 2

Maturity Level Assessment:

Step 3 consists of directing the processes, making the result meet the needs and expectations of the areas through planning, and monitoring the results obtained in step 1. It is in this stage that it is possible, through the maturity levels inspired by CMMI, to evaluate at which level the city is, within a scale that varies from 1 to 5, according to Chart 3.

LEVEL	DETAILS
1- Initial (Not Reached) (0 to 15%)	At this level, the cities begin. This phase indicates that cities plan and shape the information systems they will use to integrate their smart solutions.
2- Managed (Partially Reached) (>15% to 50%)	At this level, cities are called efficient, seeking innovation and pioneering in information technology solutions, with a greater focus on supporting decision-making for both citizens and governments, through the use of data obtained in various fields.
3- Defined (Largely achieved) (>50 to 85%)	At this level, data are already collected and accessible to the population through properly functioning information systems, and cloud computing systems are used, integrated as services, and available to both citizens and third parties.
4- Quantitatively Managed (Fully Achieved) (> 85 to 100%)	At this level, cities are in 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 (Optimized) (100%)	At this level, cities are classified as perfected, with applied innovations and becoming pioneers in technological solutions.

Table 3: Level of maturity inspired by CMMI

Analysis of results and data storage:

The fourth stage consists in the analysis of the results obtained so far through the application of COBIT because after identifying the level of maturity that the city is, it is possible to have two paths: 1) the city is below level 5, in which case the COBIT processes should be used to analyze the points that need to be improved and perform an intervention; 2) the city is already at level 5: In this case, it is possible to jump to Stage 5, already for the data storage, or still go through Stage 4, where it will be possible to review the processes keeping the continuous improvement and still seeing in which points the city can still be optimized. Stage 5 consists of the data storage, through a database, also developed for this purpose.

4. Results and Discussions

The proposed framework, SMM, aims to suggest a standardization for measuring the level of intelligence of a city. The intention is that it should be a universal model, thus being able to be applied to any city with any characteristics. The indicators of each theme are classified among general indicators, which are considered essential for the analysis of the performance of smart cities.

In this case, it was held in three large Brazilian cities, Salvador, Rio de Janeiro, and São Paulo, based on publicly available data. The data used were obtained through electronic platforms such as municipal websites and IBGE, to validate the proposed framework. It is a cross-sectional study since it was carried out in a certain instant of time, applied based on data from the year 2018.

In this article, the Intelligent Economy Domain was selected to validate SMM because it refers to the economic situation and the actions taken by a country to increase its wealth or reduce poverty and development among the 6 main existing domains that contemplate economy, people, governance, mobility, environment, and quality of intelligent life, which are at the root of the formulation of any concept of smart cities, according to Giffinger et al.

The first calculated economy domain indicator refers to the percentage of local companies hired to provide municipal services that have openly available data communication, as data communication meaning the process of using computing and communication technologies to transfer data from one place to another and vice versa.

The second indicator aims to calculate the annual number of new startups per 100,000 inhabitants. The third indicator of the Economy sub-domain seeks to calculate the percentage of labor employed in the ICT sector. The fourth and final indicator of this sub-domain seeks to identify the percentage of the labor force employed in the Education and Research and Development sectors per capita per year.

For the Finance sub-domain, the first indicator to be calculated is the percentage of the municipal budget spent on innovations and smart city initiatives per year. Smart city innovations and initiatives are helping to pave the way for more livable and sustainable cities. The second index to be calculated from this sub-domain is the annual amount of tax charged from the sharing economy as a percentage of total tax charged. Finally, the third and final indicator of the Finance sub-domain is the percentage of payments to the city that are paid electronically based on electronic invoices.

In Table 4 it is possible to visualize the results obtained with the calculation of each index of the subdomains Economy and Finance, for each city analyzed (Salvador, Rio de Janeiro, and São Paulo).

CITIES	ECONOMY				FINANCE		
	1º sub	2º sub	3º sub	4º sub	1º sub	2º sub	3º sub
Salvador	4,77%	2,53%	4,51%	20,60%	7,75%	27,53%	21,25%
Rio de Janeiro	49,75%	8,38%	10,80%	21,00%	19,75%	26,78%	30,55%
São Paulo	62,76%	37,52%	36,80%	17,28%	30,00%	29,64%	37,62%

Table 4: *Results of Economy and Finance Subdomains.*

Once the selected Domain, Intelligent Economy, has been calculated, the third stage of the Maturity Test is started, which is to fill in the Parameter Evaluation Scale according to Table 5, where it is possible to identify if the indicator has been fully met (TA - Fully Met), being in the range of 85.1% - 100%, partially attended (PA - Partially attended), being in the range of 15.1% - 85%, or not attended (NA - Not attended), being in the range of 0 - 15%, which will subsidize the next stage of the SMM of the analysis of the weights of the domains.

Maturity Test Questions for the Smart Economy Domain	SALVADOR			RIO DE JANEIRO			SÃO PAULO		
	NA	PA	TA	NA	PA	TA	NA	PA	TA
	0	1	2	0	1	2	0	1	2
1 What percentage of local companies are hired to provide municipal services with openly available communication data?	X				X			X	
2 What is the annual number of new startups per 100,000 inhabitants?	X			X				X	
3 What is the percentage of the workforce employed in the Information and Communication Technology (ICT) sector?	X			X				X	
4 What is the percentage of the workforce employed in the Education, Research, and Development sectors?		X			X			X	
Total per Subdomain	**3**	**1**	**0**	**2**	**2**	**0**	**0**	**4**	**0**
5 What percentage of the municipal budget is spent on innovation and smart city initiatives per year?	X				X			X	
6 What is the annual amount of tax collected from the total collected?		X			X			X	
7 What percentage of payments to the city are paid electronically based on electronic invoices?		X			X			X	
Total per Subdomain	**1**	**2**	**0**	**0**	**3**	**0**	**0**	**3**	**0**

Table 5: *Scale result of parameter evaluation – Salvador, Rio de Janeiro e São Paulo*

After finishing Step 1, where the Maturity Test was performed in each Municipality, finding the Evaluation Parameters of each Indicator, the application of the proposed equations (1, 2, 3 and 4) is performed, thus identifying the ICD, IMSD - Economy, and IMSD - Finance indexes, according to Table 6.

INDEX	Salvador	Rio de Janeiro	São Paulo
ICD	29,20%	45,00%	47,50%
IMSD – Economy	12,50%	25,00%	48,50%

IMSD - Finanças	33,33%	47,00%	49,50%

Table 6: *Index Results*

In the Smart Economy Domain, regarding the city of Salvador, a Domain Compliance Index (DCI) was identified from equation (3), amounting to 29.20%, as shown in Table 6. A Maturity Index by Subdomain was also obtained from equation (4), with a value of 12.50% for the Subdomain Economy, while for the Subdomain Finance, the value was 33.33%. Since we are dealing with only one Domain, the General Compliance Index (GCI), equation (1), will not be calculated, which is relevant to be observed when analyzing all Domains together.

In the City of Rio de Janeiro, a Domain Compliance Index (DCI) was found from equation (3), in the value of 45%, as presented in Chart 6. A Maturity Index by Subdomain was also obtained from equation (4), worth 25% for the Subdomain Economy, while the Subdomain Finance was found to be 50%. As in the municipality of Salvador, since we are dealing with only one Domain, the General Compliance Index (GCI), equation (1), which is relevant to be observed when analyzing all Domains together, will not be calculated.

In the City of São Paulo, a Domain Compliance Index (DCI) was found from equation (3), in the value of 47.50%, as presented in Chart 6. A Maturity Index by Subdomain was also obtained from equation (4), with a value of 48.50% for the Subdomain Economy, while for the Subdomain Finance, with a value of 49.50%.

From the result, it was possible to identify the degree of maturity of each Domain and Sub-Domain for Salvador, Rio de Janeiro, and São Paulo. Table 7 shows the Maturity levels per Domain and Sub-Domain of each analyzed Municipality.

INDEX	**Maturity Level**					
	Salvador		**Rio de Janeiro**		**São Paulo**	
ICD	29,20%	2 - Managed	45,00%	2 – Managed	47,50%	2 - Managed
IMSD – Economy	12,50%	1 - Not Reached	25,00%	2 – Managed	48,50%	2 - Managed
IMSD - Finance	33,33%	2 - Managed	47,00%	2 – Managed	49,50%	2 - Managed

Table 7 – *Maturity Level*

Thus, it is possible to observe that the cities analyzed in this study are at a level that needs development in the chosen Domain. It is observed that both the city of Rio de Janeiro and São Paulo have ICD - equation (3) - and IMSD - equation (4) -, for Economy and Finance at the Managed Level, level 2, which corresponds to a percentage between >15% and 50%, being considered partially reached.

This is the stage where cities are called efficient, seeking innovation and pioneering in information technology solutions, with a greater focus on supporting decision-making for both citizens and governments, using data obtained in various fields.

In Salvador, the city also has ICD, equation (3), and IMSD- Finance, equation (4), in the Managed Level, but its IMSD - Economy, equation (4), is in level 1, Initial - Not Reached In this level 1 is the phase where the cities begin. This phase indicates that cities plan and shape the information systems they will use to integrate their intelligent solutions.

Thus, the manager must search from the Compliance Index (DCI) by Domain and the IMSD (Sub-domain Maturity Index) to verify what measures must be taken to reach level 5 of maturity, having the four domains as direction and maintenance. It is worth mentioning that the improvement of the domains can be evaluated individually or collectively to obtain the maximum level for the city. This phase is important because it allows achieving success and, consequently, improvement in the quality of services (BALBO; VENDRAMEL; TOLEDO, 2014).

With this analysis the actors can identify the strengths and weaknesses of the city for which they are responsible, thus facilitating the implementation of measures that improve performance or even serve as a reference and inspiration for other cities that want to become smart if they are at an "In Optimization" level. Thus, with the result of the Test, it is analyzed in which degree of maturity the city is based on the 5 levels of maturity.

5. Final Considerations

This article proposed the development of the SMM framework for smart city maturity analysis, based on ISO 37122 and inspired by the CMMI maturity model, as well as using COBIT processes. From the application of SMM stages in the cities of Salvador, Rio de Janeiro, and São Paulo, it was possible to identify that the economic domain of the cities is at the initial level of maturity, thus allowing managers to analyze and take measures to reach higher levels, as well as the data that were collected, serving for comparability with other cities that use SMM. The proposed framework is a useful tool for any city, regardless of its size, type, origins, and characteristics, since it also allows the study of each domain separately and, over time, the monitoring of its evolution. According to the

established objective and proposal, SMM has proved to be a relevant tool for the analysis and evaluation of a smart city, being possible, from its domains and indicators, to identify the level of maturity of the city to be analyzed. In the absence of a diagnosis, the actions may become disoriented, poorly prioritized, and redundant, not offering the expected return. Thus, the application of SMM makes it possible to verify the diagnosis by domains, thus observing in which aspect the city under study stood out, as well as its lags.

It is observed that the proposed objectives have been achieved and the results show that the model can serve as a basis for application in the evaluation and measurement of smart cities. As contributions of future work, it is suggested the insertion of new modules to the SMM framework, as well as the use of artificial intelligence techniques to consolidate the General Compliance Index and its application in other municipalities.

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