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STREET LIGHTING MAINTENANCE: PROPOSAL FOR A CONSTRUCTIVIST PERFORMANCE EVALUATION MODEL

MANUTENÇÃO DA ILUMINAÇÃO PÚBLICA: PROPOSTA DE UM MODELO CONSTRUTIVISTA DE AVALIAÇÃO DE DESEMPENHO

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Abstract

The complexity in the provision of street lighting maintenance services, which is essential for residents, and the need to guarantee the transparency of actions make it essential to use tools to evaluate performance and support its management. Thus, the objective of this study is to develop a constructivist model of multicriteria performance evaluation to support the management of the activity of maintenance of street lighting in Joinville, based on the "Transportation and Public Roads" manager own perception. For that, the Multicriteria Methodology to Support Constructivist Decision (MCDA-C) was used, with the development of its three phases: Structuring, Evaluation and Recommendations. An evaluation model with 11 indicators was built, which made it possible to highlight the status quo of the street lighting maintenance in Joinville, which was 31.7, considered by the decision-maker at the market level. In the Recommendations phase, actions were proposed to leverage the performance of the activity in those criteria in which the performance was identified at a compromising level, contributing to a relevant increase, going to 70.3. The development of a legitimate and valid graphic performance evaluation model, composed of indicators that have not been explored in the literature on the subject until then, due to the recognition of the need to incorporate the uniqueness and ad hoc characteristics of the context based on the manager's perception, it allowed him to make informed, timely and effective decisions, starting to actively contribute to the entire municipal management.

Keywords: Performance Evaluation. Street Lighting. Municipal Management. Decision Support. Constructivist Approach. MCDA-C Methodology.

Resumo

A complexidade na prestação dos serviços de manutenção da iluminação pública, fundamental para os munícipes, e a necessidade da garantia de transparência das ações tornam imprescindíveis a utilização de ferramentas para avaliar o desempenho e apoiar sua gestão. Assim, o objetivo deste

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estudo é desenvolver um modelo construtivista de avaliação de desempenho multicritério para apoiar a gestão da atividade de manutenção da iluminação pública do município de Joinville, com base na própria percepção do gerente de "Transportes e Vias Públicas". Para isso, utilizou-se a metodologia Multicritério de Apoio à Decisão-Construtivista (MCDA-C), com o desenvolvimento de suas três fases: Estruturação, Avaliação e Recomendações. Foi construído um modelo de avaliação com 11 indicadores, que permitiu evidenciar o statu quo da manutenção da iluminação pública em Joinville, que era de 31,7, considerado pelo decisor em nível de mercado. Na fase de Recomendações, foram propostas ações para alavancagem do desempenho da atividade naqueles critérios em que a performance foi identificada em nível comprometedor, contribuindo para um relevante incremento, passando para 70,3. O desenvolvimento do modelo gráfico de avaliação de desempenho, legítimo e válido, composto por indicadores pouco explorados na literatura sobre o tema até então, devido ao reconhecimento da necessidade de incorporação da singularidade e das características ad hoc do contexto com base na percepção do gerente, permitiu-lhe tomar decisões fundamentadas, tempestivas e efetivas, passando a contribuir ativamente com toda a gestão municipal.

Palavras-chave: Avaliação de Desempenho. Iluminação Pública. Gestão Municipal. Apoio à Decisão. Abordagem Construtivista. Metodologia MCDA-C.

Introduction

Street lighting is an integral part of the municipal environment and plays an important role in society, contributing to the health and well-being of the population and influencing the observers' emotions (LECCESE; SALVADORI; ROCCA, 2017). Likewise, the maintenance and efficient functioning of street lighting is fundamental for the safety of people by inhibiting criminal practices, as well as for the safety and assistance in night traffic (MIRZAEI et al., 2015; GUTIERREZ-ESCOLAR et al., 2015).

In recent years, transparency in budgets and principles of effectiveness, efficiency and sustainability have become fundamental pillars on which public management should be based (BENITO; GUILLAMÓN; MARTÍNEZ-CORDOBA, 2020). This new premise is opposed to previous experiences that citizens were used to face, since the response of public authorities was too slow, and the control and transparency of public spending were non-existent (YU; WANG; SHEN, 2010). In this context, the provision of street lighting maintenance, when neglected, can bring extremely unfavorable consequences, as it is the case of a lighting pole remaining out of operation for long periods. The safety of the population, in this case, is impaired and the actions of vandalism are more likely to occur (YU; WANG; SHEN, 2010). Otherwise, a quick maintenance response tends to have a positive impact. Thus, in addition to citizens' satisfaction with a timely provision of services, the good performance of the public lighting system can be valuable for public administrations themselves (MIRZAEI et al., 2015).

Prado-Lorenzo and García-Sanchez (2007) state that, because municipal public services adopt different forms of management, the relevance of their assessment increases. In addition, in the view of Mirzaei et al. (2015), the structure in the provision of public lighting services, including maintenance, although it can be rearranged in different ways, is configured in three main spheres: regulation, which can be assumed by ministries and regulatory agencies and is responsible for general policies and guidelines; the management that, bringing to the Brazilian reality, is done by the municipalities themselves, which inspect and direct the local activities; and, finally, the operation and provision of the service, which can be carried out by contractors.

Given the complexity in the provision of street lighting maintenance services, their importance to society (DOULOS et al., 2019; MURRAY; FENG, 2016) and the need to guarantee transparency of actions, the performance of this activity should be evaluated so that it can be improved and monitored by all involved (THIEL; ENSSLIN; ENSSLIN, 2017). Therefore, the research question of the present work emerges: What are the criteria / indicators to be considered for the street lighting maintenance performance evaluation, in order to conduct the decision-maker's activities and, still, expand his knowledge about the context? To answer the proposed question, the general objective of this work is to develop a constructivist model for evaluating multicriteria

performance to support the street lighting maintenance management in the city of Joinville, according to the manager's perception.

In order to meet the objective, the intervention instrument selected by the authors was the Multicriteria methodology for Constructivist Decision Support (MCDA-C), due to its constructivist characteristic, which allows the streer lighting manager, in the case of Joinville is the "Transportation and Public Roads" manager, promoting a solid knowledge of the street lighting maintenance; structure and evaluate the dimensions considered relevant, implying more reliable results; and understand the impacts of the made decisions, observing improvement actions.

The importance of this work lies in the fact that street lighting is an indispensable service to the population, influencing the safety and well-being of society (MIRZAEI et al., 2015; YU; WANG; SHEN, 2010; GUTIERREZ-ESCOLAR et al. , 2015). Thus, the poor performance of maintenance is, of course, noticed by the population, since the failure in the service directly implies its dissatisfaction. The originality is due to the fact that no studies have been found in the literature that build a multicriteria constructivist model for performance evaluation of the public lighting maintenance activity (THIEL; ENSSLIN; ENSSLIN, 2017). Finally, the study is feasible due to the manager's interest of the municipality of Joinville in the construction of a performance evaluation model, which will allow him to make solid decisions, converging to the strategic objectives of the municipal administration and guaranteeing transparency of actions. In addition, management that guarantees the fulfillment of the main functions of public lighting, namely protecting people and goods, promoting better quality of life and safety, contributing to social and economic development and preventing crime, adds significant value to the urban environment, fostering economic activity and contributing to regional development (SALVIA et al., 2019).

Theoretical Framework

Street lighting is a municipal and essential service for all cities. Some characteristics, such as the inability to identify resident and non-resident users; the unavailability of the option of providing the service, since street lighting reaches all users; and the effects on the public budget, arouse great interest from public managers in improving their management (PRADO-LORENZO; GARCÍA-SANCHEZ, 2007). Maintenance, which is one of the main concerns for public managers, directly reflects the performance of the municipal administration, making it essential to have its quality managed (YU; WANG; SHEN, 2010).

The evaluation of street lighting performance can be classified, based on the literature, into three evaluation focuses: the first is the provision of the service that is concerned with evaluating, through indicators, the public lighting performance in several regions (BENITO; GUILLAMÓN; MARTÍNEZ-CÓRDOBA, 2020; IGHRAVWE et al., 2020; MIRZAEI et al., 2020; THIEL; ENSSLIN; ENSSLIN, 2017; MIRZAEI et al., 2015; YU; WANG; SHEN, 2010; PRADO-LORENZO ; GARCÍA-SANCHEZ, 2007); the second evaluation focus is energy efficiency, whose indicators are basically focused on energy consumption and photometric characteristics of the facilities (CARLI; DOTOLI; PELLEGRINO, 2018; DOULOS et al., 2019; LECCESE; SALVADORI; ROCCA, 2017; SALVIA et al., 2019; GUTIERREZ-ESCOLAR et al., 2015; CARLI; DOTOLI; PELLEGRINO, 2015; PRELOVŠEK; BIZJAK; KOBAV, 2012); and the third focus is on planning and allocating resources, which do not directly build indicators, but study ways to plan lighting to optimize the performance of their facilities (MURRAY; FENG, 2015; SHEFER; STROUMSA, 1982; SHEFER; STROUMSA, 1981; BOLINGER et al, 1978).

In addition to the evaluation focus, the selected literature was classified from the perspective of other groups, detailed in Table 1, in order to enable an understanding of how previous studies are related to each other. The first information brought refers to the article proposal; the indicators and/or criteria proposed in each of the studies are also presented; and, finally, in relation to the scope of the study field, which qualifies it in place, for a single municipality, or regional, for more than one municipality. Despite the important contributions of studies focused on assessing energy efficiency and planning and allocating resources, proposals related to the service provision will be analyzed in detail, as they are in line with the objective of this study, not only for the survey of the built indicators, but also to understand the proposed evaluation mechanisms.

Benito, Guillamón and Martínez-Córdoba (2020) apply the Data Envelopment Analysis (DEA) tool to calculate the efficiency of street lighting, in order to verify the factors that affect these efficiency levels in Spanish municipalities - based on a set of variables (population density, hours of sunlight, urbanized area, tourism index, income level, ideology and political strength and type of

management) - and which configuration in the service provision is the most proper one. Prado-Lorenzo and García-Sanchez (2007) also study the efficiency of municipal governments in the provision of public lighting services, using Data Envelopment Analysis (DEA) tool, mainly through the form of its management: whether public or private.

Ighravwe *et al.* (2020) propose a framework that assesses maintenance strategies for photovoltaic equipment for street lighting through the application of Fuzzy and TOPSIS logic. It was observed that the 'risk-based' maintenance strategy is the least appropriate; and the 'condition-based' strategy is the most appropriate. Mirzaei *et al.* (2015) present a method based on the normal distribution function to estimate the failure rate of lamps, anticipating the need to maintain street lighting. The study makes it possible to indicate the best product available on the market and the costs associated with operating the system. Continuing the study, Mirzaei et al. (2020) investigate the challenges in the areas of Human Resources management, cost estimation, price assignment and schedule for hiring a private service provider. The purpose is to determine the ideal contract price and duration.

Yu, Wang and Shen (2010) evaluate the quality in the provision of maintenance services through surveys aimed at citizens. In the authors' view, as citizens are satisfied with the provision of services, their interaction and support also improve. Finally, Thiel, Ensslin and Ensslin (2017) conducted a literature review in the area of performance evaluation of street lighting, pointing out several research opportunities and challenges for managers in the area. As a main research gap, it was identified that the literature did not present a structured model of performance evaluation that would support the manager in decision making.

Table 1: Literature Analysis for public lighting performance evaluation

ID	Reference	Article proposal	Evaluatiuon focus	Indicators/proposed criteria	Scope of the study field
1	Benito, Guillamón and Martínez-Córdoba (2020)	Efficiency in service provision	Service provision	Population density, daytime hours, nighttime hours, urbanized area, tourism index, income level, ideology and political strength, type of management (public / private / mixed)	Regional - 1,547 municipalities in Spain
2	Carli, Dotoli and Pellegrino (2017)	Equipment retrofit plan	Energy efficiency	Annual energy consumption, light pollution, color rendering index	Location - Bari (Italy)
3	Doulos et al. (2019)	Energy efficiency proposal	Energy efficiency	Luminaire power, distance between poles, angle of luminaires, color temperature, dimming	Location - Greek Highway
4	Ighravwe et al. (2020)	Photovoltaic energy maintenance strategies for street lighting	Service provision	Labor, vandalism, stakeholder support, material quality, frequency of accidents, failure rate, cost, climatic challenges, quality of urban planning, equipment availability, information available for maintenance, expected quality, credibility of information	Location - Communities in Nigeria
5	Leccese, Salvadori and Rocca (2017)	Critical analysis of energy and lighting performance indicators	Energy efficiency	Power density, annual energy consumption, luminaire energy efficiency, illuminance, luminance	Location - Pisa (Italy)
6	Mirzaei et al. (2020)	Answer questions about the management and operation of public lighting services	Service provision	Lamp failure rate	Location - Isfahan (Iran)
7	Murray and Feng (2015)	Framework for evaluating and planning public lighting based on location modeling	Resource planning / allocation	Not applicable	Location – San Diego (USA)
8	Salvia et al. (2019)	Choosing the best option for energy efficiency of public lighting based on best practices worldwide	Energy efficiency	Average monthly energy consumption (kWh / pole), number of lighting poles per capita (poles / inhabitant), % of LED luminaires	Regional – Passo Fundo, Porto Alegre, Santa Maria, Brasil
9	Thiel, Ensslin and Ensslin (2017)	Literature review looking for research gaps and challenges for managers in street lighting performance evaluation	Service provision	Not applicable	Not applicable

10	Mirzaei et al. (2015)	Method for analyzing the annual failure rate of lamps	Service provision	Lamp failure rate	Location – Isfahan (Iran)
11	Gutierrez-Escolar et al. (2015)	Propose a method to analyze points in regulations that have not been considered, from the point of view of energy efficiency	Energy efficiency	Not applicable	Regional - Spain
12	Carli, Dotoli and Pellegrino (2015)	Equipment retrofit plan	Energy efficiency	Annual energy consumption, light pollution, color rendering index	Location - Bari (Italy)
13	Prelovšek, Bizjak and Kobav (2012)	Present energy consumption data of public lighting	Energy efficiency	Average luminaire power, consumption per inhabitant, consumption per km of highway	Regional - Slovenia
14	Yu, Wang and Shen (2010)	Present public surveys on public lighting performance	Service provision	Consumer satisfaction	Regional – Taiwan
15	Pedro-Lorenzo and García-Sánchez (2007)	Analyze the efficiency of service provision and public lighting	Service provision	Total energy consumption, total cost, illuminated area, daytime hours, nighttime hours, time the lighting point remained off, number of vandalism actions	Regional - 24 cities in Spain
16	Shefer and Stroumsa (1982)	To present a systematic, rational and politically viable method for allocating resources for public lighting	Resource planning / allocation	Not applicable	Location - Jerusalem (Israel)
17	Shefer and Stroumsa (1981)	Present a decision-making tool in planning public lighting	Resource planning / allocation	Not applicable	Location - Jerusalem (Israel)
18	Bolinger et al. (1978)	Determine a method for solving engineering problems in public lighting	Resource planning / allocation	Not applicable	Not applicable

Research Methodology

This research is classified as exploratory (RICHARDSON, 2008), as it aims to generate knowledge about the study environment, that is, the Transportation and Public Roads Sector, in the municipality of Joinville, based on the manager's perception. The approach to the problem is qualitative and quantitative (RICHARDSON, 2008). The qualitative approach is present in the Structuring Phase, as it is necessary to know the context of the Transportation and Public Roads sector in the municipality of Joinville, in order to be able to identify the objectives and build their respective ordinal scales by which performance will be measured and managed; and in the Recommendations Phase, in which actions for improvement are suggested in order to improve the service provision performance. The quantitative approach, on the other hand, occurs when ordinal scales are transformed into cardinal ones, the construction of the compensation rates, the determination of the model equation and the measurement of the overall performance of the decision context, developed in the Model Evaluation Phase.

Regarding data collection, only primary data were considered (RICHARDSON, 2008), that is, those obtained with semi-structured interviews with the manager, which subsidized the model building. Finally, the technical procedure adopted is the case study (RICHARDSON, 2008; YIN, 2015), as this work aims to build a personalized model for management of public lighting maintenance activities, in the municipality of Joinville.

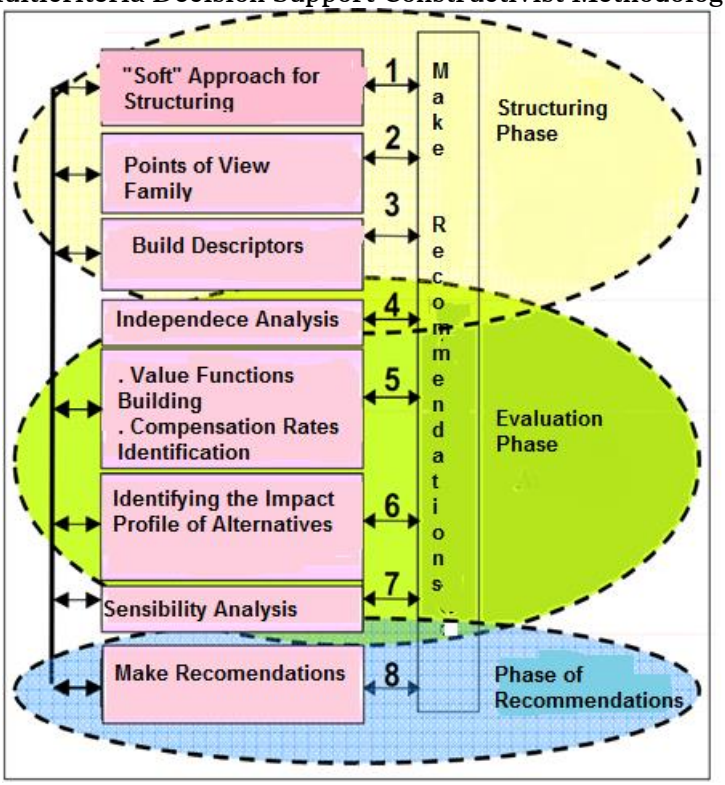
For the composition of the studies that supported the theoretical framework of this research, the Knowledge Development Process-Constructivist (ProKnow-C) (PEDERSINI; ENSSLIN, 2020; THIEL; ENSSLIN; ENSSLIN, 2017; ENSSLIN et al., 2017; MATOS; ENSSLIN; ENSSLIN, 2019) was used. The choice for this instrument was motivated by the fact that it is a structured process for the development of a systematic literature review, which guides the selection and review in a critical way and which leads to the generation of knowledge about a given theme, based on the delimitations made by the researchers (CALDATTO; BORTOLUZZI; DE LIMA, 2020; VALMORBIDA; ENSSLIN, 2016; DUTRA *et al.*, 2015; MATOS et al., 2019). To achieve this purpose, ProKnow-C presents the operationalization of its four stages: (i) Selection of the Bibliographic Portfolio (PB); (ii) Bibliometric Analysis; (iii) Systemic Analysis; and (iv) Definition of the research questions and objectives

(VALMORBIDA; ENSSLIN, 2016; ENSSLIN et al., 2013; STAEDELE; ENSSLIN; FORCELLINI, 2019).

In this work, only step (i) Selection of the Bibliographic Portfolio was developed, since the objective is to select articles aligned with the sought literature fragment: Performance Evaluation in the Street Lighting Maintenance. Based on the development of the selection sub-steps of the raw article database, filtering of the article database and the representativeness test, 18 articles were identified that supported the theoretical framework writing of this investigation.

The building of performance evaluation model for street lighting maintenance in the municipality of Joinville follows the Multicriteria Methodology for Supporting the Constructivist Decision (MCDA-C), proposed by Ensslin, Dutra and Ensslin (2000), which is configured in the execution of these three phases (Figure 1): Structuring, Evaluation and Recommendations.

Figure 1: Phases of Multicriteria Decision Support Constructivist Methodology (MCDA-C)



Source: Adapted from Ensslin, Dutra and Ensslin (2000, p. 81)

Structuring Phase consists of promoting understanding about the context in which it is inserted, identifying, characterizing and organizing the factors considered relevant to the decision support process. The operationalization of this phase occurs in a dynamic and interactive way, stimulating the debate in the learning process. In order to achieve learning in the Structuring Phase, it is done in stages. The first stage consists in the Soft Approach for Structuring and aims to (i) contextualize and build understanding about the problem to be treated; (ii) determine the problem label; and (iii) make the actors involved explicit (CALDATTO; BORTOLUZZI; DE LIMA, 2020; DE AZEVEDO et al., 2012; TASCA; ENSSLIN; ENSSLIN, 2012). In the Point of View Families stage, through the interpretation of the interviews, the facilitator identifies what are the Primary Evaluation Elements (PEEs), that is, what are the decision maker's initial concerns. Then, PEEs are transformed into concepts that represent two pieces of information: the decision maker's preferential direction regarding their concerns; and its psychological pole. By notation, the positive and psychological poles of each concept are separated by (...), which are read as 'instead of'. The decision maker is subsequently encouraged to group the concepts in different areas of concern (DE AZEVEDO et al., 2012; ENSSLIN et al., 2020a, b; TASCA; ENSSLIN; ENSSLIN, 2012). After grouping, in the Construction of Descriptors stage, the cognitive maps of each area of concern are initially constructed and clusters identified (TASCA; ENSSLIN; ENSSLIN, 2012). Each cluster is represented by a Fundamental Point of View (FPV) (strategic objective). The set of FPVs gives rise to the Hierarchical Value Structure. As FPVs are not directly measurable, they are broken down into

explanatory levels up to a level that can be measured (called Elementary Point of View - EPV). Thus, for each EPV, an ordinal scale is constructed with the possible levels of performance occurrence, and in them the decision maker establishes which level is considered good or neutral (reference levels) (ENSSLIN et al., 2020b). These reference levels determine three performance ranges: excellence level, above the good level; market level, between the good and neutral level; and compromising level, below the neutral level (ENSSLIN; DUTRA; ENSSLIN, 2000; TASCA; ENSSLIN; ENSSLIN, 2012; ENSSLIN et al., 2013). These ordinal scales are referred to in MCDA-C methodology as Descriptors.

In the Evaluation Phase, the knowledge acquired in the Structuring Phase, qualitatively, is transformed into quantitative (ENSSLIN *et al.*, 2020a; MARAFON *et al*., 2015). In the Construction of Value Functions step, ordinal scales are transformed into cardinal ones. To this end, the decision maker is asked about the difference in attractiveness of moving from one level of the ordinal scale to another level, according to his perception. To translate the decision maker's perception of attractiveness levels into mathematical values, MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) method (LONGARAY et al., 2019; DELLA BRUNA; ENSSLIN; ENSSLIN, 2014) was used. Note that, in this transformation, the value '0' (zero) is assigned to the neutral level, and the value '100' (one hundred) to the Good level, in all cardinal scales. It should be noted that, at that moment, there is a criterion (indicator). Then, the step Identifying the compensation rates consists of identifying the relative importance of each criterion in the general model, in order to be able to carry out the global evaluation. For this, the decision maker is asked to order, according to his preference, the perception of passing each of the Points of View, from a neutral level to a good level. Then, the data is inserted in the MACBETH software, and the decision maker is asked to compare the hierarchical information pairwise, resulting in the obtainment of compensation rates. To conclude Evaluation Phase, it is also necessary to Identify the impact profile of the alternatives, based on the global equation, made possible by the sum of the partial values of each criterion, weighted by the compensation rates (ENSSLIN et al., 2020b; TASCA; ENSSLIN; ENSSLIN, 2012). Finally, in the Sensitivity Analysis, the responses of the performance levels are verified through possible changes in the compensation rates, which guarantees the model robustness (LONGARAY et al., 2018; DE MORAES et al., 2010).

At the end of Evaluation Phase, Recommendations Phase is continued, whose main objective is to create possible improvement actions, indicating the probable global impact on the final evaluation and, therefore, understanding its consequences on the FPVs (strategic objectives). As it is a constructivist vision, it is not the intention of the model to prescribe an action guide, but rather to support the decision maker in the development and analysis of possible alternatives and to understand its consequences, highlighting which points of view and / or criteria deserve attention (MARAFON et al., 2015).

Results: Model Building

Structuring Phase

In the municipality of Joinville, the responsibility for Street Lighting Management, previously assumed by the Electric Company, was transferred to the municipality in 2003, even though this obligation in Brazil was formalized by the National Electric Energy Agency (ANEEL) only in 2010. The current city panorama points to an approximate number of 55,000 lighting poles (JOINVILLE, 2014), and annual operating costs and electricity estimated at R$ 30 million (JOINVILLE, 2020). Given the breadth of the study environment, it was decided to highlight, at that moment, the model building for the maintenance of public lighting, as it is the most verified and monitored by society. Thus, together with the decision maker, the following label for the model was defined: Performance evaluation model to support the maintenance of street lighting, and the following actors (Table 2):

Table 2: Context Actors

Stakeholders	Decision maker	Manager of Transportation and Public Roads Sector, in the municipality of Joinville
	Interveners	Supervisor Electrical Engineers Municipal Secretary of Urban Infrastructure Mayor
Facilitator		Research authors
Acted		Other servers of the Transportation and Public Roads Sector Company contracted to operate the Street Lighting System Bodies responsible for public security Society

Source: Research data (2020)

Afterwards, the decision-maker starts to expose the concerns that influence the activity performance. These concerns, interpreted by the facilitator, give rise to PEEs, which subsequently supported the construction of the concepts shown in Table 3.

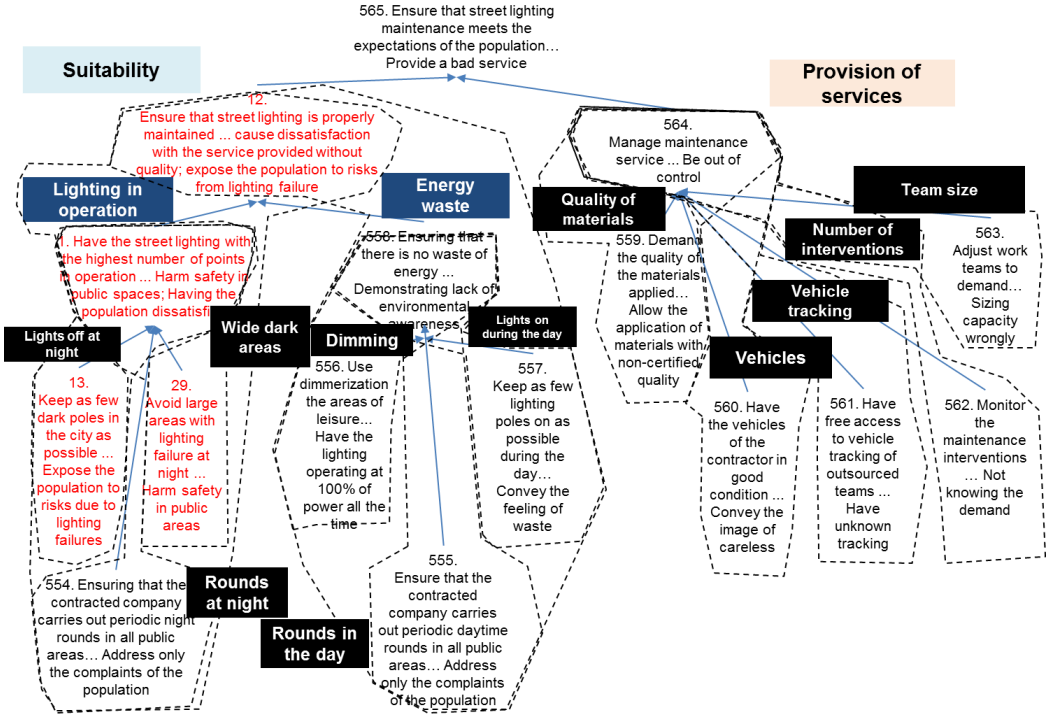
Table 3: PEEs and Respective Constructed Concepts

PEEs	Concepts
Maintenance	1 - Have the street lighting system with the highest number of points in operation ... Harm security in public spaces; have the population dissatisfied.
Properly maintained public lighting park	12 - Ensure that the lighting system is properly maintained ... Cause dissatisfaction with a service without quality; expose the population to risks from lighting failure.
Number of dark spots	13 - Keep as few dark poles in the city as possible ... Expose the population to risks due to lighting failure.
Large areas without lighting	29 - Avoid wide areas with lighting failure at night ... Impair the safety in the streets.

Source: Research data (2020)

Then, the concepts were organized into a Cognitive Map.

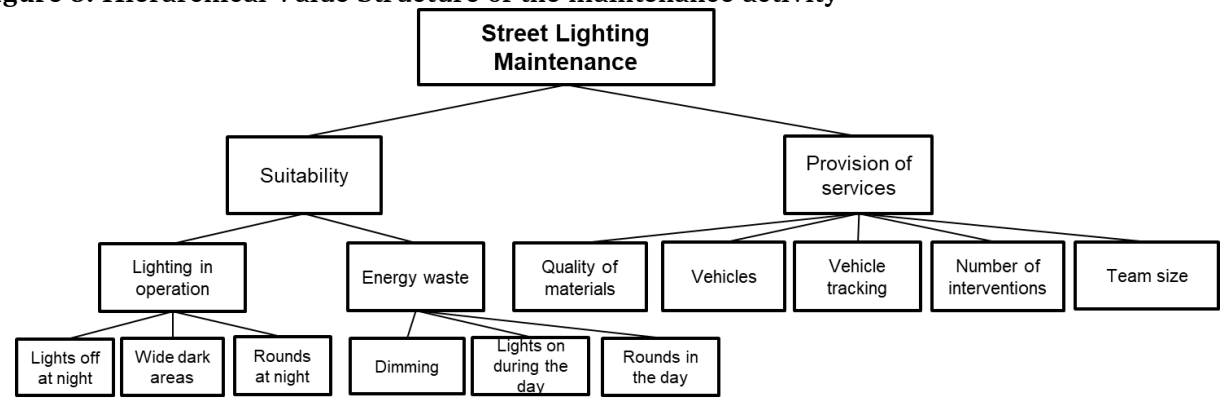
Figure 2: Cognitive Map with clusters and subclusters



Source: Research data (2020)

In this stage, new concepts perceived by the manager as essential in the context were inserted, the original concepts being highlighted in red, as shown in Figure 2. In the analysis of the Cognitive Map, the concepts are grouped into Clusters and Subclusters that, later, are associated with a name (Fundamental Point of View - FPV; and Elementary Point of View - EPV) that represents the focus of the manager's interest. FPVs and EPVs are migrated to the Hierarchical Value Structure (HVS), as shown in Figure 3. With HVS, the facilitator and the manager built ordinal scales (descriptors) for each EPV. Then, the manager identified the good and neutral levels of each of the descriptors.

Figure 3: Hierarchical Value Structure of the maintenance activity



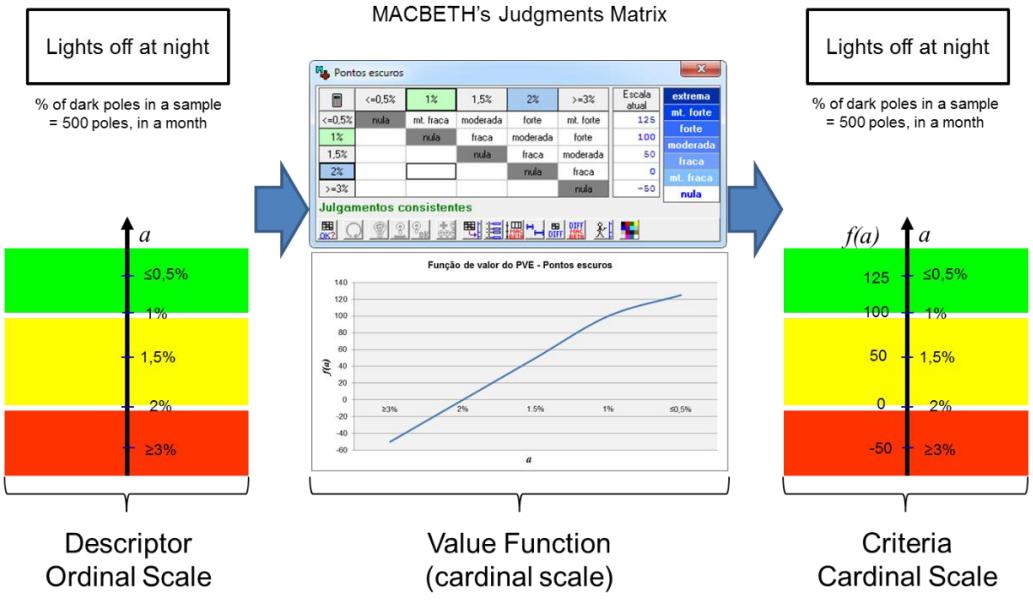
Source: Research data (2020).

Figure 3 shows the 11 built descriptors (on the right side of each scale), with the anchoring respective levels (good and neutral) and status quo of the maintenance activity of public lighting, according to the manager's statement.

Evaluation Phase

The first stage of Evaluation Phase consists of transforming ordinal scales into cardinal ones. To this end, the difference in attractiveness between the levels of the descriptors was identified, through the manager's judgment. With the aid of MACBETH Software, the transformation procedure was carried out for the 11 descriptors. As an example, the procedure applied to the descriptor 'Lights off at night' is shown in Figure 4.

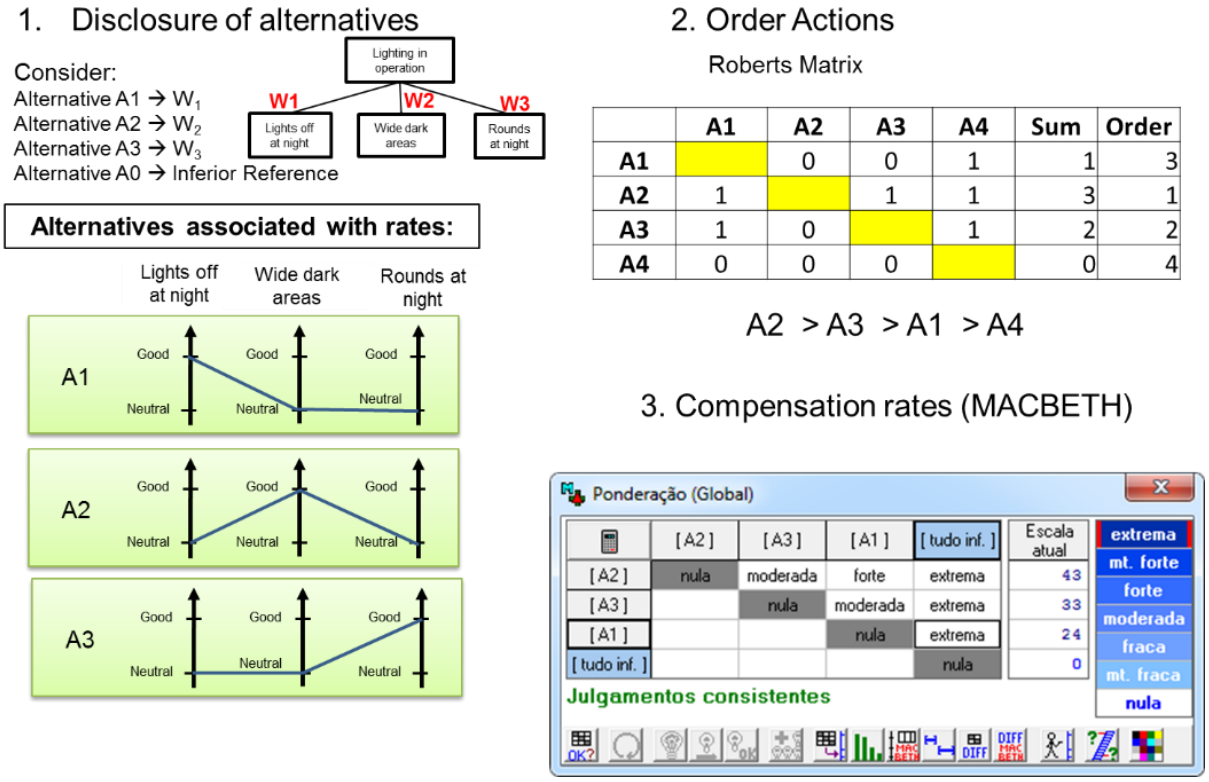
Figure 4: Construction of the Value Function for EPV – Lights off at night



Source: Research data (2020).

After defining the cardinal scales of all criteria, Compensation Rates were constructed, whose procedures adopted for EPV *Lighting in operation* are shown in Figure 5. In step 1 (of Figure 5) the alternatives are shown; in step 2, the ordering of the alternatives is continued, with regard to passing a given criterion from neutral to good level, according to the decision maker's preferences; in step 3, the weighting performed in MACBETH software is shown, in which the hierarchical criteria are inserted and judged by the decision maker. The Compensation Rates for all Points of View are shown in Figure 6.

Figure 5: Construction of Compensation Rates



	A1	A2	A3	A4	Sum	Order
A1		0	0	1	1	3
A2	1		1	1	3	1
A3	1	0		1	2	2
A4	0	0	0		0	4

Source: Research data (2020).

The global evaluation is made by applying Equation 1 (global) for the alternative in question, expressed by the sum of the Compensation Rates multiplied by the performance of each FPV.

$$V_{PVFk}(a) = \sum_{i=1}^{ni} Wi,k \times Vi,k(a) \qquad (1)$$

Where:
$V_{PVFk}(a)$ = global value of action "a" of $PVFk$, for k = 1,...m;
$Vi,k(a)$ = partial value of action "a" in the criterion i, i = 1,...n, of $PVFk$, fora k = 1,...m;
k = 1,...m;
a = level of impact of action a;
Wi,k = criterion replacement rates i, i = 1,...n, of $PVFk$, for k = 1,...m;
n_k = number of criteria of$PVFk$, for k = 1,...m;
m = FPV number of the model.

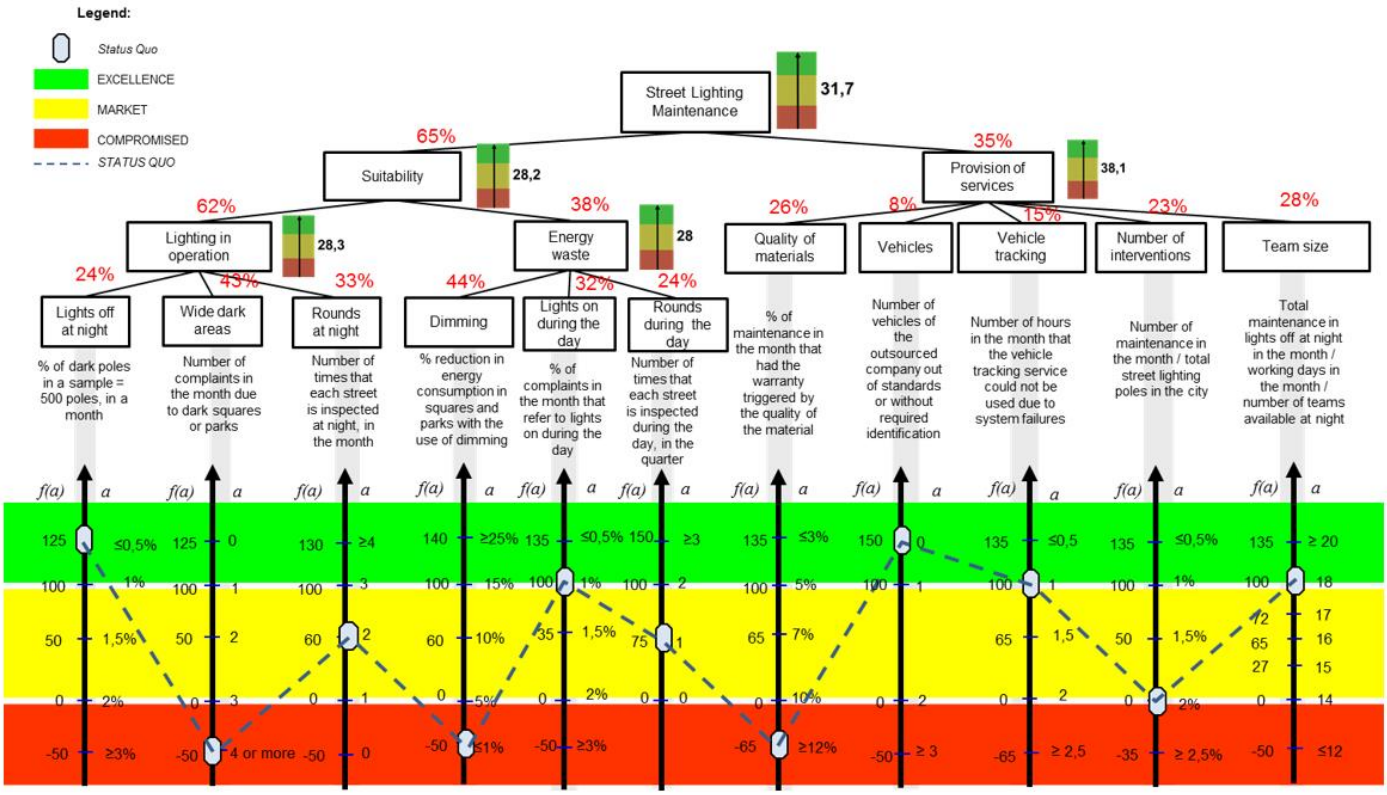
At this point, it is possible to determine the overall performance of the maintenance activity in Joinville, obtained with the integration of cardinal scales, which, in turn, are weighted by the Compensation Rates, allocated to HVS Points of View. Thus, the maintenance overall performance can be calculated from Equation (2):

$$V_{Manutenção}(a) =$$

$$0{,}65 \times \Big[0{,}62 \times [0{,}24 \times V_{PVEPtosEscuros}(a) + 0{,}43 \times V_{PVEGrandesÁreas}(a) + 0{,}33 \times V_{PVERondasNoturnas}(a)] + 0{,}38 \times \big[0{,}44 \times V_{PVEDimerização}(a) + 0{,}32 \times V_{PVEPontosAcesos}(a) + 0{,}24 V_{PVERondasDiurnas}(a)\big]\Big] + 0{,}35 \times \big[0{,}26 \times V_{PVEQualiMat}(a) + 0{,}08 \times V_{PVEVeículos}(a) + 0{,}15 \times V_{PVERastreamento}(a) + 0{,}23 \times V_{PVENumIntervenções}(a) + 0{,}28 \times V_{PVEDimensEquipes}(a)\big] = \quad (2)$$

As a result, the current performance of street lighting maintenance service is 31.7 points, being at market level. Graphical, individual and global evaluation can be seen in Figure 6.

Figure 6: Performance evaluation model for the activity of street lighting maintenance



Source: Research data (2020).

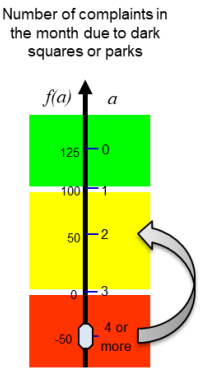
To conclude the Evaluation Phase, a Sensitivity Analysis was carried out, which demonstrated that the proposed model is not sensitive to possible variations in FPVs and EPVs Compensation Rates. The visualization of the complete model suggests some opportunities for improving individual and global performance, which will be addressed in the last step: the Recommendations Phase.

Recommendations Phase

The three EPVs were identified, whose management presented a compromising performance regarding the lighting maintenance service. In this context, it is necessary to propose actions, delegating those responsible and establishing deadlines for assistance. It should be noted that, in this phase, recommendations for improvement are proposed in conjunction with the decision maker, unlike other problem-solving approaches, which indicate actions without necessarily involving the decision maker in the process. (ENSSLIN; DUTRA; ENSSLIN, 2000; ENSSLIN *et al.*, 2020 a,b). Even so, it is possible to compare the proposed actions with the literature on the topic.

Figure 7 summarizes the actions to leverage the performance of the *Wide Dark Areas* criterion.

Figure 7: EPV improvement actions *Wide dark areas*

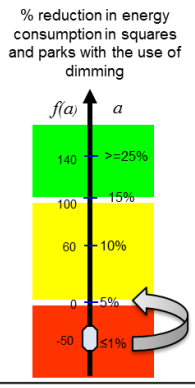
EPV	Criterion	Proposed actions
Wide dark areas		• Invest in long-term plans to modernize street lighting in squares, replacing end-of-life equipment; • Adapt the projects in a way that makes the assets less vulnerable to vandalism; • Request security agencies to carry out periodic patrols in squares and parks.
Person / Area responsible	Transport and Public Roads Manager / Electrical Engineers Supervisors	
Deadline	6 months	
Necessary resources	Investment in research for robust projects and additional materials applied; Time of the departments related to the public assets janitorial and security department of the municipality;	
Criterion impact	Compromised level to Market level	
Monitoring requency	Monthly	

Source: Research data (2020).

It is noticed that the first and second actions proposed in Figure 7, although directly improving maintenance performance, are concerns related to the modernization of public lighting. Within this area of concern there is the inclusion of new technologies, replacement of obsolete equipment and, among others, the energy efficiency initiative. Initiatives for energy efficiency of public lighting have already been addressed in other studies (SALVIA *et al*., 2019; CARLI; DOTOLI; PELLEGRINO, 2017; LECCESE; SALVADORI; ROCCA, 2017). Due to its complexity, this area of concern lacks deepening aiming at the construction of its own criteria, so that its influence on the performance of street lighting global management can be measured. The third suggested action, on the other hand, requires interaction with public security agencies and the custody of the municipal patrimony for its viability. This is because, according to the manager, the theft of underground cables, with high frequency, is a recurring concern, because, in most cases, it affects the lighting of an entire area.

The next criterion at a compromising level is the EPV *Dimming*, linked to the possibility of increasing or decreasing the light intensity at certain hours. Due to its high cost of acquisition and installation in all public places in the city, it is understood that this action must be gradual and planned for the long term. For a first moment, performance can be improved with the implementation of the action proposed in Figure 8.

Figure 8: Actions to improve EPV Dimming

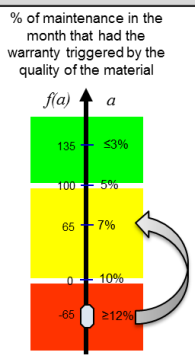
EPV	Criterion	Proposed actions
Dimming		• Inclusion of materials and services in the Bidding documentation.
Person / Area responsible	Transport and Public Roads Manager / Supervisor Electrical Engineers	
Deadline	24 months	
Necessary resources	Investment in the acquisition and installation of dimming equipment	
Criterion impact	Compromised level to Market level	
Monitoring requency	Yearly	

Source: Research data (2020).

The importance of using dimming has already been highlighted in the literature, given its ability to vary the luminous flux as a function of time and traffic conditions on the roads, which can be energized when necessary (CARLI; DOTOLI; PELLEGRINO, 2017). Doulos *et al*. (2019) add that the optimization of street lighting projects, with application of intelligent dynamic control systems, can result in up to 30% energy savings in public budget. Although it is a significant advantage, Gutierrez-Escolar et al. (2015) highlight the importance of being cautious in the levels of luminous flux reduction, since, if the cut is very low, the lighting will not be at the minimum levels and may affect the visibility of drivers and observers, being still established as a good time for testing the period from 1 to 5 am.

The last criterion at a compromising level is related to the EPV *Quality of materials*, as shown in Figure 9.

Figure 9: Actions to improve EPV *Quality of materials*

EPV	Criterion	Proposed actions
Quality of materials		• Certify for each material, the manufacturers able to supply the equipment that will be applied; • Improve the specifications of materials in the bidding documentation; • Inspect the brand of the purchased materials with determined frequency.
Person / Area responsible	Supervisor Electrical Engineers	
Deadline	3 months	
Necessary resources	Time of public servants in the preparation of certifying documents and in the inspection of materials	
Criterion impact	Compromised level to Market level	
Monitoring requency	Monthly	

Source: Research data (2020)

The improvement recommendations, indicated for performance improvement in this criterion, are of low cost and quite viable for the municipality of Joinville. It should be noted that the quality of the material assured will have a positive impact on the performance of other EPVs. A previous study concluded that the high failure rate in public lighting is due to two main reasons: quality of materials (below expectations) or vandalism (above expectations). For the first case, the authors suggest studying sanctions and / or terminating purchase contracts (MIRZAEI et al., 2015).

The implementation of these improvement actions will modify the status quo and, consequently, imply an increase in the overall performance of street lighting maintenance: from 31.7 to 70.3. Although the score, after the implementation of strategic improvement actions, is still within the market range, it will be much closer to the good level. After this first round of improvements, new enhancements may be proposed, so that the excellence level is achieved.

Final Considerations

Street lighting, present in the list of public services provided by the municipality, has been inspected by citizens, demanding transparency in the provision of services and the adoption of technical and efficient criteria. This is because the maintenance of all the equipment installed in the street lighting system of a city is a service seen daily by residents. Thus, it is essential that the municipal manager has extensive knowledge of his performance context and can justify, in a transparent and reasoned way, his decisions before society.

In this context, this research aimed to develop a constructivist model for evaluating multicriteria performance to support the management of street lighting maintenance, in the municipality of Joinville, according to the manager's perception. To achieve this objective, MCDA-C methodology was used, which allowed the construction of the model composed of 11 criteria and the assessment of the service status quo at 31.7 points. With the status quo knowledge, the criteria were identified in which the 'Transportation and Public Roads Setor' manager in the city of Joinville presents a compromising performance in the maintenance activity, as well as those criteria in which the cost for implementing improvements is low, namely: Wide dark areas, Dimming and Quality of Materials. For these criteria, actions for improvement were proposed. The explanation of Recommendations aims at improving individual and global performances, in order to bring them to the market level in the short term, and to the excellence level in the medium and long terms.

In the view of the authors of this study, the theoretical contribution lies in the development of a graphic model of performance evaluation for street lighting with the decision maker's participation and legitimation (Transportation and Public Roads manager). This model is composed of indicators that have been little explored in the literature on the subject until then, most of them being used as a way to compare the efficiency in the provision of street lighting services in several municipalities, without, however, providing the generation of knowledge in the decision maker. This generation of knowledge ensures that the model is seen by the decision maker as legitimate, as it represents their values, preferences and particularities of the municipality of Joinville, as well as being valid when guided by the procedures of a scientific methodology.

On the other hand, the practical contributions are evident as management gains control over the entire provision of the street lighting maintenance service in the municipality, whether by assessing the lighting system's conformity broadly or by assessing the provision of the service, which includes outsourced employees, vehicles used and quality of materials applied. In this case, the manager starts to actively contribute to the entire municipal management with street lighting, given the importance that the service has for the population, making informed, timely and effective decisions. Ultimately, the municipality that reaches satisfactory quality standards for the street lighting service has the potential for the development of several other areas, such as: tourism, public safety and quality of life of the population at night.

Regarding the limitations of the research, it can be mentioned the fact that the study is exclusive to the municipality of Joinville, due to the adopted constructivist bias and the uniqueness of the model. However, it should be considered that, although the model is specific, the methodology can be used to build models in different environments and with different decision makers. Furthermore, the built indicators can support new applications in different street lighting systems.

For future research, it is suggested the application of the MCDA-C Methodology to build performance evaluation models to support the management of street lighting in other Brazilian municipalities, comparing with the indicators obtained in this study. It is also suggested that the model be expanded to include as many other areas covered by the management of street lighting,

such as modernization, energy efficiency, asset management, interaction with the population and planning.

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