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ENGLISH VERSION

Development of a multicriteria matrix for decision making in the management of flexible pavements in an urban road network. Case study the city of Itagüí – Colombia

Desarrollo de una matriz multicriterios para la toma de decisiones en la gestión de pavimentos flexibles en una red vial urbana. Estudio de caso la ciudad de Itagüí – Colombia

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Abstract
Decision-making for interventions in urban road networks is often carried out reactively, addressing roads in the worst condition first, which reduces the length of intervention in the entire urban road network under an assigned budget. The objective of this work was to establish a methodology to prioritize the intervention of asphalt pavements on urban roads through a multi-criteria matrix that allows optimizing the management of pavements in the network. The criteria were previously adjusted and validated by road infrastructure experts using the Likert scale. Subsequently a large group of experts completed the multi-criteria matrix to qualify and weigh each of the criteria and intervention alternatives considered to address each of the established problems; the goal is to preserve the urban road network in good condition. With the support of Geographic Information Systems (GIS) tools, each criterion was represented by a vector shapefile format, each of them was transformed into raster format and reclassified to assign a specific score. The attributes of the raster format used information from the road network of the city of Itagüí (Colombia). The final result was the weighted overlay of maps that allowed establishing the prioritization of the roads to intervene according to the score obtained in each road segment, which allows the administrator to make efficient decisions in an urban network.
Keywords: *Management of urban pavements; multi-criteria matrix; asphalt pavements; decision making; urban roads.*

Resumen
La toma de decisiones para las intervenciones de las redes viales urbanas se realiza a menudo de forma reactiva, atendiendo primero las vías en peores condiciones, situación que reduce la longitud de intervención en la totalidad de la red vial urbana bajo un presupuesto asignado. El objetivo de este trabajo consistió en establecer una metodología para realizar la priorización de intervención de pavimentos asfalticos en vías urbanas por medio de una matriz multicriterio que permita optimizar la gestión de pavimentos de la red. Los criterios fueron previamente ajustados y validados por un grupo de expertos en infraestructura vial empleando la escala de Likert; posteriormente un grupo amplio de expertos diligenciaron la matriz multicriterio que permitió ponderar y calificar cada uno de los criterios y Alternatives de intervención que se consideran para atender cada uno de los problemas establecidos, con el objetivo de conservar la red vial urbana en buenas condiciones. Con el apoyo de herramientas de Sistemas de Información Geográfica SIG, cada criterio se representó por un archivo vectorial formato shapefile, cada uno de ellos fue transformado en formato ráster y reclasificado para asignar un puntaje determinado. Los atributos del formato ráster utilizaron la información de la red vial de la ciudad de Itagüí (Colombia). El resultado final fue la superposición ponderada de mapas que permitió establecer la priorización de las vías a intervenir de acuerdo con el puntaje obtenido en cada segmento vial, lo que permite al administrador la toma eficiente de decisiones en una red urbana.

Palabras clave: Gestión de pavimentos urbanos; matriz multicriterio; pavimentos asfálticos; toma de decisiones; vías urbanas.

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1. Introduction

Pavement maintenance is essential to avoid the loss of value of road assets and meet the expectations of all stakeholders' objectives. However, budgets are often insufficient to maintain road pavement at optimal levels. Therefore, a decision-making process must be used to prioritize different maintenance activities so as to optimize the use of the available budget and to achieve the pre-defined objectives (Augeri et al., 2019).

The above makes it necessary to develop a Pavement Management System -PMS- that must integrate and coordinate all aspects considered in the pavement asset management process. In particular, the comprehensive PMS must take into account a dynamic process that incorporates feedback regarding the various attributes, criteria and constraints involved in the optimization of maintenance scheduling and decision-making (Osorio, 2015).

The PMS provides the necessary framework to evaluate the condition of the pavement and to select appropriate strategic decisions on maintenance activities to minimize the necessary funds and to improve the performance of the road network (García et al., 2023) Neglecting the need for conservation and delaying pavement maintenance implies higher costs and a risk of structural failure. Compared to early maintenance based on preservation, late maintenance is estimated to triple agency and user costs (Torres et al.,2017).

When the network administrator is faced with the decision-making process or selection of alternatives, there are generally multiple objectives that conflict with each other, making this process more complex and generating the need for a tool or method that allows comparison. These multiple criteria are compared to the range of possible alternatives (Osorio and Orejuela, 2008).

Multi-criteria decision-making methods have been widely used in recent years to assist project managers in construction-related selection processes. Decision-making techniques can be used not only to compare or rank a set of alternatives, but also to incorporate the preferences of the decision maker in the search for the optimal maintenance plan (García et al., 2023).

Multicriteria analysis (MCA) is a decision-making aid that establishes preferences between different options in relation to an explicit set of objectives. It does this through models that help predict how a series of aspects of the real world will behave and help describe the relationships between elements of information in order to predict how real-world events will occur. The quality or results obtained are determined by the information and criteria selected by the user of this method (Aronoff, 1993).

In multi-year multi-objective optimization, the goal is to identify a multi-annual works plan that can best meet multiple objectives and the constraints (e.g. budget). To make the complexity of the problem manageable, the set of possible treatments for each road section can be restricted by utilizing decision trees (or other methods) in order to identify a reasonable subset of possible treatments (Augeri et al., 2019).

An aspect of utmost importance for this method is that it is based on the judgment of a team of decision makers who establish objectives, criteria and weights of importance for each performance criterion. It is a flexible and interactive tool that allows the decision maker to face the difficulties of managing a large amount of complex information in a consistent manner (Malczewski, 1999).

Within this framework, it is vital to have adequate information to make the best decision; that will be determined within a set of possible alternatives, which must be evaluated against multiple criteria that are defined for this purpose. The result then is a complex and delicate process in which subjectivity and dependence on information play a predominant role. For this reason, it is necessary to have tools that improve this process and allow a more scientific analysis of the alternatives (Osorio and Orejuela, 2008).

For MCA, criteria and alternatives must be established to find the most effective solution to a given problem; there are different methods that are applicable depending on the complexity of the information that must be analyzed. Among the multi-criteria methods with the greatest recognition and application is the weighted weight matrix, also called the criteria matrix. This matrix consists in an arrangement of rows and columns that face each other. This allows a choice to be made of which solution would be the best, based on the selection, weighting and application of criteria.

For this research, the methodology established in the weighted matrix was used; due to the structure of the data collected and processed, this is the most efficient methodology to continue to the next stage of data processing in the Urban Pavement Management System -UPMS- Structure for the case study.

The development of the UPMS integrates technical variables, correlate with aspects that influence decision-making, seeking to technically and economically optimize the work route to prioritize the road segments to intervene. This occurs within the scheduled Preservation, Maintenance or Rehabilitation activities (P+ M+R), to gradually raise the level of service of the sections that make up the road network.

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2. Discussion and development

2.1. Case study

The city of Itagüí in Colombia is a first-class territorial entity, according to the classification of the Colombian state. It is located in a tropical zone, with an average annual temperature of 23°C; it has 297,000 inhabitants and 205 km of urban roads with a limited budget for network intervention. The municipality has national recognition of its high commercial and industrial vocation recognized.

For the development of prioritization in the intervention of road segments, the development of a multi-criteria matrix was carried out, structured in the initial approach of criteria grouped by categories, and intervention alternatives; this allows achieving the objective of maintaining the condition of the pavement of roads that are in excellent or good condition, and improving the condition of the pavement of roads that are in fair or poor condition.

(Figure 1) shows a process map that allows the development of the established methodology.

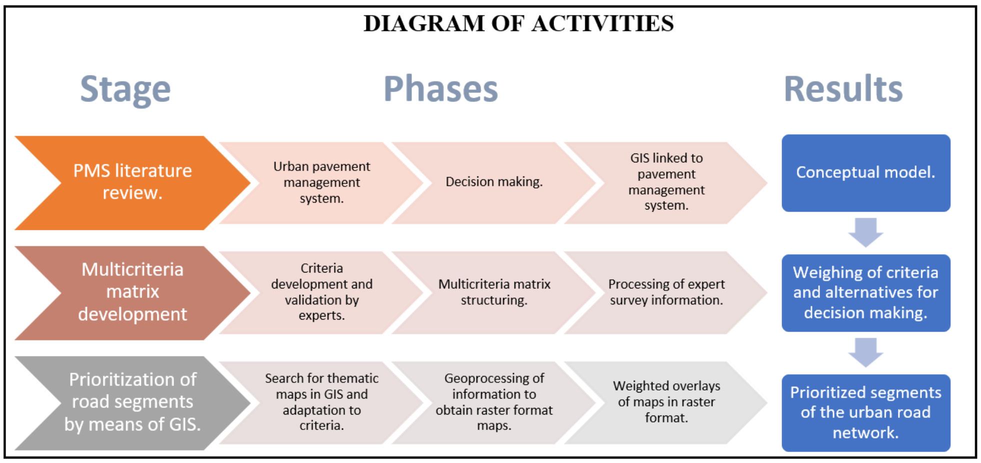

Figure 1. *Diagram of activities*

2.2. Categories considered

The established criteria were grouped into four categories:

2.2.1 Performance and comfort

The quality of a pavement can be estimated in terms of the service it provides to the user, resistance, durability and comfort. These attributes can be evaluated objectively through the use of indices and indicators that describe the current performance of the pavement and the progression of this performance over time (Solminihac et al., 2018). Comfort is associated with the functional behavior of the pavement, which transmits comfort and safety to the road user.

2.2.2 Environmental

Frequent pavement P+M+R activities can cause a negative influence on the environment. The production of asphalt, the extraction of granular material and the operation of machinery with fossil fuel, emits enormous quantities of carbon oxides, nitrogen oxides and sulfides; these compounds promote global warming, the decrease in the PH of a natural resource and photochemical contamination. (Chen and Zhengb, 2021). This category considered the impact of the P+M+R works on the pavement at an environmental level, caused by the state of the rolling surface and the volume of vehicles that circulate on it.

2.2.3 Political and social

Community participation plays an important role in the development of the city; roads and pavements are a means of communication that can represent development or, on the contrary, abandonment of the State. It is essential to benefit a large part of the citizens with roads in good condition, which allow better accessibility and vehicular connectivity, concentrating efforts on roads with a large influx of public or that are important for developing the community's own activities (hospital centers, of commercial, economic and state dynamics, etc.).

2.2.4 Economy and transportation

Determining the road corridors through which the greatest number of vehicles are mobilized is a factor that is linked to the hierarchy and importance of the road given its connectivity conditions, type of vehicles, and economic development. Keeping these roads in good condition represents a reduction in vehicle operation expenses (less travel time, reduction in polluting agents, maintenance, fuel and lubricant consumption, etc.) as well as mitigates environmental impacts.

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2.3 Validation of criteria that make up the multicriteria matrix

For the development of the multi-criteria matrix, it was necessary to validate with road infrastructure experts the relevance of the criteria initially established in each category. One of the recognized methods used was the Likert scale methodology, this is a research field methodology that allows measuring an individual's opinion on a topic through a questionnaire, which identifies the frequency with which the client performs an activity, the difficulty they have in carrying out a task, the degree of importance they attribute to an aspect, the probability that you will perform an action in the future, among other things. (Hammond, 2022).

(Table 1) presents the assessment that was given to each criterion by the panel of experts. (Table 2) represents the criteria that were taken into account to evaluate each category.
There are different Likert scales; the one used for this work was the so-called "agree" Likert Scale, with the following rating scale:

***Table 1.** Assessment of criteria*

ASSESSMENT CRITERIA	VALUE
Strongly disagree	1
Undecided	2
Totally agree	3

The survey carried out was non-probabilistic sampling because the number of elements in a population is unknown or cannot be individually identified (Kumar, 2011). Within non-probability sampling is convenience sampling, which consists of a technique where samples of the population are selected only because they are conveniently available to the researcher (Ortega, s.f.). Therefore, it was possible to survey five experts. The aforementioned is based on factors such as the difficulty in accessing more people or entities that could respond to the survey, the limitation of time for the development of the degree work, availability of professionals in the field with experience and knowledge in pavement management. The experts rated each of the criteria and made some observations; the final result was the following:

***Table 2.** Validation of criteria for each expert*

CATEGORY	No. CRITERIA	CRITERION	PUNCTUATION					
			EXPERT 1 (E1)	EXPERT 2 (E2)	EXPERT 3 (E3)	EXPERT 4 (E4)	EXPERT 5 (E5)	SUM
PERFORMANCE AND COMFORT	1	Extend pavement life	2	3	2	3	2	12
	2	Improve the quality of the running surface	3	3	3	2	3	14
	3	Improve the structural condition of the road	3	2	2	3	1	11
	4	Increasing road safety	3	3	2	3	3	14
ENVIRONMENTAL	5	Reduce pollution and pollution on the road in good condition and with low vehicular circulation	2	2	1	3	1	9
	6	Reduce pollution and pollution on roads in poor condition and with low vehicular circulation	2	2	1	3	2	10
	7	Reduce pollution and pollution on the road in good condition and with high vehicular circulation	3	2	2	3	3	13
	8	Reduce pollution and pollution on roads in poor condition and with high vehicular circulation	3	3	3	3	3	15
POLITICAL AND SOCIAL	9	Address community complaints (verbal, PQRS, social networks).	3	3	1	3	3	13
	10	Meet commitments made by the local representative.	2	2	1	3	1	9
	11	Improve accessibility to points of interest or high affluence.	3	3	3	3	3	15
	12	Increase beneficiary population.	3	2	3	3	2	13
ECONOMY AND TRANSPORT	13	Improve pavement condition on **main arterial road**: With high circulation of public transport vehicles and cargo transport	3	3	2	3	3	14
	14	Improve pavement condition in **secondary artery road**: With medium circulation of public transport vehicles and cargo transport	3	3	2	3	3	14
	15	Improve pavement condition on **collector road**: With low circulation of public transport vehicles and cargo transport	3	2	2	3	3	13
	16	Improve pavement condition on **service roads with residential characteristics**: For the circulation of light vehicles, eventually circulation of cargo vehicles.	3	2	2	3	3	13
	17	Improve pavement condition on **service roads with industrial and / or commercial characteristics**: For circulation of cargo vehicles.	3	3	2	3	2	13
		Sum by expert	47	43	34	50	41	

Taking into account the assessment scale in (Table 1), the assessments for each of the criteria were tallied to calculate the frequency of the assessment displayed in (Table 3). The term "frequency" indicates the number of times a factor is repeated within a series (Hammond, 2022). The sum is made for each assessment of the criterion to then calculate the percentage of incidence of each of them, which allows determining the favorability of 61.2% of the criteria proposed by the experts.

Table 3. *Accounting of the frequency for each assessment of the criterion*

CRITERION ASSESSMENT	ACCOUNTING FOR THE FREQUENCY OF ASSESSMENT FOR EACH CRITERION																	SUMMARY VALUATION	% DE INCIDENCE
	Performance and comfort				Environmental				Political and social				Economy and transport						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		
Strongly disagree	0	0	1	0	2	1	0	0	1	2	0	0	0	0	0	0	0	7	8,2%
Undecided	3	1	2	1	2	3	2	0	0	2	0	2	1	1	2	2	2	26	30,6%
Totally agree	2	4	2	4	1	1	3	5	4	1	5	3	4	4	3	3	3	52	61,2%
																	TOTAL	85	100,0%

The graph in (Figure 2) shows the results of the evaluation of the criteria in (Table 2), which shows unfavorable results for criteria 5 and 10, which therefore required reformulation because the "Strongly disagree" and "Undecided" evaluations prevailed; for criteria 1, 3 and 6 there were medium levels of indecision, which led to adjustments in their formulation. The rest of the criteria with favorable results of acceptance were considered validated for the structuring of the multicriteria matrix.

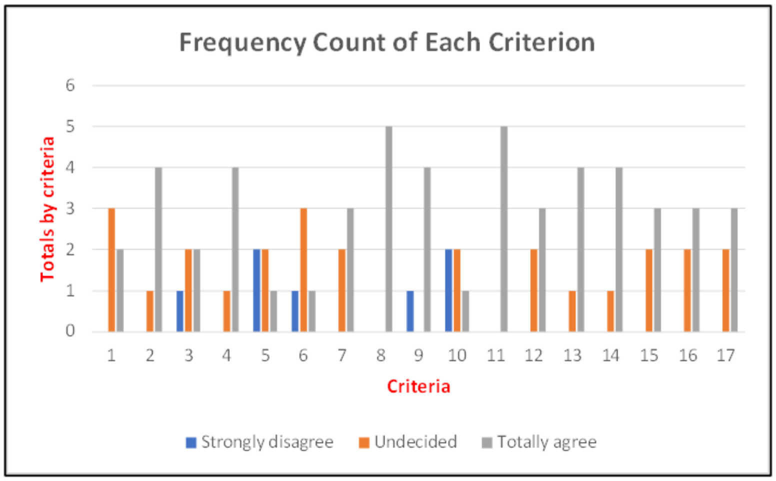

Figure 2. *Accounting of the frequency by criteria*

The experts made suggestions on modifying the criteria, which were reviewed and accepted for a consolidation of criteria that will structure the multi-criteria matrix. Those are presented in (Table 4).

Table 4. *Final result of criteria validation*

CATEGORY	No. CRITERIA	CRITERION	ADJUSTED CRITERIA
PERFORMANCE AND COMFORT	1	**Extend pavement life**	**Achieve expected service life spans**
	2	Improve the quality of the running surface	
	3	**Improve the structural condition of the road**	**Maintain the structural condition of the road**
	4	Increasing road safety	
ENVIRONMENTAL	5	**Reduce pollution and pollution on the road in good condition and with low vehicular circulation**	**Reduce noise**
	6	**Reduce pollution and pollution on roads in poor condition and with low vehicular circulation**	**Reduce traffic congestion**
	7	Reduce pollution and pollution on the road in good condition and with high vehicular circulation	
	8	Reduce pollution and pollution on roads in poor condition and with high vehicular circulation	
POLITICAL AND SOCIAL	9	Address community complaints (verbal, PQRS, social networks).	
	10	**Meet commitments made by the local representative.**	**Improve the condition of pavement of road sections with land uses of greater economic activity**
	11	Improve accessibility to points of interest or high affluence.	
	12	Increase beneficiary population.	
ECONOMY AND TRANSPORT	13	Improve pavement condition on main **arterial road**: With high circulation of public transport vehicles and cargo transport.	
	14	Improve pavement condition in **secondary artery road**: With medium circulation of public transport vehicles and cargo transport.	
	15	Improve pavement condition on **collector road**: With low circulation of public transport vehicles and cargo transport	
	16	Improve pavement condition on **service roads with residential characteristics**: For the circulation of light vehicles, eventually circulation of cargo vehicles.	
	17	Improve pavement condition on **service roads with industrial and / or commercial characteristics**: For circulation of cargo vehicles.	

It is observed that among the criteria that the experts considered to be of low importance and recommended that they be modified are criteria No. 5 and 6, which are in the "ENVIRONMENTAL" category, and within the analysis of the formulation of the survey it is concluded that to evaluate criteria for the emission of pollutants on low traffic roads in good and bad condition, the weightings assigned by experts cannot be relevant; therefore it is necessary to eliminate these criteria, and to consider other criteria for the matrix that fits in the environmental category, such as noise and the use of materials for the reconstruction of an urban road.

2.4 Definitive multicriteria matrix

A series of intervention alternatives were incorporated into the new multicriteria matrix, listed in (Table 5), which are part of the P+M+R activities; with these alternatives, the administrator of the urban road network is expected to mitigate the effect of each criterion.

Table 5. *Description of the alternatives for the MCA*

Alternative 1	Reconstruction of the pavement structure, intervention of the pavement at a structural level due to the state of deterioration of its granular layers and tread, added to the structural insufficiency.
Alternative 2	Rehabilitation of the pavement, removal of the asphalt layer due to superficial deterioration or deformations in the pavement that does not compromise its structural behavior.
Alternative 3	Resurfacing or resurfacing, Installation of an asphalt layer on an existing pavement structure, whose purpose is to carry out structural reinforcement and/or improve comfort conditions. Periodic maintenance activity.
Alternative 4	Installation of micro agglomerate type mixtures. Installation of a discontinuous asphalt layer that has no structural contribution, but does provide greater grip between the tire and the pavement, drains the pavement surface more quickly and reduces noise compared to the use of pavements with conventional asphalt mixes. All this increases comfort and road safety for the driver. Periodic maintenance activity.
Alternative 5	Maintenance with patching works, execution of repair of the pavement surface that present pathologies that need to be attended to recover the functional conditions and, in many cases, improve road safety, the decision to carry out maintenance tasks is linked to the percentage of affectation of the pavement structure, where the pavement condition index must be above the value of 55 points. for repairing holes in the tracks and eliminating faults present in the pavement surface. Routine maintenance activity.
Alternative 6	Maintenance by means of crack sealing, work carried out in isolated cracks whose purpose is to prevent water seepage into the underlying layers, prolonging the useful life of the pavement. Routine maintenance activity.
Alternative 7	Do nothing and let the pavement continue in the process of deterioration in accordance with what is established in its design period.

Based on the new criteria and the incorporation of intervention alternatives, the final multi-criteria matrix was structured, where a panel of experts from the road infrastructure area had to establish the importance of each criterion and the best intervention alternative to mitigate it. To do this, they used a scale from 1 to 10, where 10 is the most important criterion or the most appropriate intervention.

Criteria affect proposed alternatives differently, hence the importance of assigning different weights to indicate the relative importance of alternatives (Martinez et al., 2023).

(Table 6) shows the survey proposal for data collection sent to a group of experts en masse, via email and the WhatsApp application.

Table 6. *Multi-criteria analysis matrix to be completed by experts*

MULTICRITERIA MATRIX SELECTION TYPE OF INTERVENTION IN ASPHALT PAVEMENT MANAGEMENT
DEVELOPMENT OF A METHODOLOGY FOR THE IMPLEMENTATION OF AN URBAN PAVEMENT MANAGEMENT SYSTEM – CASE OF ITAGÜÍ CITY.

The urban pavement management model to be developed by applying the multicriteria matrix, starts from the premise of optimizing the investment of resources (which are usually limited) to improve and / or maintain the usefulness of the entire urban road network, applying intervention strategies (alternatives) to achieve the objective of maintaining the condition of roads that are in excellent or good condition and improve the condition of the roads that are in fair or poor condition.

INSTRUCCIONES

1. Within the defined criteria, a score will be established on a scale with values from 1 to 10, being the value of 1 that considers the criterion of less importance, and can vary up to the value of 10 that considers the criterion established as of great importance. **Note: You can not repeat the values qualification of criteria in each category, the above to determine which is the criterion of greater relevance for each category.**
2. Assign a score to each proposed alternative that seeks to meet each of the defined criteria, a score will be established on a scale with values from 1 to 10, with the value of 1 being the least favorable alternative to meet the criterion, and may vary up to the value of 10 that considers the alternative evaluated as the background solution to the criterion evaluated.

Respondent's Name: **Profession and postgraduate:**

Current employment or role: **Years of experience in the area of pavements:**

CATEGORY	No. CRITERIA	CRITERION	WEIGHTING CRITERION	ALTERNATIVES						
				Intervention of the entire structure	Removal of tread layer	Periodic maintenance activities		Routine maintenance activities		
				1. Reconstruction	2. Rehabilitation	3. Resurfacing	4. Installation of microagglomerate mixtures	5. Maintenance with patching works	6. Crack seal maintenance	7. Do nothing
PERFORMANCE AND COMFORT	1	Achieve expected service life spans								
	2	Improve the quality of the running surface								
	3	Maintain the structural condition of the road								
	4	Increasing road safety								
ENVIRONMENTAL	5	Reduce noise								
	6	Reduce traffic congestion								
	7	Reduce pollution and pollution on the road in good condition and with high vehicular circulation								
	8	Reduce pollution and pollution on roads in poor condition and with high vehicular circulation								
POLITICAL AND SOCIAL	9	Address community complaints (verbal, PQRS, social networks).								
	10	Improve the condition of pavement of road sections with land uses of greater economic activity								
	11	Improve accessibility to points of interest or high affluence.								
	12	Increase beneficiary population.								
ECONOMY AND TRANSPORT	13	Improve pavement condition on main **arterial road**: With high circulation of public transport vehicles and cargo transport.								
	14	Improve pavement condition in **secondary artery road**: With medium circulation of public transport vehicles and cargo transport.								
	15	Improve pavement condition on **collector road**: With low circulation of public transport vehicles and cargo transport								
	16	Improve pavement condition on **service roads with residential characteristics**: For the circulation of light vehicles, eventually circulation of cargo vehicles.								
	17	Improve pavement condition on **service roads with industrial and / or commercial characteristics**: For circulation of cargo vehicles.								

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2.5 Criteria articulated in the GIS

Geographic Information Systems (GIS) are information system capable of integrating, storing, editing, analyzing, sharing and displaying geographically referenced information. In a generic sense, GIS are tools that allow users to create interactive queries, analyze spatial information, edit data, maps and present the results of all these operations in graphic form (Autonomous University of Madrid, 2011). (Figure 3) graphically represents a GIS.

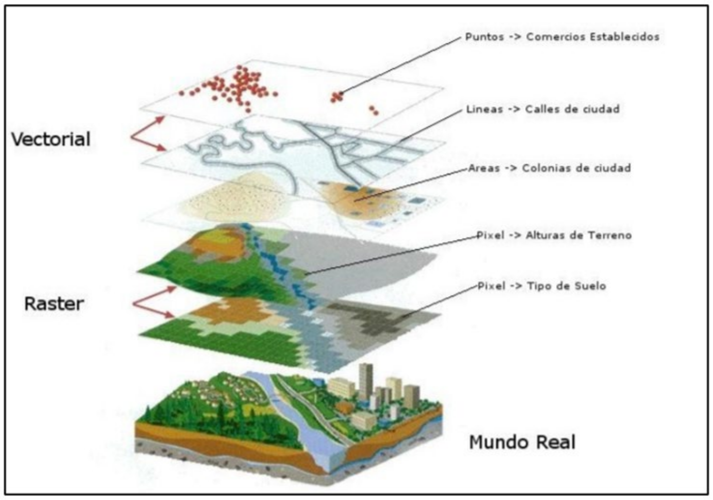

Figure 3. *Representation of vector and raster elements in a GIS. Source: (Autonomous University of Madrid, 2011)*

There are two ways to store data in a GIS:
• RASTER: Any type of digital image represented in meshes (PIXELS). It divides the space into regular cells where each one represents a single value.
• VECTORIAL: Here the data is based on the vector representation of the spatial component of the geographic data through points, lines or polygons (Autonomous University of Madrid, 2011).

GIS applications with PMS arrive at a selection or interpretation of the prioritization of resources that provide the greatest benefit to the region. The ease of consultation of the GIS provides efficiency in the management of information for the authorities in charge of the road network (Silva et al., 2018).

Manual methods use Multi-Criteria Decision Making-MCDM- to compare several alternatives, and automatic methods use MCDM-GIS and formula-based methods to generate the optimal alternative in the raster. (Jiang et al., 2023).

For the case study, each criterion established in the multicriteria matrix had an associated shapefile (vector) file, which is a simple and non-topological format that is used to store the geometric location and attribute information of the geographical entities. The geographic entities of a shapefile can be represented by points, lines or polygons (areas) (ESRI, 2023).

For a road system to be manageable, it must be divided into branches that can be taken as city streets. Because a street does not always have uniform characteristics and does not require the same maintenance and rehabilitation treatment at the same time along its entire length, it is divided into smaller, more manageable segments (sections). This will also help in collecting data and conducting analysis. Segments are defined so that the pavement within their boundaries is consistent in terms of physical and functional characteristics (Almuhanna et al., 2018).

For the case study, georeferenced information was collected in Shapefile format from the road network of the city of Itagüí, which was reviewed and processed to represent the criteria on maps. To perform the weighted overlay of the maps, they must match in cell size and area extension so that the results are executed without conflicts in the ArcGIS software.

Each of the criteria represented in the shapefile contains information that allowed a rank classification process to establish the favorable conditions for each attribute.

Each layer was classified into ranges according to the content of the information and transformed into raster format, standardizing the cell size for each one; that is followed by the process of reclassification of information. Reclassification is the process of reassigning one or more values of a raster data set to new output values. The Reclassify tool is used to transform the values of multiple input raster data sets to a common scale. (Gabri, 2020). (Table 7) presents the association of each criterion taken into consideration in the multicriteria matrix with the information contained in a shapefile. The maps transformed to raster format contain cell values that come from the rating indicators of each criterion, which are incorporated into a unified reclassification in a range from 1 to 9.

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Table 7. *List of criteria adopted in shapefile: Information and classification ranges for each shapefile and information reclassification for the case study*

CATEGORY	No. CRITERIA	CRITERION	LAYER GIS	FIELD TO EVALUATE	GIS RECLASSIFICATION FOR WEIGHTED OVERLAY PROCESS (ASSIGNMENT OF SCORES FROM 1 TO 9)								
					1	2	3	4	5	6	7	8	9
PERFORMANCE AND COMFORT	1	Achieve expected service life spans	Via_Buen_Estado2	Pavement condition index PCI roads in good condition	≤55				>85 - 100				>55 - ≤85
	2	Improve the quality of the running surface	Via_IRI	IRI International Regularity Index	<4				4 - 8				>8
	3	Maintain the structural condition of the road	Via_Estructural	IE Structural Index	≤0,5		0,5 - ≤0,7			0,7 - <1,0			>1,0
	4	Increasing road safety	Via_Fricción	CRD slip resistance coefficient	1				>45				>1 - 45
ENVIRONMENTAL	5	Reduce noise	Ruido_Automotor_Noche_4m	Decibels measured due to automotive noise.	30		35		40		60 - 65		70 - 75
	6	Reduce the use of non-renewable materials and/or recycle part of the materials in the process of improving the quality of the roadway.	Via_Reconstruccion	Structural index IE. A higher score is given to roads that have a poor structural condition and are therefore susceptible to total or partial reconstruction of the pavement structure.	>1		0,7- <1,0			0,5 - <0,7			≤0,5
	7	To reduce pollution and contamination on roads in good condition and with high vehicular traffic.	T3_Via_Buen_Estado2	Pavement condition index for roads with traffic greater than 5x10^6 equivalent axles. The highest score is assigned to roads in excellent condition.	<55				55 - <85				85 - 100
	8	To reduce pollution and contamination on roads in poor condition and with high vehicular traffic.	T3_Via_Mal_Estado2	Pavement condition index for roads with traffic greater than 5x10^6 equivalent axles. The highest score is assigned to roads in fair condition.	1				>1-25				>25-55
POLITICAL AND SOCIAL	9	Address community complaints (verbal, PQRS, social networks).	Reportes daños	Points marked as gaps in pavement within a radius of 20 meters around	Out of the range								Within the range of action
	10	Improve the condition of pavement of road sections with land uses of greater economic activity	Uso_Suelo	Main use of the land distributed throughout the municipality	Residential & Protection		Endowment		Multiple activity		Heavy Industry, Light Industry		Commercial & Services
	11	Improve accessibility to points of interest or high affluence.	Equipamiento	Places of interest of high influx of public in which a radius of action of 100 is projected around the equipment	Out of the range								Within the range of action
	12	Increase beneficiary population.	D_DensidadHabitacional_Barrio	Population density dwelling/hectare	0-50		>50-100		>100-140		>140-200		>200
ECONOMY AND TRANSPORT	13	Improve pavement condition on main arterial road: With high circulation of public transport vehicles and cargo transport.	Arteria_Principal	Road hierarchy	Rest of the territory								Main artery route
	14	Improve pavement condition in secondary artery road: With medium circulation of public transport vehicles and cargo transport.	Arteria_Secundaria	Road hierarchy	Rest of the territory								Via Secondary artery
	15	Improve pavement condition on collector road: With low circulation of public transport vehicles and cargo transport.	Colectora	Road hierarchy	Rest of the territory								Collector route
	16	Improve pavement condition on service roads with residential characteristics: For the circulation of light vehicles, eventually circulation of cargo vehicles.	Via_Servicio_Res	Road hierarchy	Rest of the territory								Residential service road
	17	Improve pavement condition on service roads with industrial and / or commercial characteristics: For circulation of cargo vehicles.	Via_Servicio_Ind_Co	Road hierarchy	Rest of the territory								Industrial service road

For the case study and as an example, (Figure 3) shows the georeferenced information of Criterion No. 1 "Reach the expected useful life periods" represented with the shapefile "Roads in Good Condition", this file in its attributes table measures the Pavement Condition Index -PCI- that through a scale of values represents graphically the surface condition of the pavements, and for the example classifies them in two states: "good (55<PCI<85)" and "excellent (85<PCI<100)". These values are an instrument to program the respective treatments on the pavements within the appropriate times, and to prolong their useful life to reach the projected service time.

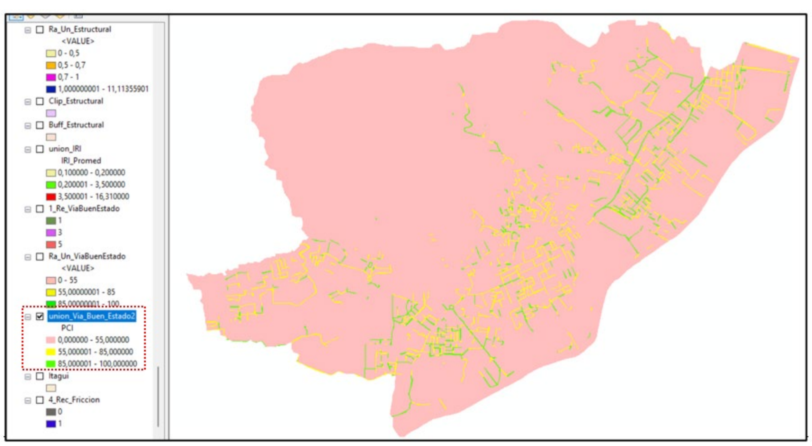

Figure 3. *Representation of vector elements on a map of Roads in Good Condition according to PCI criteria*

Revista Ingeniería de Construcción RIC
Vol 39 Nº1 2024
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3. Results of the case study

Using non-probabilistic sampling, specifically convenience sampling, information was collected from a total of 17 surveys. After the application of the definitive factorial matrix, the results obtained were entered in a Criteria Weighting Matrix, where the weightings established by each of the respondents (experts) were recorded. Within the criteria defined, the experts rated the criteria from 1 to 10, with a value of 1 being considered the criterion of less importance, and a value of 10 being considered the criterion established as of great importance; there was also a condition of not repeating the criteria rating values within the same category. The results obtained the criteria that generate greater relevance in the multicriteria matrix were identified according to the score obtained by each of the categories (Table 8ª) and (Table 8B).

Table 8. *A. Criteria weight matrix (part 1). B. Criteria weight matrix (part 2)*

A

Criteria Weight Matrix									
Criterions	**Expert 1**	**Expert 2**	**Expert 3**	**Expert 4**	**Expert 5**	**Expert 6**	**Expert 7**	**Expert 8**	**Expert 9**
Criterion 1	9	5	10	10	9	7	7	9	9
Criterion 2	8	10	6	7	8	9	9	7	8
Criterion 3	10	5	8	8	7	8	6	10	7
Criterion 4	6	6	9	9	10	10	8	5	10
Criterion 5	5	8	6	5	7	7	7	6	2
Criterion 6	10	3	5	9	8	8	9	8	6
Criterion 7	6	5	7	6	9	9	8	7	8
Criterion 8	8	5	10	8	10	10	5	5	10
Criterion 9	7	3	6	8	10	8	7	6	8
Criterion 10	10	8	8	7	9	7	8	7	9
Criterion 11	8	8	9	6	8	10	9	8	10
Criterion 12	6	8	8	5	7	9	6	4	7
Criterion 13	10	7	10	9	10	10	9	10	10
Criterion 14	9	5	8	8	9	9	10	9	8
Criterion 15	8	5	6	7	8	8	7	8	6
Criterion 16	6	5	4	6	7	7	4	6	4
Criterion 17	7	5	6	5	6	6	5	7	5
	Survey 1	*Survey 2*	*Survey 3*	*Survey 4*	*Survey 5*	*Survey 6*	*Survey 7*	*Survey 8*	*Survey 9*

B

Criteria Weight Matrix									
Criterions	**Expert 10**	**Expert 11**	**Expert 12**	**Expert 13**	**Expert 14**	**Expert 15**	**Expert 16**	**Expert 17**	**Sum**
Criterion 1	7	10	10	10	8	7	7	10	144
Criterion 2	10	9	7	5	10	8	9	6	136
Criterion 3	8	7	8	6	9	10	10	8	135
Criterion 4	9	8	9	8	5	9	8	7	136
Criterion 5	8	7	6	8	9	7	7	5	110
Criterion 6	9	9	10	9	10	10	10	9	142
Criterion 7	7	8	7	7	7	8	8	7	124
Criterion 8	10	10	8	10	8	9	9	6	141
Criterion 9	7	7	7	8	7	7	8	7	121
Criterion 10	10	8	9	9	10	10	7	8	144
Criterion 11	9	10	8	7	9	9	10	9	147
Criterion 12	8	9	10	10	8	8	9	10	132
Criterion 13	10	10	10	10	10	10	10	10	165
Criterion 14	8	9	8	8	9	9	9	8	143
Criterion 15	7	8	7	6	7	8	8	7	121
Criterion 16	6	6	6	5	6	6	6	4	94
Criterion 17	9	7	9	4	8	7	7	9	112
	Survey 10	*Survey 11*	*Survey 12*	*Survey 13*	*Survey 14*	*Survey 15*	*Survey 16*	*Survey 17*	

(Table 9) consolidates the information on the sum of the scores by criteria and determines the percentage of influence of each criterion on the total sum of all the criteria. The percentage of influence of each criterion establishes differences when superimposing all the maps involved in prioritization, allowing some road segments to be highlighted over others, when entering the information into the GIS for the geoprocessing of the information obtained.

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Table 9. *Result of the weighting of the criteria and the percentage of influence*

CATEGORY	No. CRITERIA	CRITERION	LAYER SIG	SUMMATION WEIGHTING CRITERION	% INFLUENCE ADJUSTED TO THE WHOLE
PERFORMANCE AND COMFORT	1	Achieve expected service life spans	Via_Buen_Estado2	144	7,0%
	2	Improve the quality of the running surface	Via_IRI	136	6,0%
	3	Maintain the structural condition of the road	Via_Estructural	135	6,0%
	4	Increasing road safety	Via_Fricción	136	6,0%
ENVIRONMENTAL	5	Reduce noise	Ruido_Automotor_Noche_4m	110	5,0%
	6	Reduce traffic congestion	Via_Reconstruccion	142	6,0%
	7	Reduce pollution and pollution on the road in good condition and with high vehicular circulation	T3_Via_Buen_Estado2	124	6,0%
	8	Reduce pollution and pollution on roads in poor condition and with high vehicular circulation	T3_Via_Mal_Estado2	141	6,0%
POLITICAL AND SOCIAL	9	Address community complaints (verbal, PQRS, social networks).	Reportes daños	121	5,0%
	10	Improve the condition of pavement of road sections with land uses of greater economic activity	Uso_Suelo	144	7,0%
	11	Improve accessibility to points of interest or high affluence.	Equipamiento	147	7,0%
	12	Increase beneficiary population.	D_DensidadHabitacional_Barrio	132	6,0%
ECONOMY AND TRANSPORT	13	Improve pavement condition on main **arterial road**: With high circulation of public transport vehicles and cargo transport.	Arteria_Principal	165	7,0%
	14	Improve pavement condition in **secondary artery road**: With medium circulation of public transport vehicles and cargo transport.	Arteria_Secundaria	143	6,0%
	15	Improve pavement condition on **collector road**: With low circulation of public transport vehicles and cargo transport	Colectora	121	5,0%
	16	Improve pavement condition on **service roads with residential characteristics**: For the circulation of light vehicles, eventually circulation of cargo vehicles.	Via_Servicio_Res	94	4,0%
	17	Improve pavement condition on **service roads with industrial and / or commercial characteristics**: For circulation of cargo vehicles.	Via_Servicio_Ind_Co	112	5,0%
			TOTAL	2.247	100,0%

In the multi-criteria matrix, the experts weighted each of the alternatives for each criterion to be resolved. Then through the "Payment Matrix," which is defined as a tool to organize the data to facilitate the choice of an alternative in decision making, the weights of each alternative for each criterion were averaged, as indicated in (Table 10).

Table 10. *Payment matrix (Double entry matrix – criteria vs alternatives)*

Payment matrix (Double entry matrix - criteria vs alternatives)							
	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7
Criterion 1	4	7	7	5	7	7	1
Criterion 2	4	6	8	8	5	5	1
Criterion 3	5	6	7	5	6	6	1
Criterion 4	4	6	7	8	7	5	1
Criterion 5	4	6	8	8	6	4	1
Criterion 6	5	7	6	6	5	5	1
Criterion 7	2	3	5	6	6	5	1
Criterion 8	7	7	6	5	5	4	1
Criterion 9	4	5	7	4	7	6	1
Criterion 10	5	7	8	7	6	6	1
Criterion 11	5	6	8	7	7	6	1
Criterion 12	4	6	7	6	7	6	1
Criterion 13	6	8	8	6	6	6	1
Criterion 14	5	7	8	6	7	6	1
Criterion 15	4	6	7	6	8	7	1
Criterion 16	4	5	6	6	8	7	1
Criterion 17	5	7	8	4	7	6	1

With the results of the Criteria Weight Matrix (Table 8A) and (Table. 8B) and the Payment Matrix (Table 10), the "Average of Alternatives" was calculated, which is the result of applying the average of the sum of the multiplications of the corresponding entries of two matrices (Alternative and Expert) applied for all experts. According to the score obtained, the order of priority or importance of the alternative to be used in decision making is established. The results are seen in (Table 11).

Table 11. *Calculation of the average of the alternatives*

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7
Average alternatives	603,69	822,50	940,13	798,94	845,13	750,00	131,56
Order of priority	6	3	1	4	2	5	7
% de incidence	12,34%	16,81%	19,22%	16,33%	17,28%	15,33%	2,69%

The alternative with the highest score (Table 12) is the intervention that stands out in the decision-making based on the specific evaluation of each road segment.

Table 12. *Order of importance of the alternatives*

Order of importance			
No.	**Alternative**		**Incidence %**
1	Alt 3	Resurfacing or repave, Installation of an asphalt layer on an existing pavement structure, whose purpose is to perform structural reinforcement and / or improve comfort conditions. This alternative is feasible after field evaluation, verifying that the resurfacing levels do not drastically affect the minimum curb heights of the road, nor affect the minimum clearance heights at overpasses, bridges or urban tunnels. Periodic maintenance activity.	19.22%
2	Alt 5	Maintenance with patching works, execution of repair of the surface of the pavement that present pathologies that need to be addressed to recover the conditions of functionality and in many cases improve road safety, the decision to execute maintenance work is linked to the percentage of affectation of the pavement structure, where the pavement condition index must be above the value of 55 points. to repair gaps in the tracks and eliminate faults present on the surface of the pavement. Routine maintenance activity.	17.28%
3	Alt 2	Rehabilitation of the pavement, removal of the asphalt layer due to surface deterioration or deformations in the pavement that does not compromise its structural behavior.	16.81%
4	Alt 4	Installation of microagglomerate type mixtures. Installation of a discontinuous asphalt layer that has no structural contribution, but if it provides greater grip between the tire and the pavement, drains the pavement surface more quickly and reduces noise compared to the use of pavements with conventional asphalt mixtures. All this increases comfort and road safety for the driver. Periodic maintenance activity.	16.33%
5	Alt 6	Maintenance by means of crack sealing, work executed in isolated fissures whose purpose is to prevent the filtration of water into the underlying layers, prolonging the useful life of the pavement. Routine maintenance activity.	15.33%
6	Alt 1	Reconstruction of pavement structure, intervention of the pavement at the structural level due to the state of deterioration of its granular layers and running, added to the structural insufficiency.	12.34%
7	Alt 7	Do nothing and let the pavement continue in the process of deterioration according to what is established in its design period.	2.69%

3.1 Prioritization of roads

Once the maps were consolidated and converted into raster formats with their respective reclassification according to Table No. 8, the weighted superimposition of maps was applied, which allows multi-criteria evaluations to be carried out to solve decision problems where several factors with different evaluations intervene (GEASIG, 2023).

In the weighted overlay, each input raster is weighted according to the importance or influence on the entire set of criteria (Table 9). The weight is a relative percentage and the sum of the percentage influence weights must equal 100. Influences are expressed using integer values only (ArcGIS Pro, 2023).

To determine the prioritized paths from the MCA, the influence results of each criterion were used (Table 9), and the scale of values reclassified by each "Raster" type map that represents the criterion (Table 7) was used. The results were grouped in the ArcGIS software geoprocessing tool called "Weighted Overlay" (Figure 4), which was used to perform the weighted superposition of the maps and consolidate in a single map the prioritization of the roads represented in the cell values.

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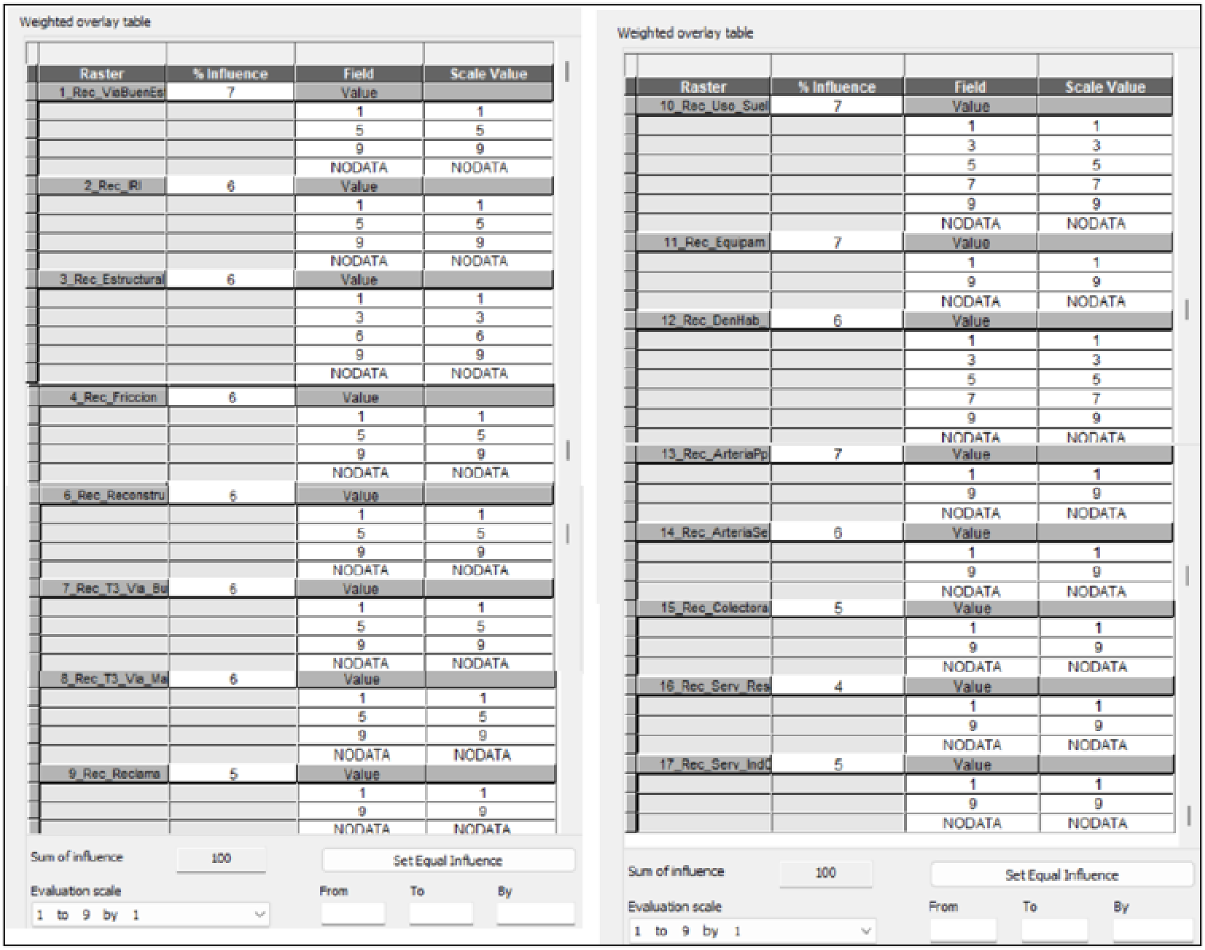

Weighted overlay table

Raster	% Influence	Field	Scale Value
1_Rec_ViaBuenEs	7	Value	
		1	1
		5	5
		9	9
		NODATA	NODATA
2_Rec_IRI	6	Value	
		1	1
		5	5
		9	9
		NODATA	NODATA
3_Rec_Estructural	6	Value	
		1	1
		3	3
		6	6
		9	9
		NODATA	NODATA
4_Rec_Friccion	6	Value	
		1	1
		5	5
		9	9
		NODATA	NODATA
6_Rec_Reconstru	6	Value	
		1	1
		5	5
		9	9
		NODATA	NODATA
7_Rec_T3_Via_Bu	6	Value	
		1	1
		5	5
		9	9
		NODATA	NODATA
8_Rec_T3_Via_Ma	6	Value	
		1	1
		5	5
		9	9
		NODATA	NODATA
9_Rec_Reclama	5	Value	
		1	1
		9	9
		NODATA	NODATA

Sum of influence 100 Set Equal Influence
Evaluation scale 1 to 9 by 1 From To By

Weighted overlay table

Raster	% Influence	Field	Scale Value
10_Rec_Uso_Suel	7	Value	
		1	1
		3	3
		5	5
		7	7
		9	9
		NODATA	NODATA
11_Rec_Equipam	7	Value	
		1	1
		9	9
		NODATA	NODATA
12_Rec_DenHab	6	Value	
		1	1
		3	3
		5	5
		7	7
		9	9
		NODATA	NODATA
13_Rec_ArteriaPp	7	Value	
		1	1
		9	9
		NODATA	NODATA
14_Rec_ArteriaSe	6	Value	
		1	1
		9	9
		NODATA	NODATA
15_Rec_Colectora	5	Value	
		1	1
		9	9
		NODATA	NODATA
16_Rec_Serv_Res	4	Value	
		1	1
		9	9
		NODATA	NODATA
17_Rec_Serv_IndC	5	Value	
		1	1
		9	9
		NODATA	NODATA

Sum of influence 100 Set Equal Influence
Evaluation scale 1 to 9 by 1 From To By

Figure 4. *Information loaded for the weighted overlay of the 17 criteria in the GIS tool "Weighted Overlay"*

The result of the geoprocessing using the weighted overlay is seen in the "Prioritization" map in (Figure 5) and (Figure 6), in which the required priority of the urban road network of the case study can be spatially identified in traffic light-type color convention on a scale from 1 to 6, the highest and most critical value (red).

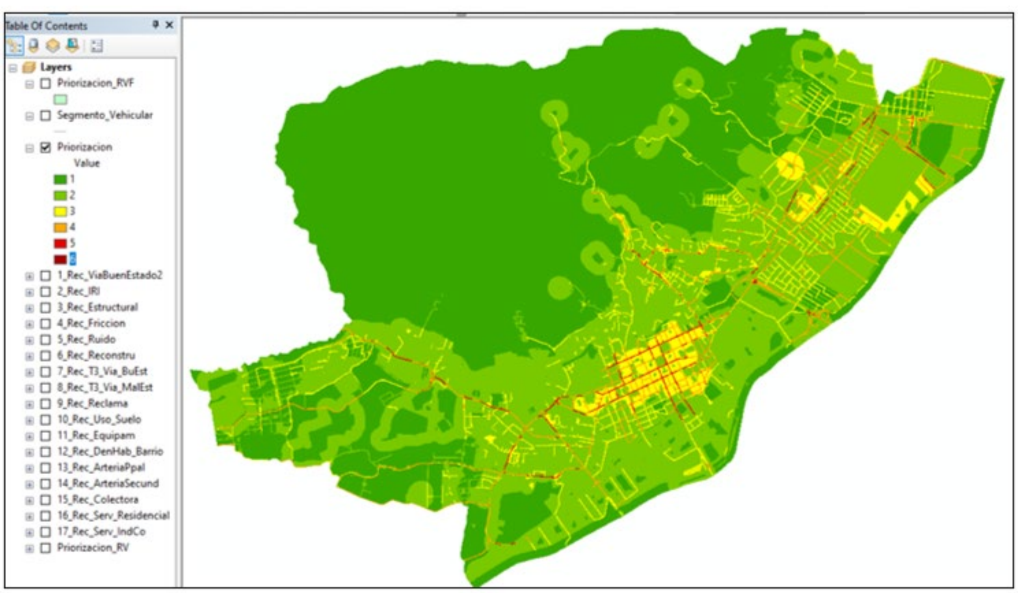

Figure 5. *"Priorizacion" Map. Result of the weighted overlay of the criteria represented in maps*

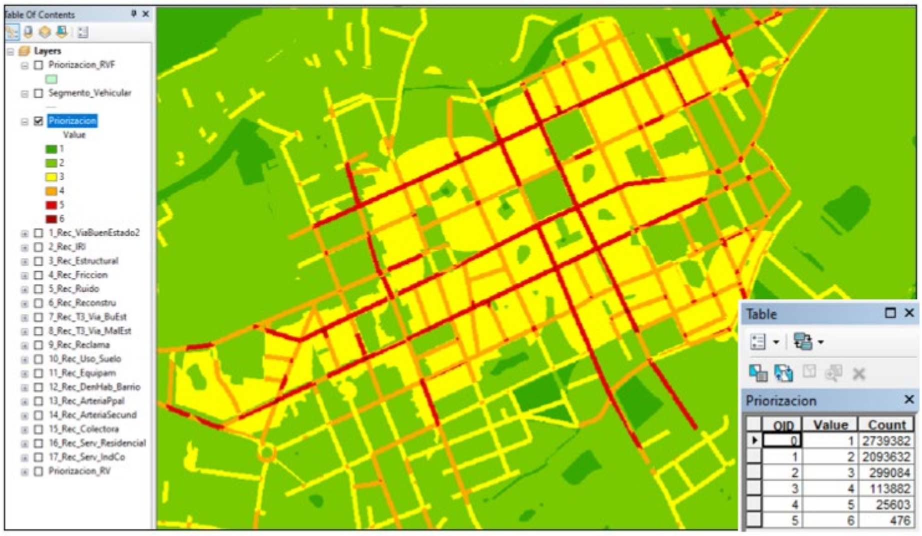

Figure 6. *"Priorizacion" Map Detail, result of the weighted superposition of the criteria represented on maps*

In the result obtained from the "Priorizacion" raster map in the attribute table, cell values that range from 1 to 6 are obtained; each cell value contains the pixel count that are part of that value. To simplify the visualization of the information, the cell values were grouped into four priority categories, according to what is indicated in (Table 13).

Table 13. *Classification of cell values of the prioritization raster map*

Grouped cell value	Priority	Convention
1 a 2	Low	
2,001 a 3	Half	
3,001 a 4	high	
4,001 a 6	Very high	

The "Priorizacion" map has cell values that are not part of the road network, so they were extracted by performing geoprocessing with a "vehicular road network buffer" from the case study, found in the box of GIS tools "Zonal," specifically the tool "Zonal Statistics." This tool also allowed the cell values to be unified within a road segment by statistically applying the MEDIAN, which determines the average value of all the cells in the raster of values that belong to the same area (segment) as the output cell. The result of the geoprocessing is shown in (Figure 7).

Figure 7. *Map "Resultado" of prioritization of the road network of the city of Itagui case study*

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In the result obtained from the "Resultado" raster map, cell values ranging between 1 and 5 are obtained in the attribute table. Each cell value contains the count of pixels that are part of that value; to simplify the visualization of the information, the cell values were grouped into four priority categories, according to what is indicated in (Table 14).

Table 14. *Prioritization raster map cell value sorting*

Grouped cell value	Priority	Convention
1 a 2	Low	
2,001 a 3	Half	
3,001 a 4	high	
4,001 a 5	Very high	

Once the information has been purified, the results of prioritization in greater detail are seen in (Figure 8), which presents the sections fully defined in the cell values for each road segment, a situation that can be compared with (Figure 8) showing different cell values for the same road segment.

Figure 8. *Detail "Resultado" map of prioritization of the road network of the case study*

To identify the nomenclature and other relevant data of the roads to be prioritized, the "Resultado" map is subject to geoprocessing to convert it back to the "Prioridad_Vial" shapefile format in the attribute table that contains the information of each road segment (Figure 9). The "Prioridad" column stands out, indicating the scale of importance, with the highest value being the most critical value in prioritizing the road network; that is why each road segment with a high priority scale must be the object of review and attention by the administrator of the urban road network to schedule the interventions according to the state of the road, validating with the order of importance of the intervention alternatives in (Table 12).

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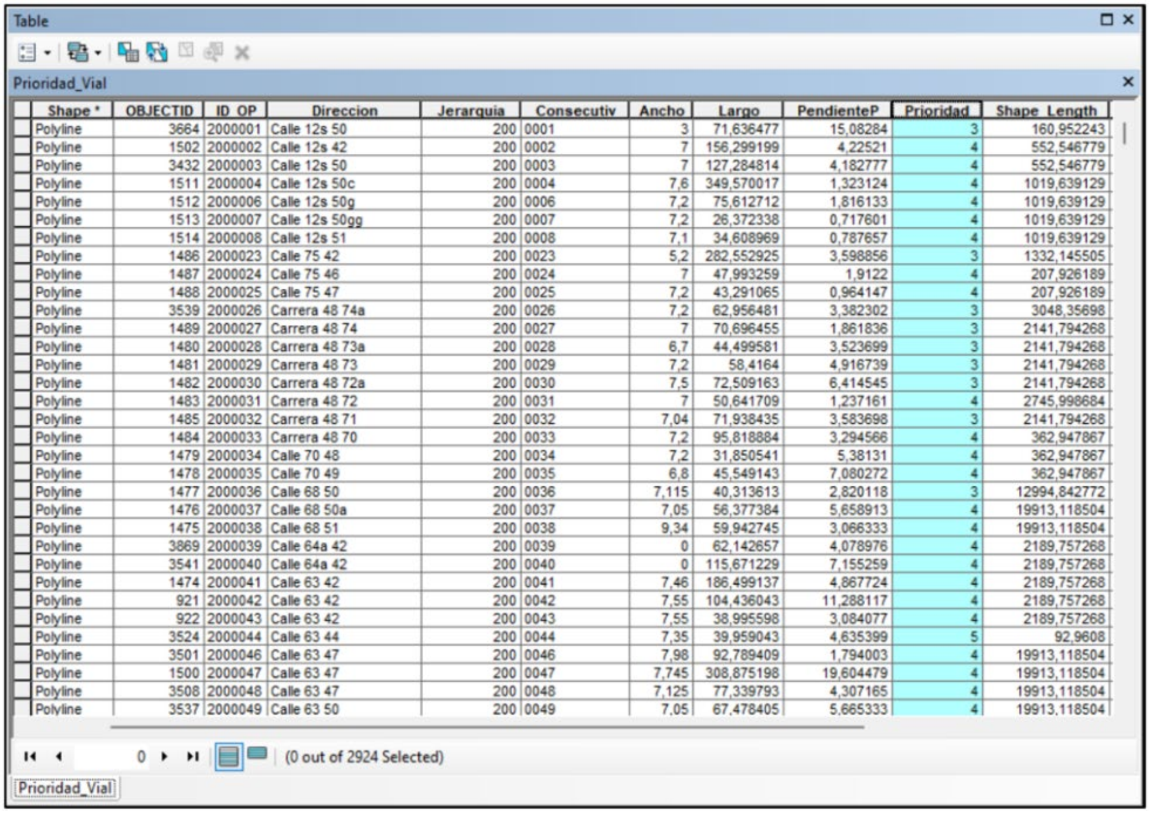

Table

Prioridad_Vial

Shape *	OBJECTID	ID_OP	Direccion	Jerarquia	Consecutiv	Ancho	Largo	PendienteP	Prioridad	Shape_Length
Polyline	3664	2000001	Calle 12s 50	200	0001	3	71,636477	15,08284	3	160,952243
Polyline	1502	2000002	Calle 12s 42	200	0002	7	156,299199	4,22521	4	552,546779
Polyline	3432	2000003	Calle 12s 50	200	0003	7	127,284814	4,182777	4	552,546779
Polyline	1511	2000004	Calle 12s 50c	200	0004	7,6	349,570017	1,323124	4	1019,639129
Polyline	1512	2000006	Calle 12s 50g	200	0006	7,2	75,612712	1,816133	4	1019,639129
Polyline	1513	2000007	Calle 12s 50gg	200	0007	7,2	26,372338	0,717601	4	1019,639129
Polyline	1514	2000008	Calle 12s 51	200	0008	7,1	34,608969	0,787657	4	1019,639129
Polyline	1486	2000023	Calle 75 42	200	0023	5,2	282,552925	3,598856	3	1332,145505
Polyline	1487	2000024	Calle 75 46	200	0024	7	47,993259	1,9122	4	207,926189
Polyline	1488	2000025	Calle 75 47	200	0025	7,2	43,291065	0,964147	4	207,926189
Polyline	3539	2000026	Carrera 48 74a	200	0026	7,2	62,956481	3,382302	3	3048,35698
Polyline	1489	2000027	Carrera 48 74	200	0027	7	70,696455	1,861836	3	2141,794268
Polyline	1480	2000028	Carrera 48 73a	200	0028	6,7	44,499581	3,523699	3	2141,794268
Polyline	1481	2000029	Carrera 48 73	200	0029	7,2	58,4164	4,916739	3	2141,794268
Polyline	1482	2000030	Carrera 48 72a	200	0030	7,5	72,509163	6,414545	3	2141,794268
Polyline	1483	2000031	Carrera 48 72	200	0031	7	50,641709	1,237161	4	2745,998684
Polyline	1485	2000032	Carrera 48 71	200	0032	7,04	71,938435	3,583698	3	2141,794268
Polyline	1484	2000033	Carrera 48 70	200	0033	7,2	95,818884	3,294566	4	362,947867
Polyline	1479	2000034	Calle 70 48	200	0034	7,2	31,850541	5,38131	4	362,947867
Polyline	1478	2000035	Calle 70 49	200	0035	6,8	45,549143	7,080272	4	362,947867
Polyline	1477	2000036	Calle 68 50	200	0036	7,115	40,313613	2,820118	3	12994,842772
Polyline	1476	2000037	Calle 68 50a	200	0037	7,05	56,377384	5,658913	4	19913,118504
Polyline	1475	2000038	Calle 68 51	200	0038	9,34	59,942745	3,066333	4	19913,118504
Polyline	3869	2000039	Calle 64a 42	200	0039	0	62,142657	4,078976	4	2189,757268
Polyline	3541	2000040	Calle 64a 42	200	0040	0	115,671229	7,155259	4	2189,757268
Polyline	1474	2000041	Calle 63 42	200	0041	7,46	186,499137	4,867724	4	2189,757268
Polyline	921	2000042	Calle 63 42	200	0042	7,55	104,436043	11,288117	4	2189,757268
Polyline	922	2000043	Calle 63 42	200	0043	7,55	38,995598	3,084077	4	2189,757268
Polyline	3524	2000044	Calle 63 44	200	0044	7,35	39,959043	4,635399	5	92,9608
Polyline	3501	2000046	Calle 63 47	200	0046	7,98	92,789409	1,794003	4	19913,118504
Polyline	1500	2000047	Calle 63 47	200	0047	7,745	308,875198	19,604479	4	19913,118504
Polyline	3508	2000048	Calle 63 47	200	0048	7,125	77,339793	4,307165	4	19913,118504
Polyline	3537	2000049	Calle 63 50	200	0049	7,05	67,478405	5,665333	4	19913,118504

0 (0 out of 2924 Selected)

Prioridad_Vial

Figure 9. *Image of the Attribute Table of the "Prioridad_Vial" shapefile of the case study*

The table of attributes in the GIS (Figure 9) allows calculating the intervention lengths of the road network according to the established priority, as shown in (Table 15).

Table 15. *Results: Intervention lengths and road prioritization*

PRIORIDAD	No. SEGMENTOS	LONGITUD (KM)	CATEGORÍA
5	137	9,46	
4	654	49,27	
3	1110	73,36	
2	956	56,59	
1	58	7,45	
TOTAL	**2.915**	**196,13**	

4. Conclusions

• This research established that it is possible and viable to prioritize road intervention, through the operation of a UPMS applying multi-criteria analysis; its main objective is to improve the service conditions of the road segments that make up the urban road network, using Geographic Information Systems.
• This process generates a list of priorities of the road segments included in the urban road network. The scores obtained are used by the road network administrator to make decisions, so as to execute the required alternative based on the condition of the road segment.
• The work carried out allowed us to structure the prioritization of roads for the intervention of urban asphalt pavements, which for the case of study are of high incidence in the network; based on a similar structure of multi-criteria analysis, the research can be expanded to prioritize the intervention of concrete and cobblestone pavements in cities that have a large extension of this type of pavements.
• The structuring of the multi-criteria matrix can be adjusted or complemented in criteria according to the availability of cartographic information that the territorial entity has; however to do so, the MCA surveys must be completed by experts in road infrastructure.
• The preference of the experts surveyed to resolve the proposed criteria is to use alternative number 3 "Resurfacing or repaving on existing pavement structures." Within the development of the UPMS, that is an economically and technically viable alternative, given that it allows the restoration of the pavement conditions at a low cost (depending on the surface condition of the road to be intervened and the height of the existing curbs in the road segment), as well as reinforces the existing pavement structure, prolonging its useful life.
• The criterion that indicates the highest value in the general weighting is number 13 "Improve pavement condition on the main arterial road: With high circulation of public transport vehicles and freight transport." When validating the data from the payment matrix (Table 13), the intervention alternatives to be used for this criterion, with an average score of 8 points each, are alternatives No. 2 "Pavement rehabilitation" and No. 3 "Repaving

or resurfacing on existing pavement structures." This allows us to conclude that these should be the preferred alternatives to execute the UPMS on main arterial roads.

• In each of the categories, with the results obtained in the development of the multi-criteria matrix, the UPMS must be oriented to "Achieve the expected useful life periods" (criterion No. 1, category No 1), "Reduce the use of non-renewable materials and/or recycle part of the materials in the process of improving the quality of the road" (criterion No. 6, category No. 2), "Improve accessibility to points of interest or high traffic" (criterion No. 11, category No. 3), "Improve pavement condition on main arterial road: With high circulation of public transportation vehicles and freight transportation" (criterion No. 13, category No. 4). These criteria must represent greater attention to the implementation of a UPMS according to the needs qualified by the panel of experts.

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