DESIGN ALTERNATIVES FOR THE URBAN RING ROAD OF THE CITY OF VIÇOSA-MG-BRAZIL, THROUGH GIS INTEGRATION – MULTICRITERION ANALYSIS

Taciano Oliveira da Silva[1]
Maria Lúcia Calijuri[1]
Vicente Paulo Soares[2]

[1]Federal University of Viçosa - UFV
Civil Engineering Department
Av. P.H. Rolfs s/n, Campus Universitário, CEP-36570-000. Viçosa-MG, Brazil.
taciano@vicosa.ufv.br
calijuri@ufv.br

[2]Federal University of Viçosa - UFV
Forest Engineering Department
Av. P.H. Rolfs s/n, Campus Universitário, CEP-36570-000. Viçosa-MG, Brazil.
vicente@ufv.br

ABSTRACT

The routines of support to decision-making in the environment of Geographical Information Systems (GIS) have provided an increase in both flexibility and complexity of analyses by means of this tool. This work presents the application of tools of support to the decision-making in Geographical Information System in order to assist in the evaluation of design alternatives for the urban ring road of the city of Viçosa, Minas Gerais State, Brazil. The selection of alternatives was possible through the application of integration GIS – Multicriterion analysis, employed in analyses related to available and viable areas according to geotechnical, relief, socio-economical, operational and environmental aspects. The spatial data analysis and processing was performed with the utilization of supporting modules to the decision of software GIS Idrisi 32. The result of the accomplished simulations comprises a very important subsidy to the decision-making on the best design alternatives, making possible a technical selection according to the previously mentioned aspects. The model proposed in this work can be easily incorporated to studies and anteprojects of road designs or to other infrastructure works without necessarily incurring high costs.

Keywords: Planning, Transport System, Geographical Information Systems, Multicriterion Analysis.

1. INTRODUCTION

At the beginning of this XXI century, one of the biggest challenges for administrators and municipal planners consists of improving the quality of life in big cities. One of these challenges takes into account the requirements of the population regarding its needs of transit inside the city perimeter. It is then important to invest in road systems as well as in transport systems in order to ease the transit of people and merchandise and minimize the impact created by the massive use of vehicles. However, it is necessary to decrease operational costs, atmospherical and noise pollution caused by the intensity of traffic of vehicles and, mainly, the social and psychological problems created by traffic due to traffic jams.

The possibility to combine cartographic and tabular information, as well as inlay specific and/or subjective knowledge into one analysis, makes GIS a useful tool to the planning of undertakings. Planning can be defined as the human rational application of knowledge to the process of decision-making in order to obtain an optimal utilization of resources for getting the maximum benefits to the collectivity (Santos & Nascimento, 1992).

In Brazil, the main urban transportation means and good distribution is the highway transportation system. In this context, urban and rural roads are remarkable to make the transit of people and distribution of products viable, being irrefutable the importance of a safe transport system with capacity to attend the demand.

Over the years, the city of Viçosa-MG has gone through transformations in its design due to the bulk of urban population growth, not followed by a continuous planning system, which has resulted in an untimely appearance of urban problems such as the concentrated transit of vehicles and people.

This work presents an application of supporting tools to the decision in GIS in order to help in the evaluation of design alternatives for the ring road of the city of Viçosa-MG. The aim was to identify the best alternatives of design to be, afterwards, submitted to more detailed studies. The studied area (hydrographic basin of São Bartolomeu stream) is located in the municipal district of Viçosa at North of Zona da Mata of the state of Minas Gerais, and it comprises a surface of 54,74 km^2, as shown in figure 1. The proposed designs must enable mutual accessibility between downtown and the suburbs as well as the intercenter access besides taking advantage of the designs of existing paved and non-paved roads as a way of minimizing costs and environmental impacts.

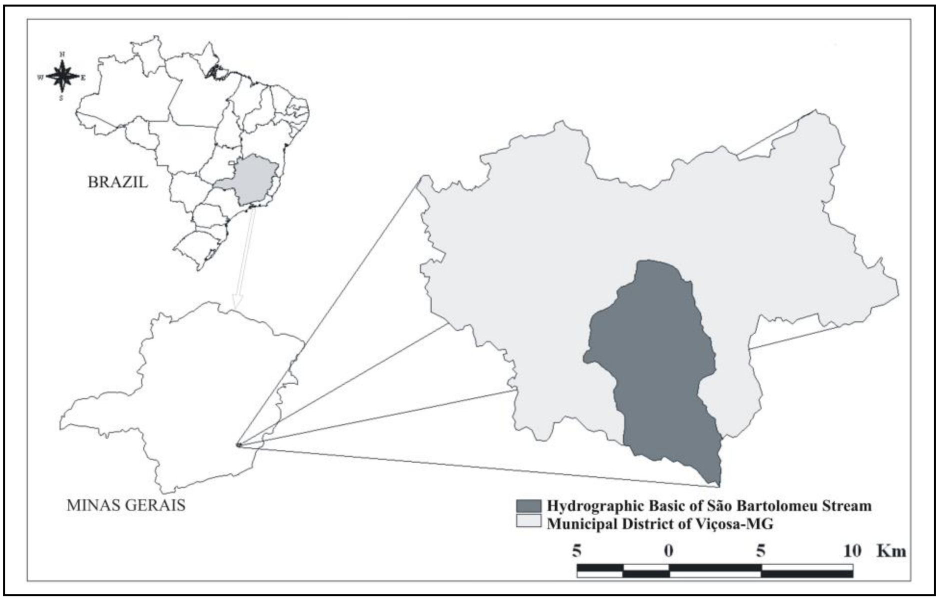

Fig. 1 - Site of the studied area.

2. MATERIALS AND METHODS

The materials and equipments used in the development of the present work were:

- Planialtimetric map, in digital format, of the city of Viçosa-MG (2000), with vertical equidistance of 10 meters between contour line, in the 1:50.000 scales, provided by SAAE-Viçosa-MG (Serviço Autônomo de Água e Esgoto de Viçosa).
- Map in digital format of hydrography (IBGE, 1979) of the hydrographic basin of São Bartolomeu stream, in the 1:50.000 scales.
- Map in digital format of soil classes (1994) of the hydrographic basin of São Bartolomeu stream, in the 1:50.000 scales.
- Map in digital format of soil use and occupation (2000) of the hydrographic basin of São Bartolomeu stream, in the 1:50.000 scales.

- Map of the road system of the city of Viçosa (IBGE, 1979), in the scale of 1:50.000.
- Software AutoCAD 2000, © Autodesk, Inc (1982 – 1999).
- Software GIS ArcView 3.2a, © Environmental System Research Institute, Inc.
- Software GIS Idrisi 32, Version l32.2, May 2001, © The Clark Labs for Cartographic Technology and Geographic Analysis.
- Microcomputer *Pentium* and peripherals.

The methodological proposal of the research and evaluation of the possible areas for the design of the urban ring road proposed for the city of Viçosa, utilizing *fuzzy* logic and multicriterion analysis comprised the survey and analysis of conditioners that were considered according to data available in altitude maps, hydrography, declivity, transport system, soil class, and mainly use and actual coverage of land and soils, and posterior spatial analysis of these georeferenced data.

2.1 Evaluation Multicriterion

The influence of data on the definition of congruent areas to the design of the urban ring road of the city of Viçosa was defined taking into account the criteria (restrictions and factors) adopted. As a result, some data were classified in intervals due to their aptitude for the desired use, becoming factors, and others, in absolute barriers, hindering the use of the areas, becoming restrictions.

The influence of data on the definition of congruent areas to the design of the urban ring road of the city of Viçosa was defined taking into account the criteria (restrictions and factors) adopted. As a result, some data were classified in intervals due to their aptitude for the desired use, becoming factors, and others, in absolute barriers, hindering the use of the areas, becoming restrictions.

2.1.1 Definition of the criteria and indicators

According to Pomeranz (1992), the most common way to translate the divergent interests of society is to determine criteria by category. The final evaluation in this case requires consideration among the diverse values of society (economical, social, political, and so on), that is, the attempt to find a satisfactory balance point among these values.

Regarding the formulation of indicators, Pomeranz (1992) identifies two groups of problems being one theoretical and the other, operational. From the operational point of view, the author suggests the curtailment of the indicators to a sufficient number for judgment and a reasonable decrease in order not to make difficult the creation of an evaluation chart and its utilization. In addition, she recommends the selection of indicators that effectively constitute evaluation factors; the expression of indicators in language of common meaning, particularly when it refers to qualitative indicators; the establishment of criteria and rating systems of qualitative indicators, which would not allow the minimum doubt in the interpretation of the results.

From the theoretical point of view, it is recommended to search for fundaments for the resolution of the referred operational problems in a way to obtain coherence between the proposed methodology and its theoretical basis. It is also recommended to identify not only the magnitude of effects but also their distribution in time with the intent to make possible the reduction of effects in compatible temporal basis (Pomeranz, 1992).

Table 1 shows the criteria (restrictions) and indicators that were established in order to found the proposed methodology, which takes into consideration multiple criteria disposed in hierarchical levels. Such criteria and indicators were selected as the most significant aspects to the analysis.

TABLE 1: CRITERIA (RESTRICTIONS) AND INDICATORS OF THE PROPOSED MODEL

CRITERIA (Restrictions)	INDICATORS	
Level 1	Level 2	Level 3
SOCIO-ECONOMICAL ASPECT	▪ Urban nucleus	
ENVIRONMENTAL ASPECT	▪ Biotic medium	▪ Crossing of areas of ponds and riverheads

Table 2 shows the criteria (factors) and indicators of the proposed model.

TABLE 2: CRITERIA (FACTORS) AND INDICATORS OF THE PROPOSED MODEL

CRITERIA (Factors)	INDICATORS	
Level 1	Level 2	Level 3
RELIEF ASPECT	▪ Classes of declivity	▪ Propitious areas
		▪ Areas with some restrictions
		▪ Areas with severe restrictions
GEOTECHNICAL ASPECT	▪ Estimate of classification MCT (Miniature, Compacted, Tropical) for the types of soils (subgrade)	▪ Cambissoil Lotossolic (CL)
		▪ Red Yellow Podzolic Cambic (PV)
		▪ Red Yellow latossoil (LV)

SOCIO-ECONOMICAL ASPECT	▪ Impacts on the use of rural soil	▪ Crossing of areas of coffee plantations
		▪ Crossing of areas with other uses
		▪ Crossing of reforesting areas
		▪ Crossing of exposed soil areas
		▪ Crossing of pasture areas
OPERATIONAL ASPECTS	▪ Distance of the limits of the city of Viçosa-MG	
	▪ Distance of the highways (BR 120, MGT 356, MGT 482, MG 280)	
ENVIRONMENTAL ASPECTS	▪ Biotic medium	▪ Crossing of brushwood and secondary forest areas
	▪ Physical medium	▪ Interferences with hydric resources

2.2 Standardization of the Criteria (factors)

After the establishment of the hierarchical structure of the criteria and indicators, the attention was turned to the existence of a diversity of scales in which several criteria are evaluated. At this point, a process of conversion of values of the original data in intervals of aptitude to the desired proposal, applying the pre-established criteria through expressions of pertinence to decision groups is essential.

In addition to allowing the transformation of units of the criteria (factors) into one unique basis of mensuration, standardization also serves the purpose of internally hierarchizing each criterion (factors) describing how the aptitude for highway designs varies spatially. The values of all factors were converted to the interval of one byte (0 to 255) in the proposed model.

Table 3 shows the indicators associated with the criteria (factors) of the proposed model, the adopted *fuzzy* functions and their respective control points.

TABLE 3: INDICATORS ASSOCIATED WITH THE CRITERIA (FACTORS) OF THE PROPOSED MODEL, THE ADOPTED FUZZY FUNCTIONS AND THEIR RESPECTIVE CONTROL POINTS

Criteria (factors)	Indicators	*Fuzzy* function	Control point			
			a	b	c	d
Relief aspect	▪ Classes of declivity	Scale [0 – 255]	-----------------------------			
Geotechnical aspect	▪ Estimate of classification on MCT for the types of soils (subgrade)	Scale [0 – 255]	-----------------------------			
Socio-economical aspect	▪ Impacts on the use of rural soil	Scale [0 – 255]	-----------------------------			
Operational aspects	▪ Distance of the limits of the city of Viçosa-MG (m)	Linear Symmetric with Platform	1.000	2.000	5.000	6.000
	▪ Distance of the highways (m)	Linear Decreasing Monotonic	1.500	3.000	3.000	3.000
Environmental aspects	▪ Biotic medium	Scale [0 – 255]	-----------------------------------			
	▪ Physical medium	Linear Increasing Monotonic	200	500	500	500

2.2.1 Description of the criteria (restrictions) of the proposed model

<u>I. socio-economical aspect</u> - Urban nucleus: The urban nucleus was individualized. Area of the urban nucleus: Suitability zero.

<u>II. environmental aspect</u> - Biotic medium: areas of protection that circumvent areas of ponds and riverheads were determined at a marginal range of 100 and 50 meters respectively. Areas of ponds and riverheads: Suitability zero.

2.2.2 Description of the criteria (factors) of the Proposed Model

<u>I. relief aspect</u> - Classes of declivity: Three categories of areas based on the classes of declivity of the terrain of the studied area were established according to Cunha (1991). The suitability of the classes of declivity was adopted taking into account the maximum longitudinal inclination (greide) acceptable for the roads for the transit of vehicles. In this way, smaller suitability values were adopted for the topographically unfavorable areas as observed below:

- Areas with Severe Restrictions: 31% - 50% (17,3º - 26,6º). Suitability: 130;
- Areas with some restrictions: 16% - 30% (9,1º - 16,7º). Suitability: 210;
- Favorable Areas: 0% - 15% (0º - 8,5º). Suitability: 255.

The reason why the suitability value of 130 was adopted to the indicator *Areas with Severe Restrictions* was that in some multicriterion analyses carried out previously utilizing suitability values equal to 60, 80 and 100, it was verified that these suitability ranges curtailed the analysis making impracticable the selection and determination of areas for the proposed aim as the studied area is characterized by a strongly irregular topography, presenting reduced portions of plane areas.

II. geotechnical aspect - Estimate of classification MCT for the types of soils (subgrade): From the point of view of the terminologies of classification MCT (Miniature, Compacted, Tropical), the suitability referring to the behavior of the subgrade soils had the following adopted values:

- Non Lateritic Clay Soil – Cambissoil Lotossolic (CL): Suitability 120;
- Non Lateritic Clay Soil – Red Yellow Podzolic Cambic (PV): Suitability 200;
- Lateritic Clay Soil – Red Yellow Latossoil: Suitability 255.

III. socio-economical aspect - Impacts on the use of rural soil: The types of soil use and occupation considered to be a socio-economical criterion (factors) were coffee plantation areas, areas with other uses, reforesting areas, pasture and exposed soil areas.

In this case, the suitability of the types of soil use and occupation was elected considering them as criteria (factors) related to society and to the cost of highway construction. Therefore, socially and economically unfavorable areas were considered with smaller suitability values. The chosen values were as follows:

- Crossing of coffee plantation areas: Suitability 160;
- Crossing of areas with other uses: Suitability 190;
- Crossing of reforesting areas: Suitability 210;
- Crossing of pasture areas: Suitability 230;
- Crossing of exposed soil areas: Suitability 255.

IV. operational aspects - Distance of the limits of the city of Viçosa-MG: The *fuzzy* function utilized for the continuous standardization of suitability was the Linear Symmetric with Platform, for which determined augmentation in the distance regarding the limits of the city of Viçosa, the value of suitability remained constant as the existence of an interval was considered, in which the sites are equally adequate.

The suitability ranges were adopted taking into account the importance of the urban ring road design to be relatively close to the limits of the city concerning its operational conditions. The distances between 2,000 m and 5,000 m were considered with maximum suitability.

Distance of the highways: This indicator presents as main characteristic the maximum acceptable distance of 3,000 m in order to attend the economically viable need of connections between the proposed model and the highways BR 120, MGT 356, MGT 482, MG 280. It is understood that distances which are superior to 3,000 m would burden the costs of the undertaking. With the aim to determine the continuous standardization of suitability of this indicator, the fuzzy function Linear Decreasing Monotonic was utilized.

V. environmental aspects - Biotic medium: The indicator "*Crossing of Brushwoods and Secondary forests areas*" presents as main characteristic the area of deforesting and subgrade preparation in areas of native forests. With the intent to attend the need of minimization of negative environmental impacts, the continuous standardization of suitability of the mentioned areas was adopted taking into consideration their low aptitude for the implementation of the project being carried out. In this way, these environmentally unfavorable areas were considered with the suitability value of 160.

Physical medium: The indicator "Interferences with hydric resources" presents as main characteristic the minimum distance of 200 meters from rivers, streams and brooks circumventing the studied area. The indicator was established based on the eventuality of impacts during the work stage such as silting ups caused by land work as well as during the operation stage such as spilling of toxic loads as grease and oil released by vehicles. For such case, the fuzzy function Linear Increasing Monotonic was utilized.

2.3 Evaluation of Weights for the Criteria (factors)

For the estimation of the factors, the comparison method between aspects was applied. Although it comprises a more complex and time-consuming method, which sometimes imposes interaction in order to guarantee a certain degree of acceptable consistency, the results and the procedure itself adapt perfectly to the problem of establishing design alternatives for a ring road. The module *Weight* utilizes this technique of comparison of pairs to develop a group of weights whose sum comprises the unity.

In this stage, a relation of importance was proposed among the factors involved in the process. This relation comprehended a group of assumptions about the factor that allowed both the verification of the importance degree of a factor in detriment of the other and the quantification of this importance. This happened due to the need to attribute different values to each factor during the aggregation process.

2.3.1 Aggregation of second level indicators

Aggregation of Operational indicators: The operational indicators "*Distance of the limits of the city of Viçosa-MG-MG*" and "*Distance of the highways*" were aggregated through the method of multicriterion analysis by Weighted Linear Combination (WLC) after the attribution of their respective weights.

- Balanced weight of the indicator "*Distance of the limits of the city of Viçosa-MG*": 0,75;
- Balanced weight of the indicator "*Distance of the highways*": 0,25.

The balanced weight of the operational indicator "*Distance of the highways*" was considered to be slightly less important than the balanced weight of the operational indicator "*Distance of the limits of the city of Viçosa-MG*" since it was the intention to prioritize the site of design of the ring road closer to the city limits.

Aggregation of Environmental indicators: The environmental indicators "Biotic medium" and "Physical medium" were also aggregated through the method of multicriterion analysis by Weighted Linear Combination (WLC) after the attribution of their respective weights.

- Balanced weight of the indicator "*Biotic medium*": 0,6;
- Balanced weight of the indicator "*Physical medium"*: 0,4.

The balanced weight of the environmental indicator "*Physical medium*" was considered to be a little less important than that of the indicator environmental "*Biotic medium*" since it was the intention to prioritize the crossing of native forest area a little more once this type of soil coverage takes up 20,57% of the studied area. An inverse analysis would restrict the application of the proposed model even more.

2.3.2 Aggregation of first level criteria (restrictions and factors)

The first level criteria (restrictions and factors) were aggregated through the method of multicriterion analysis by combination of Ordered Weighted Average (OWA), in which the respective balanced and ordered weights of the criteria (factors) were considered.

In the method OWA each criterion (factors) is multiplied by its respective weight. Then, these weights are added and divided by the number of criteria (factors). Finally, the weighted average is calculated for each image pixel.

By utilizing the method OWA, it is possible to control the position of the analysis in the risk axes and compensation, which allows the variation in the risk level assumed in the analysis and the degree in which the weight of the criteria (factors) influences the image of the final suitability.

Before aggregation, the relative weight among the criteria (factors) was performed through the module *Weight*, in which the factors were compared two by two in terms of their relative importance.

The criteria (factors) of the first level (Relief aspect, Geotechnical aspect, Socio-economical aspect, Operational aspects and Environmental aspects) were aggregated after the attribution of their relative importance and consequent calculus of balanced weights.

Table 4 shows the distribution of relative importance attributed to the first level factors.

TABLE 4: MATRIX OF COMPARISON BETWEEN ASPECTS AMONG THE FIRST LEVEL STANDARDIZED CRITERIA (FACTORS) WITH IMPORTANCE VALUES DEFINED TO THE PROPOSED AIM

	Relief Aspect	Geotechnical Aspect	Socio-economical Aspect	Operational Aspects	Environmental Aspects
Relief Aspect	1	-	-	-	-
Geotechnical Aspect	1/3	1	-	-	-
Socio-economical Aspect	1/5	1/3	1	-	-
Operational Aspects	3	3	5	1	-
Environmental Aspects	1/5	1/3	1	1/7	1

Table 5 presents the autovector of balanced weights calculated for the first level criteria (factors).

TABLE 5: AUTOVECTOR OF BALANCED WEIGHTS CALCULATED FOR THE FIRST LEVEL CRITERIA (FACTORS)

The vector author for the weights is:	
• Relief Aspect	0.2772
• Geotechnical Aspect	0.1421
• Socio-economical Aspect	0.0601
• Operational Aspect	0.4656
• Environmental Aspects	0.0550
Consistency Ratio = 0.04 (acceptable)	

The value of the Consistency Ratio (CR) was 0,04, showing that the judgment matrix was not inconsistent once values of consistency ratio inferior to 0,10 do not require reevaluation.

2.4 Criteria Combination (restrictions and factors)

In the combination of criteria (restrictions and factors) the most adequate sections were found for the designs of the proposed model.

2.4.1 Evaluation scenarios

Once all the weights were obtained, they were used as coefficients and multiplied by the image of the respective criterion (factors), being the addition of the products performed afterwards. In this way, in the final image each pixel represents the rate received taking into consideration all the chosen criteria (factors) and the weights attributed to them in the joint analysis. The sections of larger values were those that, according to pre-established criteria (factors), were the best ones to delineate the designs for the proposed model. The routine MCE (Multi Criteria Evaluation) was used for the application of weights to each criteria (factors), employing the Ordered Weighted Average method.

From the variation of risk levels and compensations among the first level criteria (factors), some evaluation scenarios were suggested as shown in table 6.

TABLE 6: PRESENTATION OF THE PROPOSED EVALUATION SCENARIOS

Evaluation Scenarios	Situation and value of ordered weights					Risk	Compensation
	1st Weight	2nd Weight	3rd Weight	4th Weight	5th Weight		
1	0,35	0,30	0,20	0,10	0,05	0,70	0,71
2	0,15	0,20	0,25	0,30	0,10	0,50	0,82
3	0,05	0,10	0,20	0,25	0,40	0,29	0,70
4	0,10	0,15	0,20	0,25	0,30	0,37	0,82

Evaluation scenarios that represent analyses in which the risk positions are extreme, with zero risk and maximum risk, were not created due to their lack of compatibility with the conditions that comprise future decisions about the alternatives for the design of the urban ring road of the city of Viçosa-MG.

3. RESULTS

The design alternatives proposed for the urban ring road of Viçosa-MG were obtained considering the best sites that correspond to the areas with larger suitability values respecting the restrictions that possess zero suitability.

3.1 Design alternatives for the urban ring road of the city of Viçosa-MG

The design alternatives created in this work are located near the urban area of the city, with the aim to decrease traffic intensity of vehicles in residential and business areas downtown as well as to make possible a mutual accessibility between downtown and the suburbs. These alternatives cross the main water courses present in the studied area (streams São Bartolomeu, Araújo and Posse), and intercept, at different levels, the main state and federal highways that cross the city (BR 120, MGT 356, MGT 482 and MG 280) without causing additional traffic on great parts of the mentioned highways. Figure 2 shows the highways that had some sections used by the proposed design alternatives.

Figures 3, 4, 5 and 6 show the design alternatives created with the existing utilized sections.

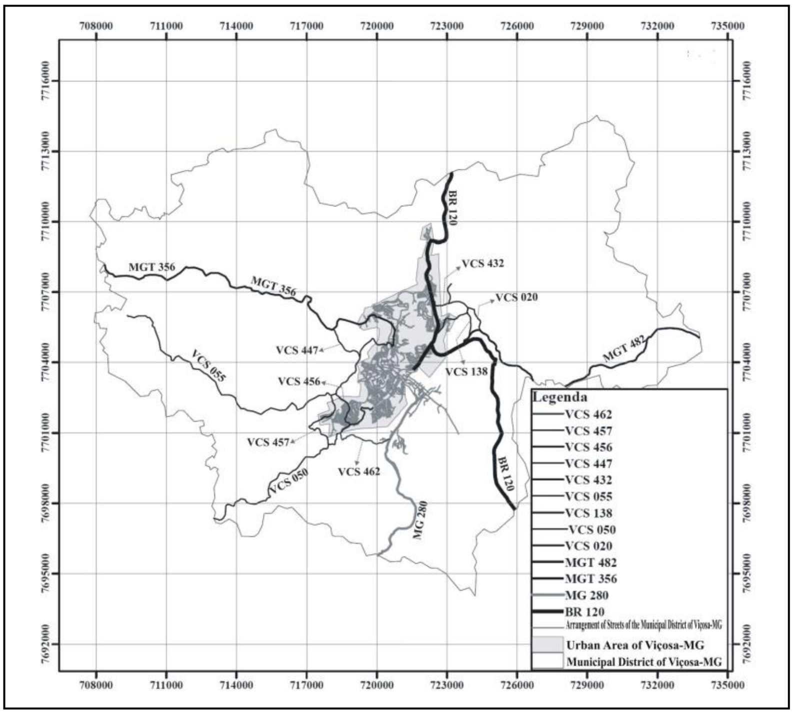

Fig. 2 - Highways that had sections utilized by the proposed design alternatives.

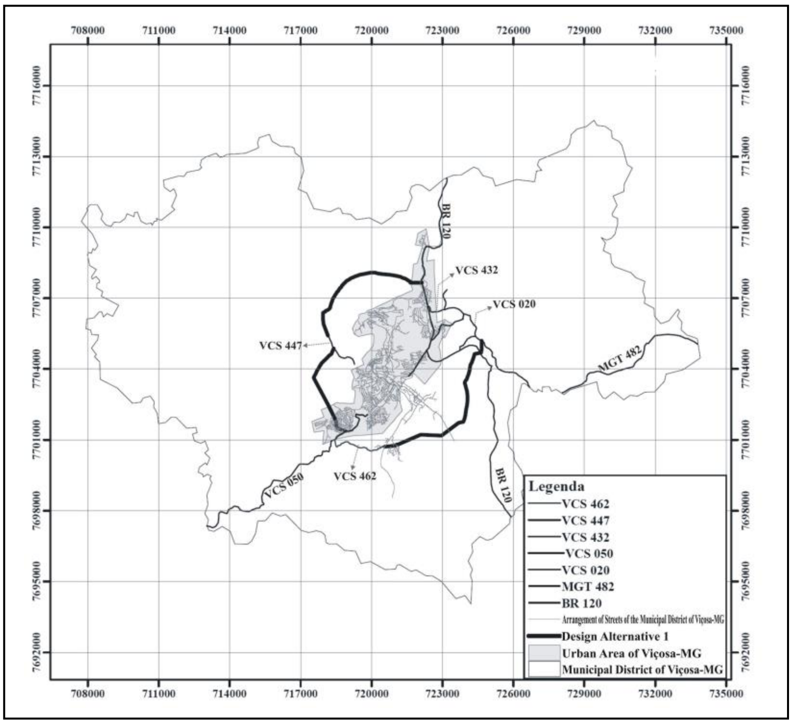

Fig. 3 - Design alternative 1 and existing connections.

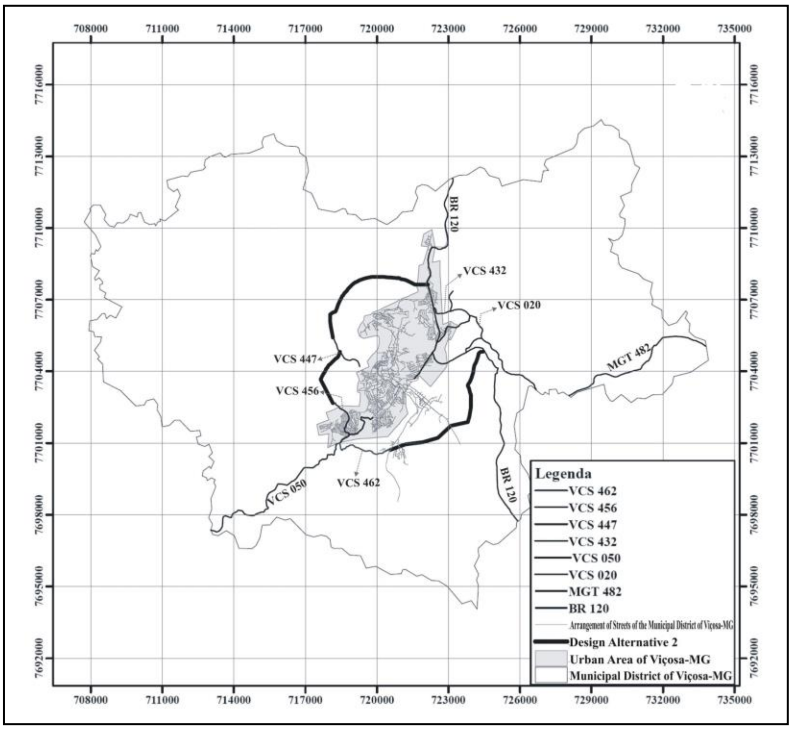

Fig. 4 - Design alternative 2 and existing connections.

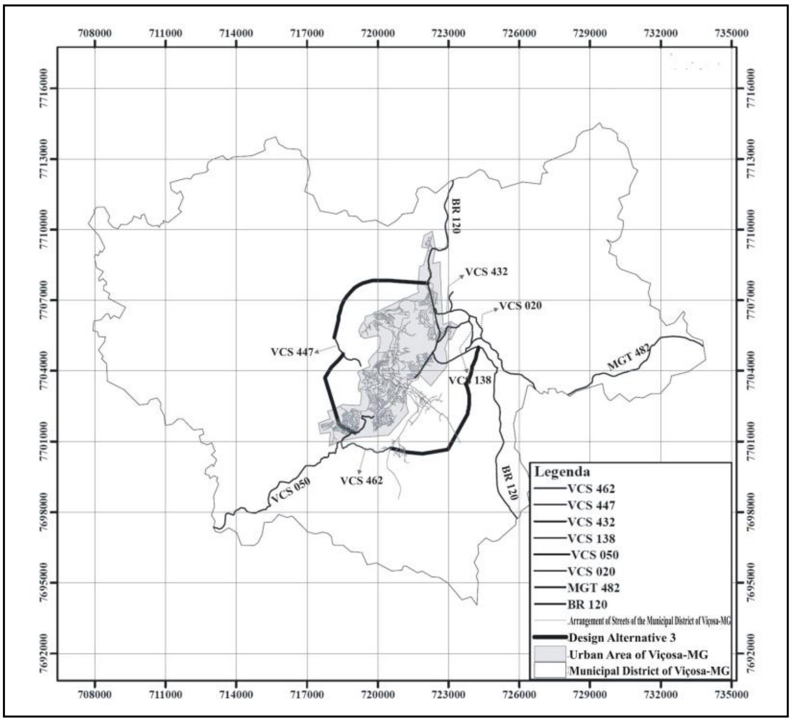

Fig. 5 - Design alternative 3 and existing connections.

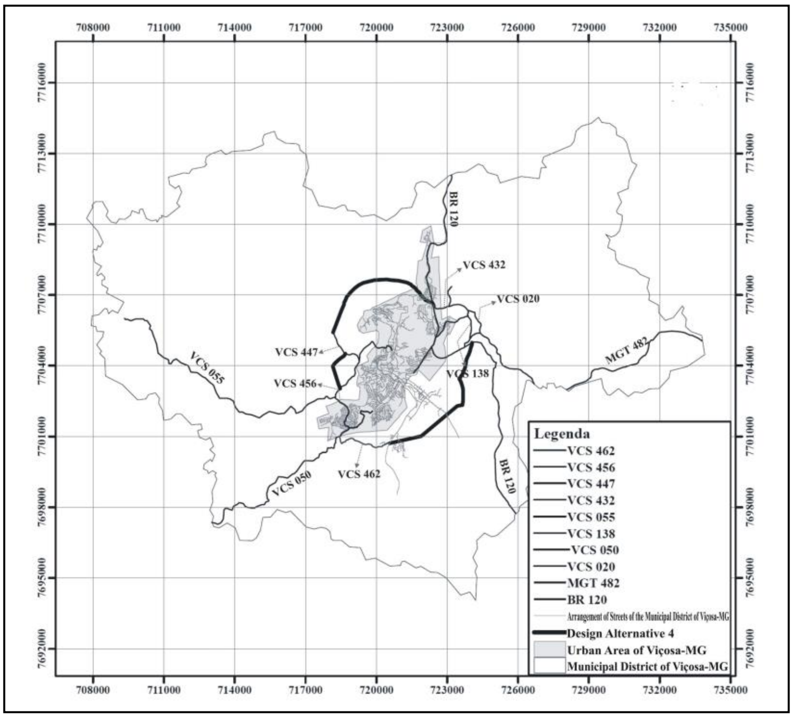

Fig. 6 - Design alternative 4 and existing connections.

According to the Highway Plan of the city of Viçosa – VCS (Municipal Law n.º 160 of 04/17/1978 updated for 2000), some existing connections were considered as an option to avoid impacts caused by the need of appropriation of urbanized areas once it was the desire that the designs were developed in unoccupied areas, what is not always possible in urbanized regions.

Table 7 presents a synthesis of the characteristics of the design alternatives proposed for the urban ring road.

TABLE 7: CONCISE PRESENTATION OF THE CHARACTERISTICS OF THE PROPOSED DESIGN ALTERNATIVES

Characteristics	Design alternatives			
	1	2	3	4
Evaluation scenario (km)	24,80	23,96	22,92	21,03
Evaluation scenario plus existing utilized sections (km)	25,99	26,89	26,12	24,21
Existing utilized sections to be paved (km)	6,90	8,76	7,29	9,55
Sections to be constructed (km)	17,76	15,32	16,69	13,85
Maximum distance of the city of Viçosa (km)	1,72	1,65	1,51	1,30

4. CONCLUSIONS

The four best design alternatives were identified in order to be, afterwards, submitted to more detailed studies. The design alternatives created circumvent great part of the urban area of the city and make good use of existing highways as an option to decrease both costs and environmental impacts.

The proposed alternatives of design presented here, considering the criteria (factors) and utilized indicators, show the viability of application of the proposed model and point out some advantages to its utilization.

The methodology presented and tested looks forward to the beginning of an evaluation of criteria at strategic and preliminary level. Therefore, the result obtained from the evaluation of scenarios through their weight ordering has the objective to indicate to the decision-maker and the entrepreneur which alternative of design is the most suitable for the studied highway proposal taking into account technical, socio-economical, operational and environmental criteria.

BIBLIOGRAPHICAL REFERENCES

CUNHA, M. A. **Operação de encostas**. São Paulo: Instituto de Pesquisas Tecnológicas (IPT – Publicação, 1831), 1991. 216p.

POMERANZ, L. **Avaliação de Projetos Públicos. Metodologia Alternativa**. São Paulo: IPE/USP, 1992. 141p.

SANTOS, M. A. & NASCIMENTO, J. A. S. A inserção da variável ambiental no planejamento do território. **Revista da Administração Pública**. Vol. 26. nº 1, 1992. 6-12pp.

IBGE - Instituto Brasileiro de Geografia e Estatística. **Carta de Viçosa**. Escala 1:50.000. Folha SF-23-X-B-V-3. 1979.