A MULTICRITERIA-BASED LOCATION OF AN INDUSTRIAL PARK IN A DEFINED AREA IN IPATINGA, MINAS GERAIS STATE, BRAZIL

Localização de um parque industrial em uma área definida em Ipatinga-MG utilizando a análise multicritério

Saulo Henrique de Faria Pereira
Geógrafo, mestrando do Programa de Pós – Graduação em Solos e Nutrição de Plantas UFV-Viçosa, MG
saulohf@hotmail.com

Maria Lúcia Calijuri
Professora titular do Departamento de Engenharia Civil da UFV-Viçosa
calijuri@ufv.br

Sheila Cristina Martins Pereira
Engenheira Civil, Mestre em Saneamento Ambiental

Nolan Ribeiro Bezerra
Engenheira Ambiental, doutoranda – Departamento de Engenharia Civil da UFV-Viçosa

Maria de Nazaré Costa de Macedo
Engenheira Florestal, Doutoranda – Departamento de Engenharia Florestal da UFV-Viçosa

Artigo recebido para publicação em 30/10/2007 e aceito para publicação em 18/02/2008

RESUMO: *O presente trabalho teve como objetivo identificar uma área com mais de 5 ha para a implantação de um Parque Industrial na microrregião de Ipatinga no Estado de Minas Gerais. Ipatinga é reconhecida nacional e internacionalmente como uma das cidades modelos de desenvolvimento pelo fato de ter instalada em seu município a empresa Usiminas, uma das grandes potências industriais do Estado de Minas Gerais em siderúrgica. Neste sentido, é de primordial importância à instalação de um Parque Industrial para atrair potenciais investidores que garantam a compra dos produtos desenvolvidos pela empresa Usiminas, proporcionando maiores incentivos fiscais para o município, garantindo assim o desenvolvimento socioeconômico de Ipatinga. Foi utilizado a análise multicritério com o uso da lógica fuzzy (Software IDRISE), ArcGis e as imagens disponibilizadas pelo Google Earth, e feito um mosaico. Foram encontradas três áreas aptas para a implantação do Parque Industrial e com o auxílio da análise de custo e benefício encontrou-se a área mais apta. Com a implantação do Parque, será necessária a contratação de mão de obra qualificada, o que conseqüentemente implicará na migração de um grande número de pessoas advindas de outras localidades. Portanto, fez-se necessário um estudo para a localização habitacional. Os resultados obtidos revelam que a análise multicritério mostrou-se uma ferramenta importante para tomada de decisão no processo de avaliação e seleção de áreas para implantação de empreendimentos impactantes.*

Palavras-chave: Localização industrial. Companhia Usiminas. Sistema de informação geográfica. WLC e OWA.

ABSTRACT: *This paper aims to identify an area of over 5 ha for setting up an industrial park in Ipatinga microregion in Minas Gerais State, Brazil. Ipatinga is both nationally and internationally regarded as a model city in terms of development because of Usiminas Company, which is one of the greatest metallurgic industrial powers of Minas Gerais State. Setting up an industrial park in this framework is essential to attract potential investors, to foster purchase of products manufactured by Usiminas, and thus to promote fiscal incentives to the municipality, which may contribute to Ipatinga socioeconomic development. A multicriteria analysis was carried out, applying fuzzy logic (IDRISE software), ArcGis and images available from Google Earth and made a mosaic. Areas suitable for the industrial park implantation and the most suitable area were found by means of a cost-benefit analysis. Since hiring qualified labor after setting the park up would eventually implicate migration of several people from other regions, a dwelling study was also carry out. The results indicate that multicriteria analysis is an important tool for decision-making throughout the process of assessing and selecting areas to set up striking enterprises.*

Keywords: Industrial Location. Usiminas company. Geographic information system. WLC and OWA.

1. INTRODUCTION

Increasing urbanization has caused the number of available areas for location of industrial enterprises matching entrepreneurs', environmentalists' and civil society's expectation to decrease. As a result, demands for more accurate technical analyses have enhanced. Industrial location is essentially a process of decision-making aiming to compare different space alternatives to set industrial units up or, in a more general way, aiming to identify areas in a territory found to be more suitable to industrial use (Soares et al., 2005).

Ipatinga Municipality is located in Steel Valley microregion. Its population increased by the end of the 50s after the setting up of Usiminas facilities, which is an important attraction point for regional labor. Usiminas Company manufactures steel-derived products (e.g., heavy plates, hot strips, cold strips, metallic and galvanized sheets) for a wide range of application. Its main customers are the following industries: automotive, household appliance, electric motor and compressor, packaging, furniture, civil construction and parts supply in general. Such potential urges proposing a metallurgic industrial park implementation aiming to rationalize costs of raw material flow to the greatest laminate consumers in Southern and Southeastern Brazil.

Building on multicriteria analysis and geographic information systems, this paper outlines the methodology applied for assessing and selecting areas to set an industrial park up in Ipatinga Municipality, Minas Gerais State, Brazil.

2. REVIEW OF LITERATURE

Several theories concerning location have been postulated by economists and geographers, and Alfred Weber has particularly defined the grounds for industrial location theory. Notwithstanding, this paper builds on multicriteria analysis applying *fuzzy logic* in order to establish industrial location.

2.1. Multicriteria analysis

The relevant features in a process of multicriteria assessment are: evaluation of criteria weights, criteria normalization, and criteria combination. For a better understanding of these topics, including detailed description of feasible methods, see Ramos (2000), Mendes (2000), Ramos & Mendes (2001), Calijuri & Lorentz (2003), and Soares et al. (2005).

In a general way, a location model comprises a group of factors and constrictions covering, on the one hand, goals, objectives and policies drafted throughout planning and, on the other hand, theoretical models regarding each particular use (Ramos, 2000). Constriction is a criterion which limits alternatives reckoned during analyses, whereas a factor enhances or increases the suitability of a given alternative.

2.1.1. Evaluation of criteria weights

A pair comparison method was carried out for this paper. According to Ramos & Mendes (2001), despite its complexity, slowness and usual need for interaction in order to retain an acceptable consistence degree, the results and the very procedure of this method fit perfectly to the industrial location problem.

2.1.2. Criteria normalization

This process allows for normalizing criteria values that are not comparable to each other into the same scale, enabling thus their aggregation (Zambon et al., 2005). Normalization process is essentially identical to the process introduced by fuzzy logic (Calijuri et al., 2002).

The authors also claim that the *fuzzy* set is a generalization of the ordinary group. It is defined building on a continuous domain, and it degrees relevant range from 0 to 1, or from 0 to 255, after normalization. In the general theory, relevance or affirmative of a given phenomenon is relative. Such a theory affords an appropriate conceptual framework to decision-making, because fuzz logic contributes to reduce subjectivity in choice as well as to increase reasoning in the decision process.

Several functions can be applied to set the range between the minimum point and maximum point in criteria normalization. Criteria scores contribute to decision from the minimum point on, and higher scores bring no additional contribution to decision beyond the maximum point (Ramos, 2000). Some of the most applied functions are: *Sigmoidal, J-Shaped, Linear* and *Symmetrical*.

2.1.3. Criteria combination

After normalizing criteria scores in a 0-1 scale (or any other scale), it is possible to aggregate them as determined by the decision rule (Zambon et al., 2005). In the decision processes, the most applied procedures regarding space are *Weighted Linear Combination* (WLC) and *Ordered Weighted Average* (OWA) for criteria aggregation.

WLC technique enables total trade-off among factors by means of weighed values, also called factor weights. The risk assumed in the analysis is average, placed exactly between AND (minimum) and OR (maximum) in the *Boolean Analysis*.

Factors are compound in WLC by applying a weight for each of them, and results are summed to produce a final adequacy map. The most important feature of WLC is factor trade-offs, which means that low adequacy in a factor may be traded-off by a set of good adequacies in others (Calijuri et al., 2002).

According to (Ramos & Mendes, 2001), OWA applies criteria weights carried out in WLC and also includes a set of weights that are not specifically linked to any factors, but are applied to them in an order that depends on factor values after the application of the first set of weights.

Calijuri et al. (2002) point out that risk level depends on ranking position of weights and magnitude of their values. The highest values in the first positions represent lower risks, and values in the last positions stand for higher risks. The authors emphasize that, by varying order weights, any combination is possible provided that its sum equals one.

OWA enables a wide range of aggregation. Displacement in order weights from the minimum point towards the maximum point controls risk level, called ANDness. Alternatively, distribution homogeneity in order weights throughout different positions controls overall trade-off level (Calijuri et al., 2002; Soares et al., 2005).

As shown in Figure 1, the result is a mostly triangular strategic-decision spectrum, set, on the one hand, by risk attitude, and, on the other hand, by trade-off (Eastman, 1998).

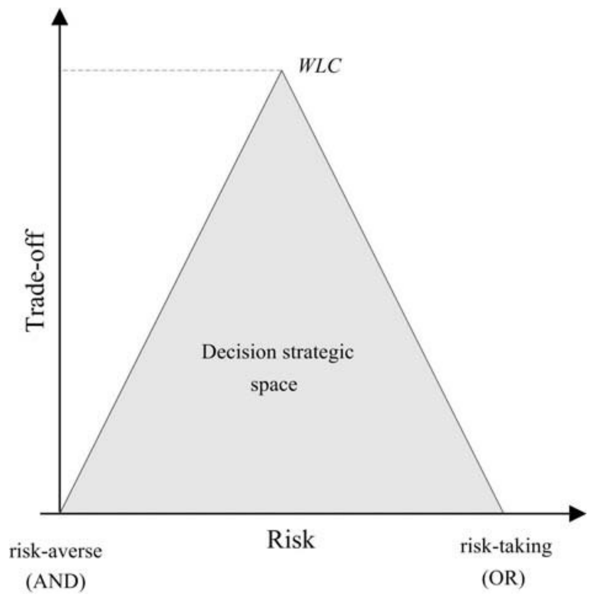

Figure 1. Strategic Graphic of decision (OWA).

$$Trade-off = \frac{1}{n-1}\sum_i ((n-i)O_i)$$

$$Risk = 1-\sqrt{\frac{n\sum_i (O_i - 1/n)^2}{n-1}}$$

where n is the total number of factors, i is the factor order, and O_i is the order weight for the order factor.

3. MATERIALS AND METHODS

3.1. Materials

The following materials were used for this paper:

- Data available from the Graduate Program in Civil Engineering of the Federal University of Viçosa;
- Federal Law no. 6,766, December 19, 1979 – Urban Soil Plotting;
- Federal Law no. 4,771, September 15, 1965 – Forest Code;
- Federal Law no. 6,803 , July 2, 1980 – basic guidelines for industrial zoning in critical pollution areas;
- Municipal Law no. 6,803, May 02, 1972 – Code of Conduct of Ipatinga Municipality – Minas Gerais State;
- Municipal Law no. 565, June 01, 1977 – Urban Planning Code of Ipatinga Municipality – Minas Gerais State;
- Municipal Law no. 1,475, September 30, 1996 – Environmental Code of Ipatinga Municipality – Minas Gerais State;
- GIS Idrisi 32 Software, version Kilimanjaro, May 2003, ©The Clark Labs for Cartographic Technology and Geographic Analysis;
- ArcGIS/ArcGRID Software, version 9.0, ©Environmental Systems Research Institute.

3.2. Methods

3.2.1. Location and features of the studied area

Ipatinga is located in Steel Valley microregion, Eastern Minas Gerais State, at 19°20’30'' South latitude, and 45°32’30'' West longitude. It is 217 km far from Belo Horizonte (capital of Minas Gerais) and holds around 200,000 inhabitants.

Usiminas is placed in Ipatinga, and it is one of the largest Brazilian metallurgic industries. The fact that the municipality and its trade depend on the steel industry reveals the importance of this company. Since the building of Usiminas, the area is regarded as one of the most important industrial agglomerates in Brazil. Figure 2 shows the location of Ipatinga municipality in relation to Usiminas.

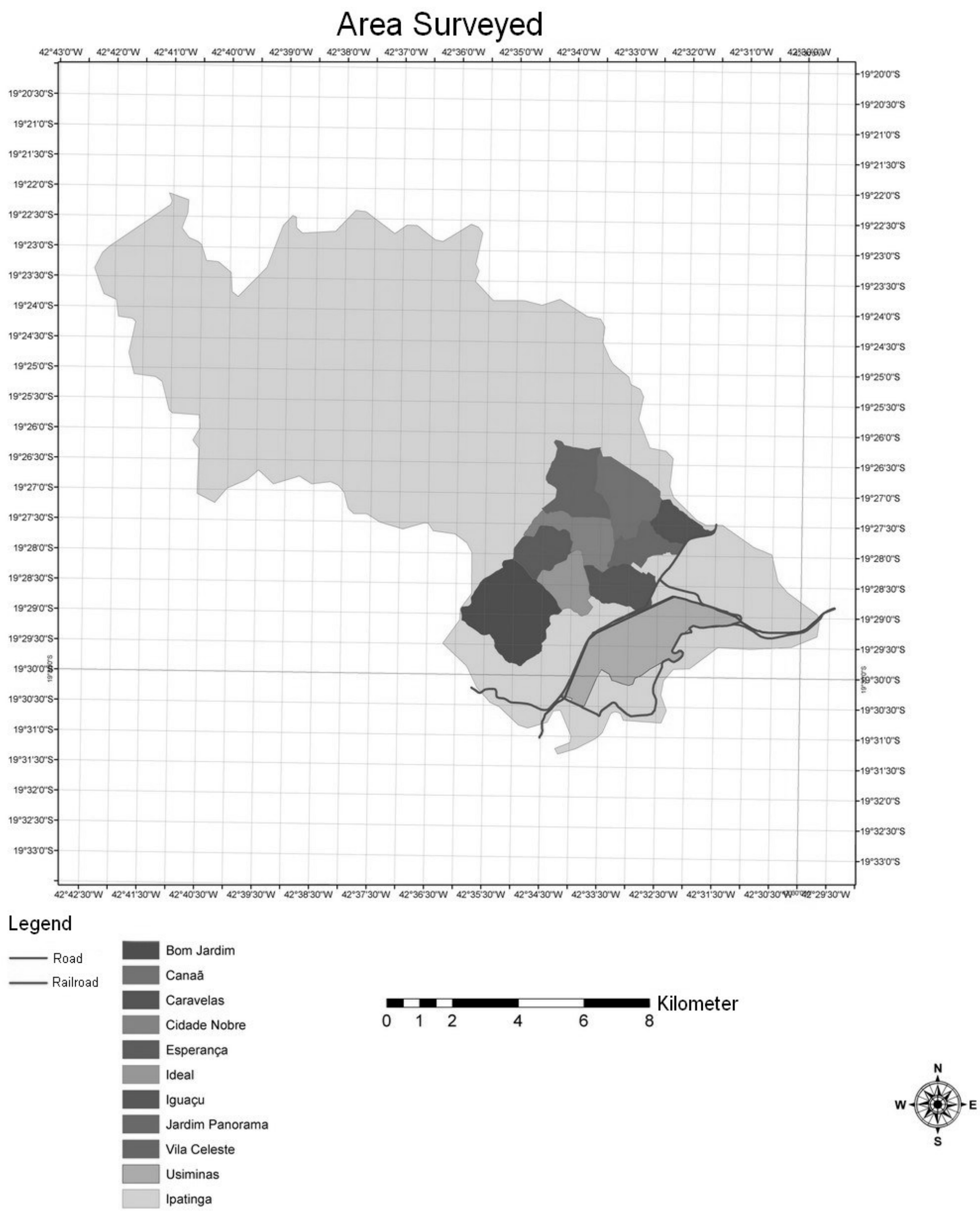

Figure 2. Location of the studied area.

Owing to the excellent location of Southern and Southeastern regions, pre-selected districts of Ipatinga municipality were skimmed off to establish suitable industrial park areas. The objective is to set up industries which may demand Usiminas products as their main raw material and also to attract investors for products manufactured by this company.

3.2.2. Stages of the research

The methodology carried out in this research built on a multicriteria analysis applying fuzzy logic. The following stages were espoused in the research development: (i) criteria establishment; (ii) definition of factors and restrictions; (iii) criteria prioritization; (iv) criteria normalization, by means of fuzzy function; (v) weight attribution to criteria in a weight matrix; (vi) criteria combination; (vii) assessment and definition of suitable industrial areas; (viii) analysis and assessment of the most suitable area.

In the first stage, criteria establishment complied with industrial location theory (Ramos, 2000; Ramos & Mendes, 2001). Criteria, thus, comprised industrial, environmental, and socioeconomic activities. In the second stage, factors and constrictions were outlined building on industrial, environmental and socioeconomic concerns for Ipatinga municipality. Data available from Civil Engineering Department of UFV (Federal University of Viçosa, Minas Gerais State)[1], from the Brazilian Institute of Geography and Statistics (2000), specific dispositions of federal and municipal legislations, and researches on the issue were also taken into account.

In the next stage, criteria prioritization was drawn in function of each factor importance. Socioeconomic features relevant to the municipality and from entrepreneurs' and environmentalists' standpoints were observed at this moment. For criteria normalization, *Sigmoid* and *Linear* functions were applied to the fuzzy set.

The criteria were compound according to WLC and OWA procedures in order to run on *run macro* tool, which displayed the most suitable areas for the industrial park location in Ipatinga.

Satellite images have been carried for environmental, social, economic and agricultural analyzes for the last years. There is a wide range of satellites providing images nowadays, yet they are often very expensive for the Brazilian reality. The use of free images such as CBERS has thus posed a solution for Brazilian researches. However, resolution is still a deadlock for creating maps displaying scales under 1:50.000. For this reason, this study suggests the use of Google Earth images as a tool for territory analyzes, although this resource is possible only for areas available from Google Earth.

Images of the focused area at a previously determined height were stored on the very Google Earth, and V*isual Stitcher* software was used in order to connect images. After connecting each line, images were displayed in a mosaic. It enabled georeferencing images on Arcgis software in the last stage, and such a georeference was used for research analysis.

The generated images may be worked at a larger scale (1:10.000) provided that several control points are fixed to georeference the image precisely. Moreover, 1 pixel was verified to contain 24in. The potential of this tool could then be verified, and it can generate maps displaying scales superior to 1:10.000, if it is well georeferenced.

In the stage of analysis and selection of the most suitable area, transportation cost was assessed building on a methodology provided by National Department of Roads (DNER, 2003). The following transportation-cost formula was applied for determining transportation cost: Operative Hourly Cost (OHC) divided by Production, that is, Y=OHC/ Production. OHC can be determined either by a

[1] Soil use and occupation, soils, landslide area, hydrograph, altimetry, green areas, districts, recreation club, day nursery, schools, slums, boundaries, basic urban mapping, squares, and care units.

particular method or by a method recommended DNER or other institutions.

4. RESULTS AND DISCUSSION

4.1. Industrial park location

4.1.1. Factors

Table 1 shows the factors associated to environmental, industrial and socioeconomic criteria, including respective code, description, types of fuzzy functions applied to normalize data, and their control points.

Increasing F*uzzy Sigmoid functions* were applied to those factors in which a given area was intended to become suitable from a certain distance (control point b). Alternatively, decreasing linear function was applied for maintaining factors as close as possible to the industrial park location. In this function, the maximum distance of each factor was applied after the generation of maps by means of distance tool.

Table 1. Factors associated to the industrial, environmental and socioeconomic activity.

Code	Description	MD* (m)	Fuzzy Function	Control Point a	b	C	D
EF	**Environmental Factors**						
EF1	Soils – to prioritize Latosol (255), Argisol (200), Cambisol (150), and Neosol (130) *						
EF2	Soil usage – pasture (255), copse (230), exposed soil (180), green areas (50) *						
EF3	Green areas		Increasing Sigmoidal	0	200		
EF4	Areas susceptible to landslide: Very low (255), low (200), average (150), high (80), very high (50)**						
IF	**Industrial Factors**						
IF1	Railroad – the closer, the better		Decreasing Linear	0	20252.32		
IF2	Road system – the closer, the better		Decreasing Linear	0	19155.71		
IF3	Usiminas - the closer, the better		Decreasing Linear	0	20162.60		
IF4	Infrastructure – water and sewage systems, electric power, telecommunication		Decreasing Linear	0	14964.21		
IF5	Declivity – the flatter, the better (from 1 to 15%) (Ramos, 2000)		Decreasing Sigmoidal	1	15		
IF6	Urban areas – the closer, the better		Decreasing Linear	0	3243.22		
SF	**Socioeconomic factors**						
SF1	Resident economically active population - higher		Increasing Sigmoidal	0	15510.04		
SF2	Life qualitity – better salaries		Increasing Sigmoidal	0	1673		
SF3	500m far from slums		Increasing Sigmoidal	0	500		

Source: adapted from Ramos (2000), Mendes (2000), Ramos & Mendes (2001), Calijuri et al. (2002), and Soares et al. (2005).
** Minimum distance*
*** These values refer to reclassification according to data importance.*

Data used to find both economically active population's socioeconomic and life-quality (considering the best wages) factors were determined according to the census of the Brazilian Institute of Geography and Statistics (IBGE, 2000).

Table 2 shows the following data: Ipatinga total population; population of each district surveyed; economically active population (EAP) of each district. For this analysis, districts were assumed to hold similar EAP values, and calculation basis had a 36.4% value for Ipatinga municipality.

Table 2. Establishment of EAP socioeconomic and life-quality factors.

Districts	**Population ***	**EAP**	**Salaries ***
Vila Celeste	16,133	5,872	468
Jardim Panorama	8,550	3,112	785
Ideal	9,310	3,389	1,056
Esperança	15,960	5,809	451
Cidade Nobre	11,584	4,217	1,673
Caravela	8,133	2,960	589
Canaã	42,610	15,510	604
Bom Jardim	18,134	6,601	469
Iguaçu	14,324	5,214	948
Ipatinga Total Population*		212,446 inhabitants	
Ipatinga EAP *			36.40%

Note: (*) Data available from IBGE (2000).

4.1.1. Constrictions

Constrictions associated to environmental, industrial and socioeconomics criteria are shown in Table 3.

Table 3. Constrictions associated to industrial, environmental and socioeconomics activities.

Code	**Description**
RA	Environmental constrictions
RA1	Hydrograph, minimum distance of 100 m from any water stream (50 m from any border) posing 10 to50m width (Federal Law no. 4,771/65 – Forest Code) 328,08 ft buffer
RA2	Green areas
RI	Industrial constrictions
RI1	Declivity over 30% (Law no. 6,766/79 – Urban Soil Plotting)
RI2	Urban Area Boundary
RI3	Area Boundary
RE	Economic Constrictions
RE1	250 m distance from road system- buffer 250 m
RE2	250 m ft distance from railroad - buffer 250 m

Source: Adapted from Ramos (2000), Mendes (2000), Ramos & Mendes (2001) Calijuri et al. (2002), and Soares et al., (2005).

4.2. Structure of the assessment model

Criteria assessment was based on Figure 3, adapted from Ramos (2000). In this framework, factors were firstly normalized by means of fuzzy logic. Secondly, weights were ordered conforming to their order of relevance. Factors were compounded pair-to-pair, and then weights were computed and ordered by means of weight matrix. Once results were found, the criteria were combined in MCE module (WLC and OWA), where several scenarios were found.

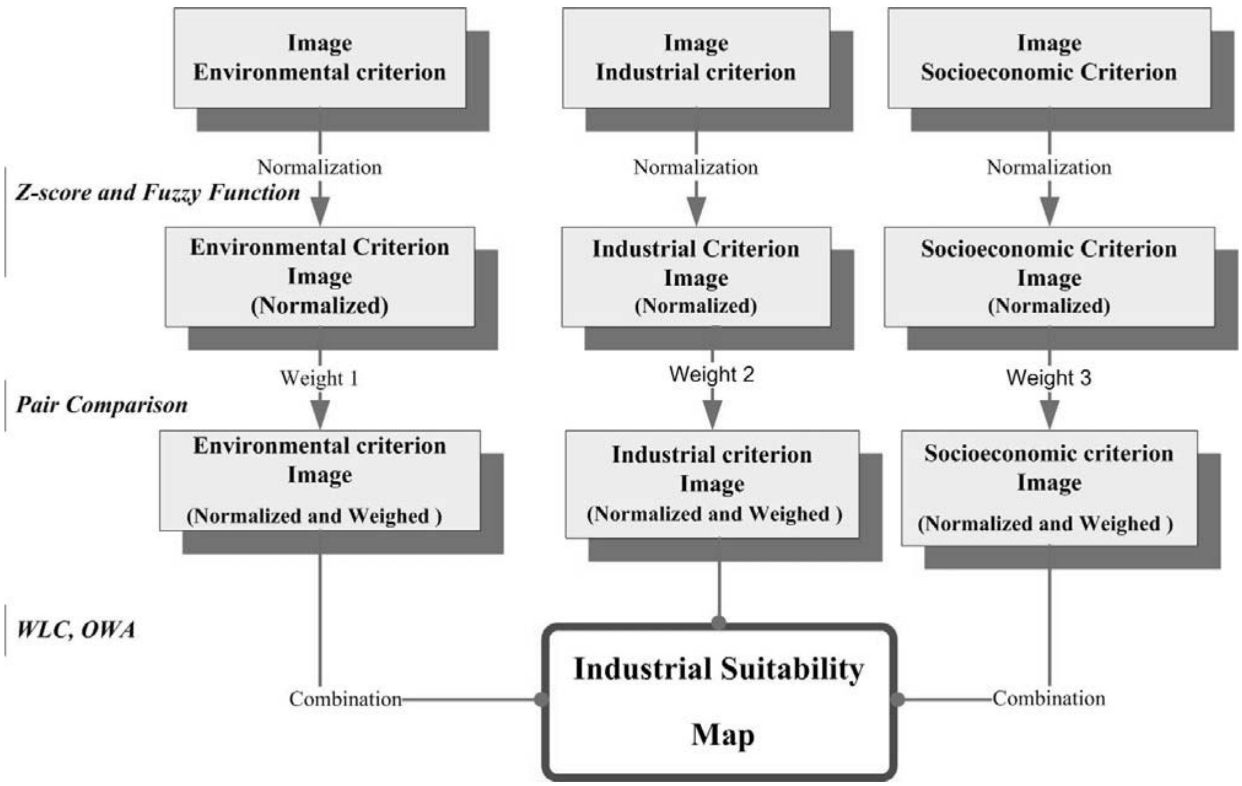

Figure 3. Analysis structure according to level and criteria set.
Source: adapted from Ramos (2000).

Table 4 shows weights calculated in the weight matrix, where weight values were ordered according to the importance of the normalized factors.

Table 4. Weight values obtained in the Comparison Matrix.

Priorities of Normalized Factors (*fuzzy)*	**Weight Matrix**
Declivity	0.1204
Highway nearness	0.1159
USIMINAS nearness	0.1198
Railroad nearness	0.1060
Infrastructure (water and sewerage systems)	0.0950
Distance from urban area	0.0880
Distance from slums	0.0797
Soil usage	0.0746
Life quality	0.0684
Economically active population	0.0507
Soil	0.0384
Prioritization of high and low risk areas	0.0249
Distance from green areas	0.0172

Risk and trade-off analysis was carried out by means of MCE (WLC and OWA) in order to locating the most suitable areas for setting up the industrial park. This analysis provided several scenarios, as shown in Table 5. A deep study drawing on these scenarios was carried out in order to identify the most suitable area.

Table 5. Scenarios of assessment.

Scenario	**Weighed values**	**Risk**	**Trade-off**	**Feature**
S1	MCE - WLC = same weights (0.077)	0.50	1.00	Medium risk – Maximum trade-off
S2	[1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]	1.00	0.00	Minimum risk – No trade-off
S3	[.001, .001, .24, .24 , .23, .06, .05, .06, .05, .055, .01, .002, .001]	0.65	0.66	Low risk – Partial trade-off
S4	[.001, .001, .24, .24 , .23, .06, .05, .06, .05, .055, .01, .002, .001]	0.35	0.66	High risk – Partial trade-off
S5	[.15, .12, .1, .09 , .08, .08, .06, .06, .06, .055, .055, .045, .045]	0.61	0.89	Low-medium risk – High trade-off
S6	[.2, .12, .12, .09 , .08, .08, .06, .06, .05, .04, .04, .03, .03]	0.66	0.83	Low risk – High trade-off
S7	[.2, .15, .125, .1 , .11, .08, .07, .06, .005, .004, .003, .002, .01]	0.78	0.71	Low risk – High trade-off
S8	[.03, .03, .04, .04 , .05, .06, .06, .08, .08, .09, .12, .12, .2]	0.33	0.83	High risk – High trade-off
S9	[.04, .04, .05, .05 , .05, .1, .11, .08, .07, .1, .1, .1, .11]	0.41	0.90	High risk – High trade-off

Source: Adapted from Ramos (2000), Mendes (2000), Ramos & Mendes (2001) Calijuri et al. (2002), and Soares et al. (2005).

For comparison reasons, some scenarios were structured in such a way that different risk and trade-off levels could be assessed, allowing for an analysis involving from the most conservative to the riskiest solutions.

In a decision analysis, choosing low risk criteria turn the analysis very conservative, and a risky option urges large knowledge of the surveyed area. Nevertheless, a little riskier analysis was chosen because of high trade-off values. In other words, the higher the compensation is and the higher the risk is, the more efficient the analysis is likely to be.

Therefore, values found in WLC, medium risk and total trade-off, were applied, aiming to compare them with OWA values regarding high risk and high trade-off. Scenario S9, carrying 0.41 risk and 0.90 trade-off, was chosen in this paper.

In the face of the results, areas of over 5 ha were found by running macro tool, aiming to find the most suitable areas. Figure 4 presents the areas posing values of 210, which is the highest score found for suitability.

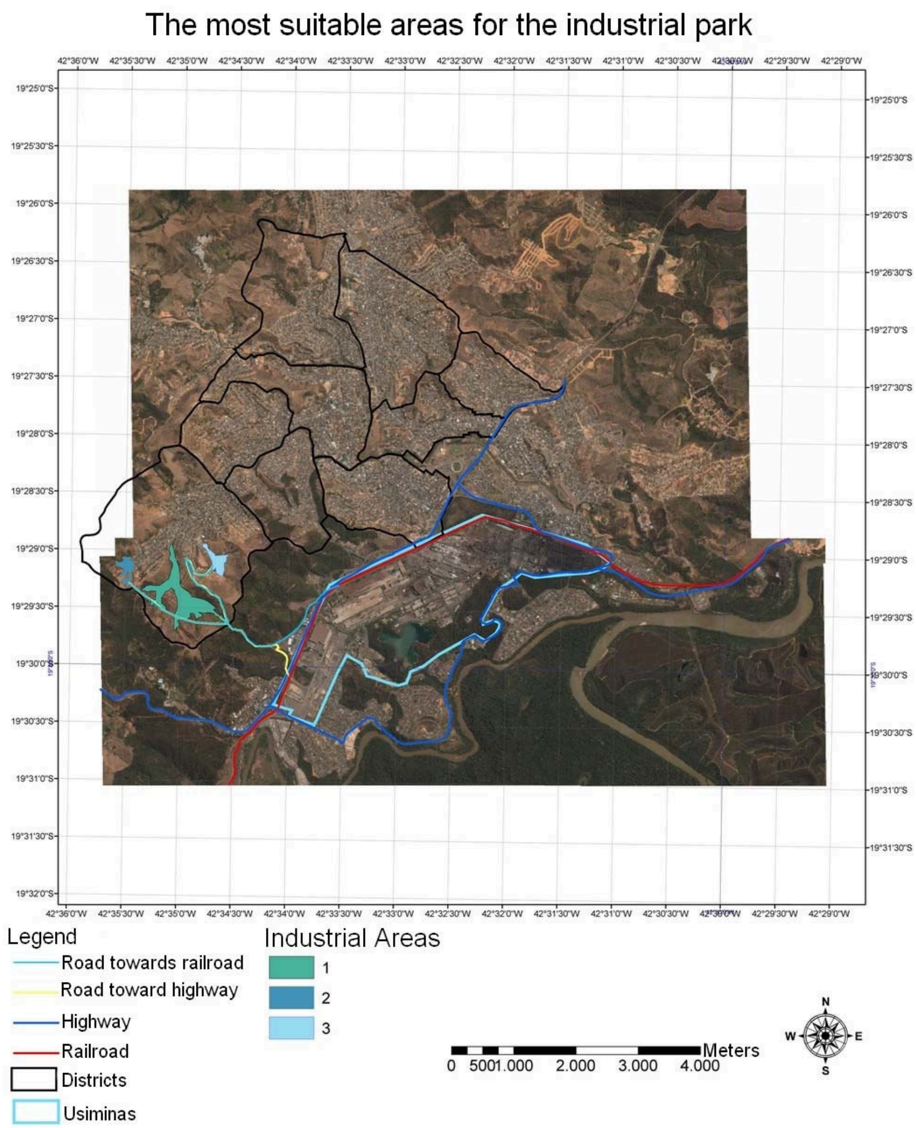

Figure 4. Industrial suitability map.

4.3. Analysis and selection of the most suitable area for the industrial park location

Building on environmental, industrial and socioeconomics criteria previously defined and using IDRISI software tool, three most suitable areas were found for the industrial location.

The objective of this paper demanded a wide evaluation comprising economical, environmental and industrial standpoints. Furthermore, nearness to the raw material location (Usiminas) and nearness to highway and railroad for production flow were included in the analysis.

As transportation taxes increase with distance, entrance and exit costs are prevailing location force. In other words, a facility placed between a source of raw materials and a market point will find a minimum transportation cost. This can be thus considered a suitable solution.

For the situation under scrutiny, efficient solutions were found to be those posing the lowest cost and the largest benefit, and impossible solutions are those carrying high costs and low benefits.

In this context, an assessment was carried out considering the current structure of Usiminas. Possible storage costs of the generated products (heavy plates, cold strips, hot strips and coated products) and road and rail transportation costs to Southern and Southeastern Brazil were estimated for this evaluation. The objective was to compare these costs with transportation costs in the future industrial park location. Figure 5 demonstrates the assessment of these costs.

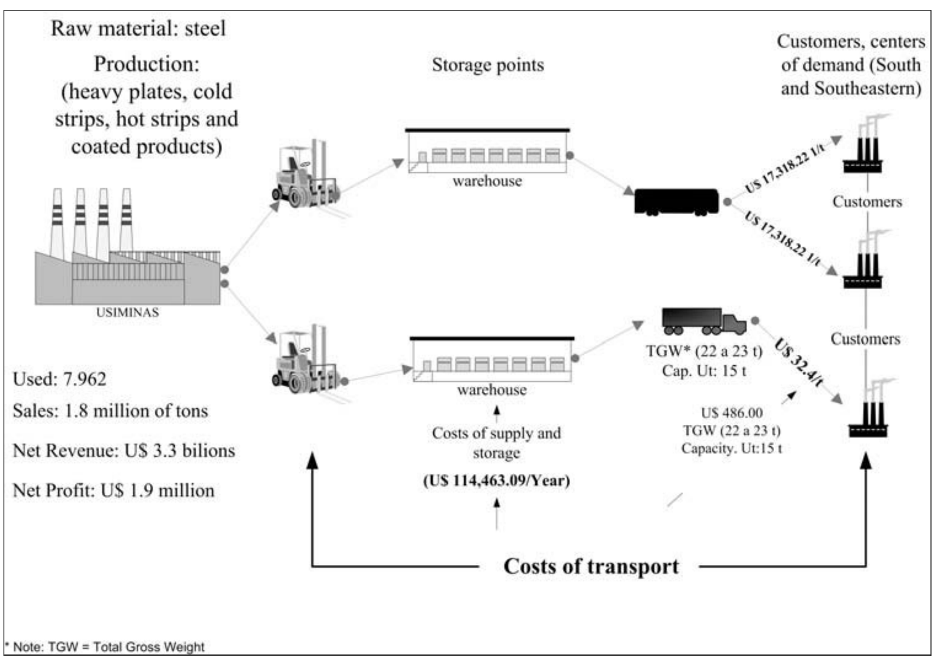

Figure 5. Assessment flow of raw material storage and transportation costs.

The highest suitability was found for the scenario outlined in Figure 5. This one was chosen for the assessment of the most suitable area. Some criteria were applied, and transportation cost was the most relevant economic criterion. It specifically involved the observation of shortest distances from raw materials (USIMINAS) and production flow distances by highways and railroads. Table 6 shows distance values run on *Lengh tool* and *ArcGis* software. Other features observed in this study were distance from urban area, existent infrastructure[2], water stream, and green areas. Table 7 shows cost values for distances from highway, railroad, Usiminas and infrastructure.

Table 6. Distances run on *Lengh* tool and ArcGis software.

Distance (m)	**Area 1 (36.97 ha)**	**Area 2 (5.5 ha)**	**Area 3 (7,2 ha)**
Highway	1648	2853	3377
Railroad	2370	3713	4117
Usiminas	2370	3713	4117
Infrastructure	753	364	0
Not Paved	200	1743	0
Green areas	283	50	318
Sewerage and water system	753	364	0
Airport	13600	15200	15300

Source: National Department of Infrastructure and Transportation (DNIT, 2003).

Table 7. Synthesis of transportation costs.

Area	**Distance (Km) from the Highway**	**Cost (U$/t)**
1	1.648	11.809
2	2.853	19.990
3	3.377	23.547
Area	**Distance (Km) from the Railroad**	**Cost (U$/t)**
1	2.37	16.710
2	3.713	25.828
3	4.117	28.570
Area	**Distance (Km) from the Usiminas**	**Cost (U$/t)**
1	2.37	16.710
2	3.713	25.828
3	4.117	28.570
Area	**Distance (Km) from the Infrastruture**	**Cost (U$/t)**
1	0.753	5.733
2	0.364	3.092
3	0	0.621

Source: National Department of Infrastructure and Transportation (DNIT, 2003).

2 Infrastructure – Existence of water and sewerage systems and electric and telecommunication network. Once some infrastructure-related data are missing, some data refer to infrastructure in the urban area edge.

Figure 5 points out that areas 2 and 3 are in the urban area edge. Table 7 shows that area 1 presented the lowest cost, the shortest distance from raw material source and the largest distance from urban area.

After the selection of the area, the construction of 200m pavement, industrial wastewater treatment station and water treatment station, and enlargement of electric network (700m of the urban area) were found to be necessary. Moreover, duplication of the access roads was also observed to be necessary, owing to increase in truck traffic.

As stated by Macedo (2005), 1 kg steel production consumes 95L of water. Considering that each 1m^3 of treated water in Southeastern Brazil costs U$ 0.5, the consumption from water supply network of the municipality would not be feasible. Building a Water Treatment Station capturing underground water was then found to be a plausible solution.

As current researches recommend recycling industry-generated solid residues, the construction of an industrial landfill was not necessary.

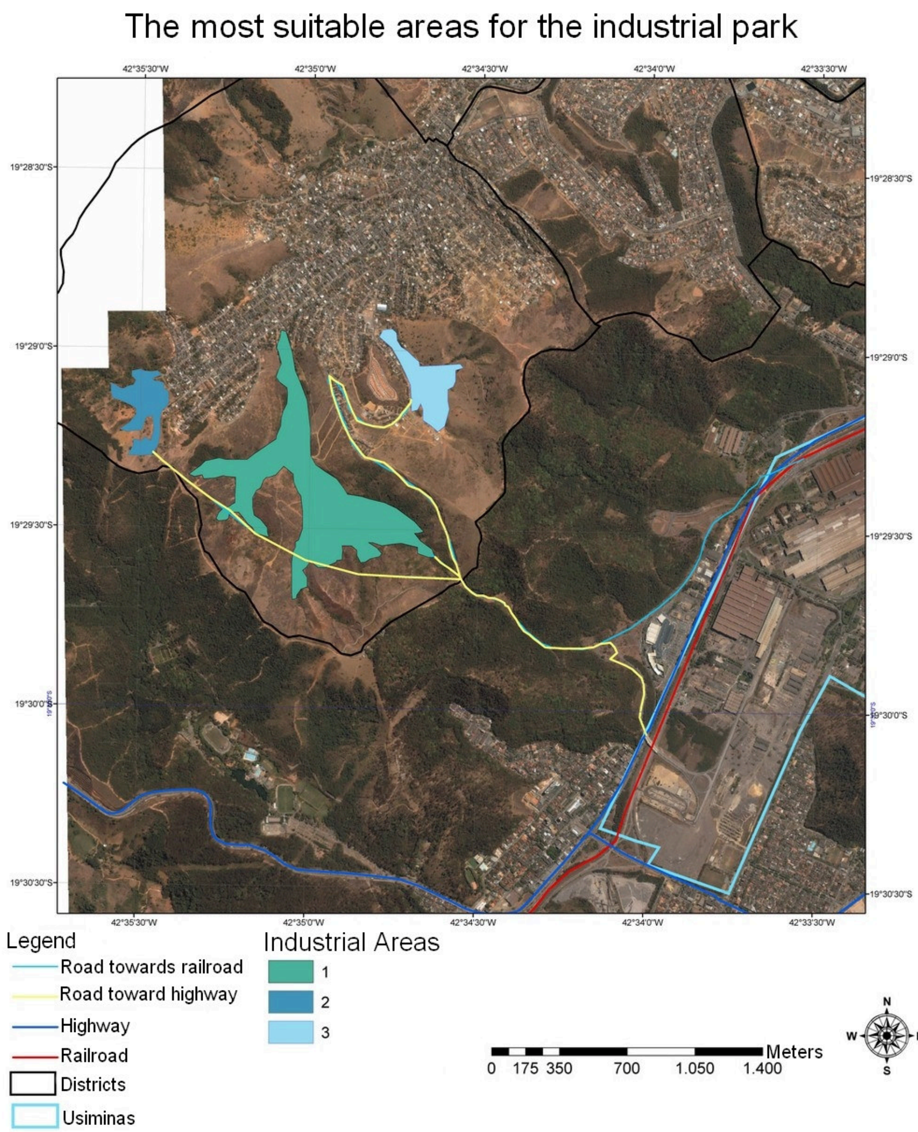

Figure 6. Cost-assessment scenario for selection of industrial area.

The setting up of the industrial park close to raw material source ascribes for reducing costs generated by keeping raw materials in Usiminas patio and by transporting products to Southern and Southeastern Brazil. It also aims to match economic interest of the municipality and of Steel Valley microregion.

4.4. Analysis and selection of the most suitable area for residential location

After the Industrial Park implantation, hiring qualified labors will consequently implicate a great number of people migrating from other places. For this reason, a study of dwelling location was performed, aiming to provide dwellings to future workers.

The same methodology was applied to select the best area conforming to locational and environmental criteria (see data displayed in Attachment 1). Figure 7 shows the areas found for this purpose.

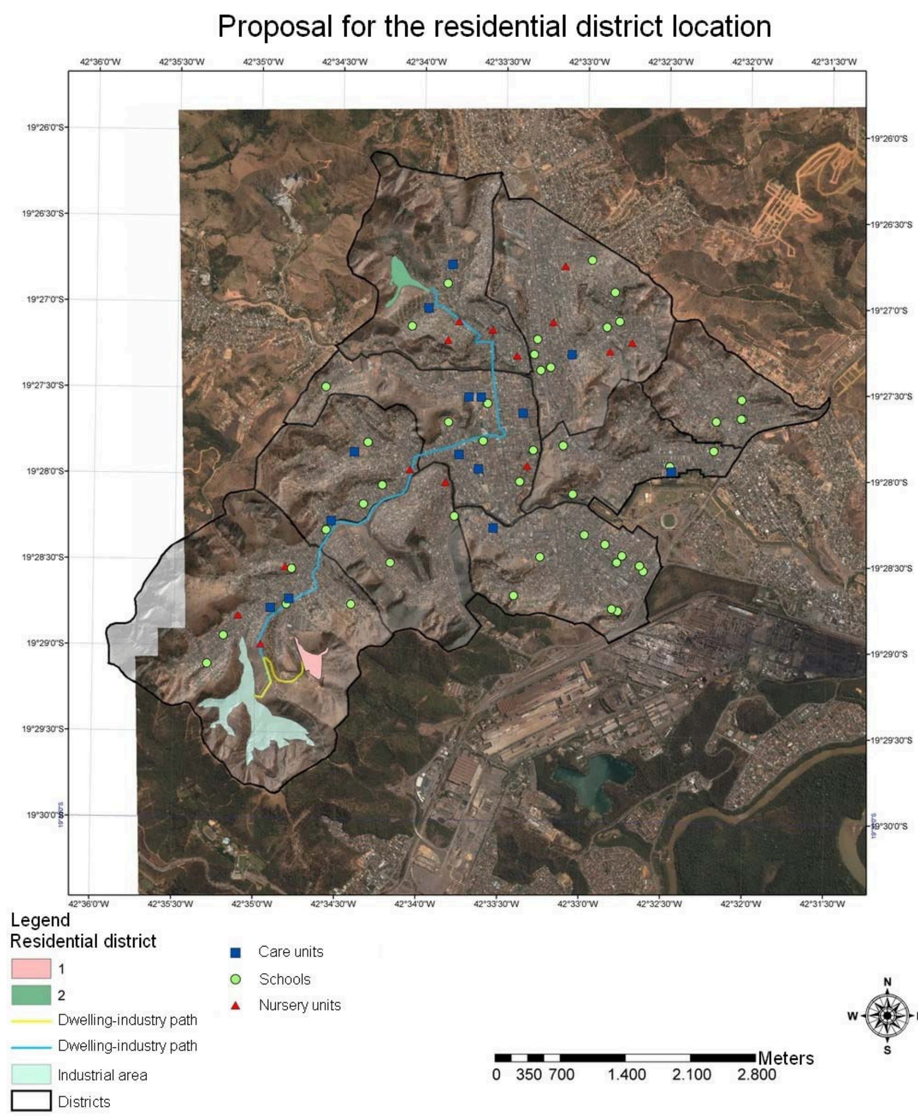

Figure 7. Map of residential district suitability.

The assessment of the best habitation area included the following factors: the shortest distances from the area where the industrial park will be set up, and the shortest distance from locations such as urban area, schools, day nurseries, and care units. The best area was the one closest to the future industrial area, and both areas are relatively close to the infrastructure, which will thus implicate no high costs. Area 1 was selected owing to low cost for employees' displacement towards the industrial park as well as to its nearness to infrastructure, which implicates no need to set up day nurseries, schools and other supporting places. Figure 8 shows variation in costs.

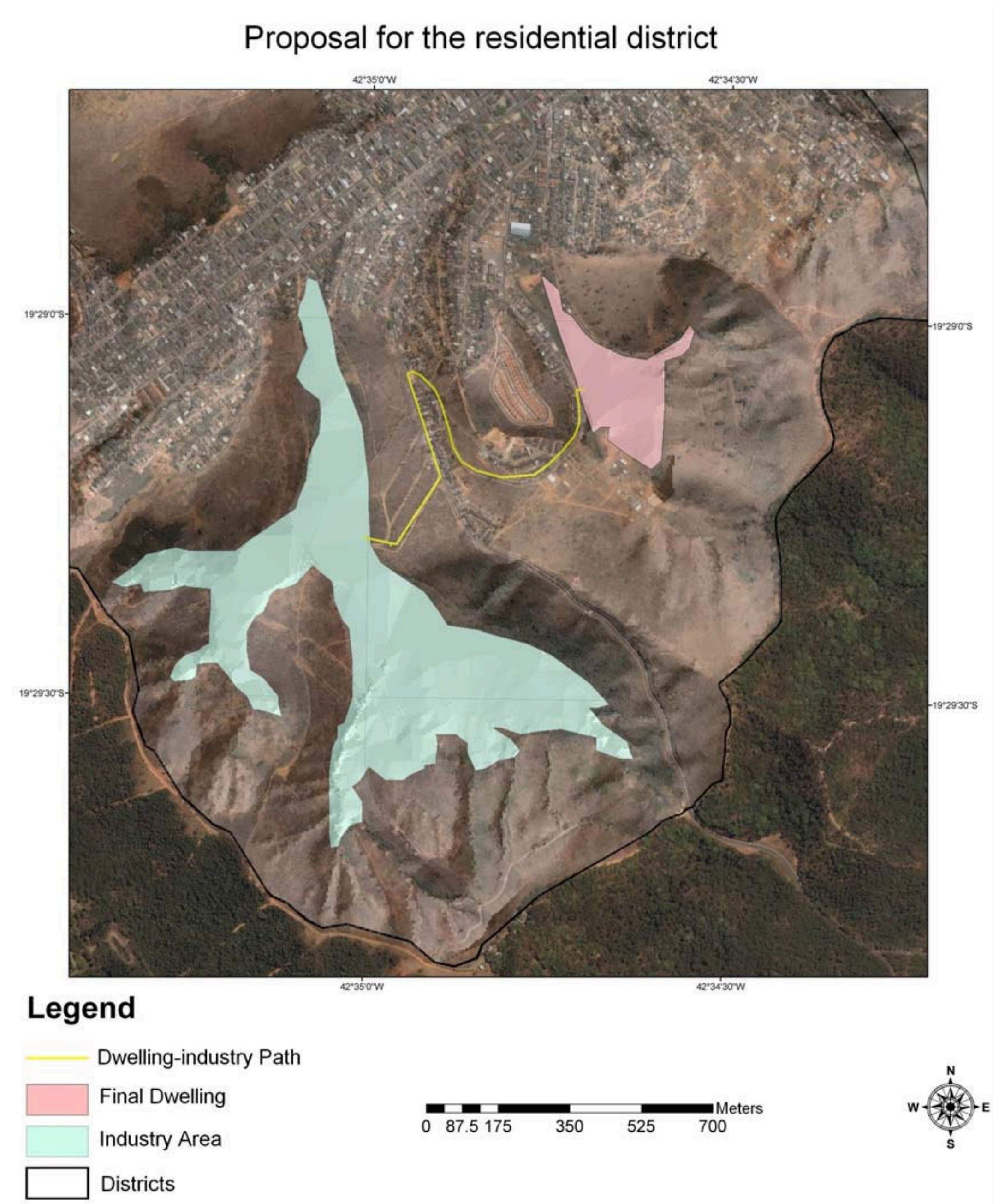

Figure 8. Cost-assessment scenario for selecting the residential area.

4.5. Costs Analysis

The most suitable areas for setting up the industrial park and for implanting dwellings are located in Bom Jardim district (Attachment 2). The table 8 presents plot-of-land costs in this district, total area of each lot and its respective value, and unitary cost of each dwelling (IBGE, 2006). A useful 80 m² area and total dwelling construction costs were also computed.

Table 8. Cost Analysis.

	Lot – Lot Bom Jardim District	**Area U$**	**R$ / m² m²**	**m² area**	**Total lot value R$**
Industrial Park	64,000.00	600	106.732	369,700	39,458,949.00
Residential district	64,000.00	600	106.732	60,900	6,500,000.00
	House building Unit Value /m²	Area	Total Value		
	*	80 m²	150 dwellings		
Each dwelling	261.32	20,905.21	3,135,842.00		

* BRASIL (2006). Available from: <http://www.ativaimoveis.com/det_imoveis.asp?cd=152>.

5. CONCLUSION

The results point out that multicriteria analysis is an important tool for decision-making in the processes of assessing and selecting areas for setting up striking enterprises. The model being structured in SIG ambient provided the observer with larger support for locational decision.

Several scenarios were modeled by means of compounding different criteria aggregated on OWA. Value weights were tested by altering risks and trade-offs, which allowed for strategic-decision-space definition.

An optimal analysis demands a greater trade-off among factors. As high trade-off values were found in this study, a riskier scenario carrying more suitability in relation to other possible scenarios could be chosen.

The choice of the most suitable area drew mainly on economical criteria, and transportation cost was the most significant one in the analysis. These factors alongside environmental and socioeconomic considerations allowed for identifying the best area for the industrial park setting up.

6. BIBLIOGRAPHIC REFERENCES

Brazilian Transportation Ministry. (2006). *Análise de custos de transporte em diferentes rotas – capítulo 5*. Research carried out in 18 August 2006. Available from: <www. transportes.gov.br/bite/estudos/interligados/Cap.5/htm>.

Calijuri, M. L.; Lorentz, J. F. (2003) *Análise multicritério*. Viçosa, UFV/Programa de Pós-Graduação em Engenharia Civil, 76 pp.

Calijuri, M.L.; Melo, A.L.O.; Lorentz, J.F. (2002) *Identificação de Áreas para Implantação de Aterros Sanitários com Uso de Análise Estratégica de Decisão. Informática Pública*, v.4 (2), pp. 231-250.

Centro de Estudos em Logística (2006) *Research carried out on 16 August 2006*, Rio de Janeiro, Coppead, available from <www.cel.coppead.ufrj.br/htm>

DNIT – National Department of Transportation Infrastructure (2003) *Manual de custos rodoviários*. 3. ed. Rio de Janeiro.

Environment Code. Ipatinga Municipal Law no. 1475. 30 September 1996.

Environment protection, conservation and improvement policy Act. Ipatinga Municipal Law no. 1475. 30 September 1996.

Filho, P.C. (2004) *Método para Apoio à decisão na verificação da Sustentabilidade de uma Unidade de Conservação, Usando Lógica Fuzzy*, PhD dissertation, Universidade Federal de Santa Catarina, Florianópolis-SC.

IBGE – Brazilian Institute of Geography and Statistics. (2000). *População Economicamente ativa do Município de Ipatinga - Minas Gerais*. Available from: <http: www.ibge.org.br>. Cited in: 01 August 2006.

IBGE – Brazilian Institute of Geography and Statistics (2006) *Sistema Nacional de Pesquisa de Custos e Índices da Construção Civil*.

Industrial zoning in critical pollution areas Act. Federal no. 6803. 2 July 1980.

Macedo, J.A.B. (2000). *Águas & Águas*. Ortofarma, Belo Horizonte, 505 pp.

Metcalf & Eddy (1991) *Wasterwater engineering: treatment, disposal and reuse*. Metcalf & eddy, Inc. 3. ed, 1334 pp.

New Forest Code, Federal Law no. 4.771. 15 September 1965. Uptaded on: 6 January 2001.

Ramos, R.A.R.(2000). *Localização Industrial: Um Modelo Espacial para o Noroeste de Portugal.* PhD dissertation, Universidade do Minho, Escola de Engenharia, Braga, Portugal.

Ramos, R.A.R.; Mendes, J.F.G. (2001) Avaliação da Aptidão do Solo para Localização Industrial: O Caso de Valença. Portugal. *Engenharia Civil. Um*, n.10, 29 pp.

Silva, T. O. (2004) *Alternativas de traçado do anel viário urbano da cidade de Viçosa – MG, através da integração SIG: análise multicritério.* Viçosa, UFV, 125 pp.

Soares, M., E., S., Ramos, R., A., R., & Mendes, J., F., G. (2005) *Modelo Espacial de Avaliação do Uso do Solo em Ambiente SIG: O caso da Localização Industrial.* Universidade do Minho, Departamento de Engenharia Civil e Instituto Politécnico da Guarda, Departamento de Engenharia Civil, Portugal. Available from: <https:// repositorium.sdum.uminho.pt/>. Cited in: 25 June 2006.

Soares, M.E.S. (2002) *Cenários de Localização Industrial em Ambiente SIG.* 2002. Master dissertation. Universidade do Minho, Escola de Engenharia, Braga, Portugal.

Uban Code. Ipatinga Municipal Law no. 6565. 1 June 1977.

Urban lot dismembering Act. Ipatinga Municipal Law no. 1545. 13 October 1997.

Urban lot plotting Act. Ipatinga Municipal Law no. 565. 1 June 1977.

Zambon, K.L; Carneiro, A.A.F.M.; Silva, A.N.R. & Negri, J.C. (2005) Análise de Decisão Multicritério na Localização de Usinas Termoelétricas Utilizando SIG. *Pesquisa Operacional*, v.25, n.2, pp.183-199.

Attachment 1. Methodological procedures applied for selecting the dwelling area.

a) Factors associated to the location of the dwellings

Code	**Description**	**MD (m)**	**Fuzzy Function**	**Control Point**			
				a	**b**	**c**	**D**
EF	**Environmental Factors**						
EF1	Minimum distance of 60m from any water stream (Law no. 565/97, Urban Code of Ipatinga Municipality	60	Increasing Sigmoidal	60	300		
EF2	Areas susceptible to landslide: very low (255), low (200), medium (150), high (80), very high (50)						
EF3	Soil usage – pasture (255), copse (230), exposed soil (180), green areas (50)						
EF4	Green areas		Increasing Sigmoidal	0	300		
LF	**Locational Factors**						
LF1	Nearness to the Industrial Park		Decreasing Linear	0	8184.16		
LF2	Infrastructure: water and sewage systems, electric energy, telecommunication		Decreasing Linear	0	3245.75		
LF3	Nearness to care units		Decreasing Linear	0	3859.66		
LF4	Nearness to clubs		Decreasing Linear	0	5086.27		
LF5	Nearness to nursery units		Decreasing Linear	0	4202.77		
LF6	Nearness to schools		Decreasing Linear	0	3459.84		
LF7	Nearness to squares		Decreasing Linear	0	3855.44		
LF8	1000m distance from the slums		Increasing Sigmoidal	0	1000		
LF9	Declivity - 1 a 30%		Increasing Sigmoidal	0	1%	15%	30%

*. MD: Minimum distance

b) Constrictions associated to the location of the dwellings.

Code	Description
EC	**Environment constriction**
EC1	Minimum distance of 60m from any water stream (Law no. 565 – Urban code of Ipatinga Municipality
EC2	Minimum distance of 500m from the Industrial Park
EC3	Green areas
LC	**Locational Constrictions**
LC1	Declivity above 30% (Law no. 6,766/79)
LC2	Boundaries of the surveyed districts
LC3	Built urban area

c) Weight Matrix – dwelling

Priority of Normalized Factors (*fuzzy*)	**Weights**
Infrastructure (water and sewage systems)	0.1330
Declivity	0.1276
Prioritization of low and very low risk areas	0.1413
Nearness to the Industrial Park	0.1347
Nearness to schools	0.0916
Nearness to care units	0.0865
Nearness to nursery units	0.0773
Nearness to clubs	0.0599
Nearness to squares	0.0465
Distance from slums	0.0399
Soil usage	0.0289
Distance from hydrograph	0.0190
Distance from green areas	0.0137

d) Scenarios of assessment- dwelling

Scenarios	**Weighed weights**	**Risk**	**Trade-off**	**Feature**
S10	MCE _ WLC = equal weights (0.077)	0.5	1	Medium risk – Maximum trade-off
S11	[.03, .03, .04, .04 , .05, .06, .06, .08, .08, .09, .12, .12, .2]	0.33	0.83	High risk – High trade-off
S12	[.04, .04, .05, .05 , .05, .1, .11, .08, .07, .1, .1, .1, .11]	0.41	0.9	High risk – High trade-off

Attachment 2 – Summary of distance costs in suitable residential areas.

AREA	**Distance (Km) from care units**	**Cost (U$) /Km***	**Cost (U$)**
1	0.847	0.23	0.1961
2	0.330	0.23	0.0764
AREA	**Distance (Km) from Nursery units**	**Cost (U$) /Km**	**Cost (U$)**
1	0.762	0.23	0.1764
2	0.844	0.23	0.1954
AREA	**Distance (Km) from Industrial Park**	**Cost (U$) /Km**	**Cost (U$)**
1	1.268	0.23	0.2935
2	6.809	0.23	1.5764
AREA	**Distance (Km) from infrastructure**	**Cost (U$) /Km**	**Cost (U$)**
1	0.308	0.23	0.0713
2	0.226	0.23	0.0523
AREA	**Distance (Km) from schools**	**Cost (U$) /Km**	**Cost (U$)**
1	0.721	0.23	0.1669
2	0.223	0.23	0.0516
Total	**AREA 1**	**AREA 2**	
	1.83582	**3.96304**	

* Source: Lima (2005). The expenditure of the road transport. Available from: <www.cel.coppead.ufrj.br/htm>. Access on 16/08/2006.