GEOGRAPHICAL INFORMATION SYSTEM & REMOTE SENSING IN BICYCLE PLANNING

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1 – Introduction

Pollution, congestion, accidents, no parking space and increasing of public transportation fares are some of the problems usually related to urban transportation. So many efforts have been made in order to solve these kinds of problems. Bicycle solution can be a very healthy answer. Bicycle mode can be pointed as a cheap, flexible, healthy and sustainable alternative. It is a mode that does not consume extra energy except produced by cyclist (user) and consequently does not generate pollution. In addition, it can be used anytime, anywhere giving to the user possibilities to select routes, schedule and to integrate with other transportation modes.

It is necessary to provide for cyclist all support to make their trips efficacious. This support is not only related to physical structure conception and construction, but also knowledge of trip pattern. Trip pattern is an important element related to the analysis of bicycle mode characteristics. Spatial geographical information is a very important issue to be considered in bicycle mode planning. The nature and patterns of bicycle mode trips have specific characteristics that minimize distances and routes that require lower human energy consummation. This kind of information has to be obtained and treated dynamically once a strong relationship is verified. In this way, it is verified that planning agencies has suffered with absence of a good theoretical formulated methodology for this transportation mode. In this sense, bicycle mode has not been treated considering realistic needs.

The recent computational development provides in transportation analysis a new perspective for the treatment of spatial – geographical variables. Now, it is possible to use instruments such as Geographical Information Systems (GIS) and Remote Sensing (RS), which are specially constructed to obtain / treat spatial data and generate new information. Specifically for bicycle planning these data and information are decisive, once they can eliminate the lack of reliable and updated information about cyclist displacements. The use of GIS and RS can also provide a new perspective for the bicycle planning, because it can be act coordinately with transportation concepts and models.

In this paper a new methodology is proposed based on application of GIS and RS for bicycle mode planning. We intend to explore GIS and RS introducing significant variables such as land use patterns, topography, real distances and routes in bicycle displacement analysis.

2 – Current Methodologies for Bicycle Transportation Planning

The current methodologies used are basically concerned with the definition of infrastructure requirements. In general it is described only geometric features of cycle way and not taking in account the displacement problem. Studies developed by Brazilian Government Agency - GEIPOT[1)], United States in North Carolina [2)] and Wisconsin [3)] carry out some activities such as: traffic survey, O/D survey, home base survey, and accident qualification in order to diagnose the circulation performance. However, these studies do not evaluate under a real systemic view, once the relationship between the activities mentioned is unconsidered. Each phase has a distinct aim, which hardly considers previous and future methodological steps.

In this way, is verified the absence of the specific bicycle planning models. Traditional transportation models were developed for motorized vehicles and are not applicable in the bicycle case, because of their contrasting characteristics. In addition Greenberg [4)] points up that there is an incompatibility between the traditional network for bicycle mode. While motorized vehicles are restricted to streets, avenues and highways, the bicycle mode is more flexible due to the adaptation to different types of routes. Consequently, a large number of alternatives route must be analyzed, making the planning process more complex leading a network construction and allocation process more detailed.

The difference between the traditional variables for motorized studies and for bicycle case can be considered a barrier. Generally, the use of relation considering simple distances or trip time that are changed in costs (Ran and Boyce)[5)], is observed in transportation models. Such basic condition is not valid for bicycle analysis. The realistic variables that affect cyclist is related psychological (space, familiarity etc.) and energetically (calorie energy consuming), depending on the cyclist capacity and purpose.

3 – GIS & RS Integration

A specific planning for bicycle transportation has to be concerned to geographical – spatial characteristics of this mode. Consequently, the variables considered in the methodologies and models have to be related to the reality that cyclist

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perceives on displacements. In this sense, it has not been possible to analyze considering geographical spatial characteristics using traditional methodologies. In order to solve this limitation and provide a specific analysis, it is necessary data and information directly collected from the geographical – spatial reality. In this sense, a powerful instrument has been used to solve transportation problems, that is the integration of Geographical Information Systems (GIS) and Remote Sensing (RS).

This integration explores dynamically the potential of GIS and RS in order to obtain new information. RS is responsible for the generation of primary data and techniques to process a spatial modeling. On the other side, GIS provides computational tools and the special capability to process spatial analysis. These analysis are defined by Goodchild (1988) *apud* (Gatrell)[6)] as a group of analytic methods which demand access to the attributes (properties) of the study objects and information of their location. The integration process (see Figure 1) starts with RS generating raster data from satellites, radar and planes (aerial photographs). In the next stage, data is transferred and georeferenced into GIS and the geographical – spatial database is consolidated. In sequence, using GIS computational tools is proceeded a preliminary data treatment. The next two integration phases is the most important and complex, due to geographical – spatial interpretation and modeling. Common characteristics are grouped as patterns and possible measures of the interesting variables are generated / stored in the GIS database. These data receive a secondary treatment separately using GIS tools. In this phase is used all the instruments to generate new information.

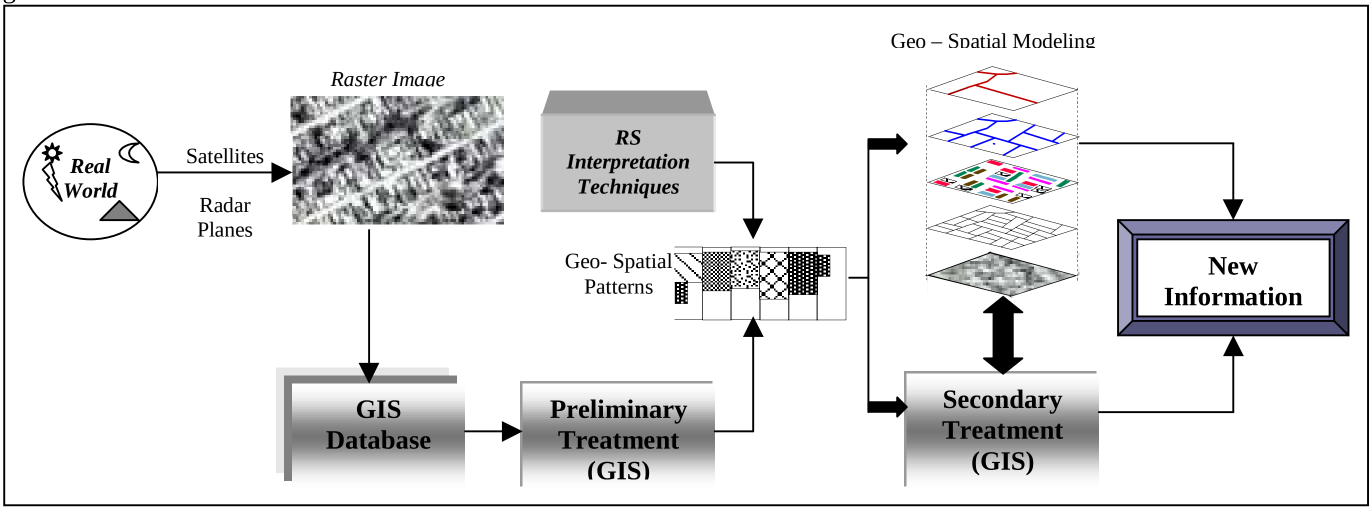


Figure 1 – GIS & RS integration Process

Recently, results of this integration can be observed in some transportation studies. There are already some experiences developed by Taco [7)] about trip generation analysis using the identification of land uses patterns; Brown [8)] worked with corridor analysis and Dantas [9)] about freight terminal location. It can be observed that the integration is based in different logic that provides new information from the raster images. In addition, it is noticed advances in the treatment of the variables related to the geographical – spatial. Considering the actual development stage of this integration, it can be point out the potential to insert new approaches in the solution of the traditional transportation problems.

4 – Proposed Methodology

A proposed methodology is developed with an objective to analyze the movements of cyclists in urban areas and to contribute to transportation planning for bicycle mode. In special, it intends to define the routes from the generation pole to the attraction pole and quantify numbers of trips, considering alternative "ways", conditions of pavements and slopes which are not commonly focused on traditional studies. These elements are taken account using aerial photographs and GIS software. In order to achieve the objective of this study following methodology is adopted: a) definition of trip generation and attraction; b) bicycle transportation network building; c) route definition. The steps mentioned will be explored below.

a) **Definition of trip generation and attraction pole**: the trip generation and attraction poles are identified and characterized. The photo-interpretation technique is used for this purpose, which consists of identification of the objects and conditions presented on aerial photographs in order to obtain the interpretation of the meanings. (see Avery and Berlim)[10)]. This identification process consists of hierarchical properties that allow identifying the photo-interpreted classes. Depending on how the characteristics of the photo-interpreted classes are identified, it is possible to define the trip generation or attraction pole. Once the trip attraction or generation pole is defined, it is possible to estimate the number of trips generated or attracted by each type of land use identified on the photo-interpreted classes in a traffic zone. The number of trips generated or attracted can be estimated by Taco's model [7)] represented by following equation:

$$V^{ZT} = u + f_1^V \ A_{f1} + f_2^V \ A_{f2} + . \ . \ . + f_n^V \ A_{fn} + U \qquad \text{(Eq.1)}$$

Where V^{ZT} is the number of trip generated or attracted from a traffic zone; f_K^V is the factor of photo-interpreted class k, $\forall \ k \in \{1, 2, 3, 4, ..., n\}$; u is the constant of regression; U is the random component; A_{fk} is the area of photo-interpreted class k, $\forall \ k \in \{1, 2, 3, 4, ..., n\}$ and n = number of class photo-interpreted;

b) **Bicycle transportation network building**: the identification and construction of bicycle network are developed in this step. It is formed by consideration of real links (providing the obtainment of real distances on a plane surface) and topographical slopes. The former is the set of all the possible routes available to a cyclist, mixing motorized vehicles links and alternative shortcut links, not identified as traditional paved route option. The alternative links, usually shortcut route, are defined using aerial - photographs that are interpreted according to RS techniques associated with GIS and principles of pedestrian displacement developed by Kovacs and Galle [11] . The alternative links can be obtained checking green coloration areas such as the grassed and no built areas, that latter will have high probability to transform in alternative bicycle and pedestrian route. Kovacs and Galle [11] also describe that displacement is always happening in a very smoothly way connecting two points into the urban space looking for a minimum distance. Once it is identified the network structure, the topographical slopes are attributed to it. This attribution process starts with the creation of the Digital Terrain Model (DTM) using specific GIS tools. From DTM are calculated the topographical slopes, which are related to areas with similar surface characteristics. In the sequence, it is necessary to compute the real distance of each network link (*dr(i,j)*), considering the link distance on the plane surface (*dp(i,j)*) and topographic slopes of each link (α *(i,j)*), where *i* and *j* are the identification nodes of the link. In this sense, using the following Eq. 2, it is possible to integrate the variables:

$$dr(i,j) = {dp(i,j)} \Big/ {\cos[\alpha(i,j)]} \qquad \text{(Eq.2)}$$

where cos [(α *(i,j)*] is the cosine function for the respective link;

c) **Routes definition**: the number of trips generated in each photo-interpreted classes (item 4-a) are allocated to the bicycle network (item 4-b) using a shortest path algorithm, that are frequently described in the literature (Whitehouse and Wechesler [12] ; Khisty [13] ; Ran and Boyce [5]). The optimal solution consists in the definition of the best set of links between to nodes (initial and final), through the minimization of the function based on distance *dr(i,j).* Then, it is used the Eq. 3

$$Min\{L(S)\} = \sum_{(i,j)\in S} dr(i,j) \qquad \text{(Eq.3)}$$

Where *L(S)* is the extension of the route *S*, that connects two nodes of the network. This equation is applied to determinate the optimal route between a generation and the attraction pole, which receive the correspondent trips. This assignment is developed separately for each attraction pole of a traffic zone, due to the necessity to evaluate the condition of the bicycle flow. In addition, it is also necessary to develop a specific analysis of the internal and external trips. So, for a selected attraction pole of a traffic zone are assigned all the internal trips and in the sequence the external ones. Once is finished this assignment process, the final routes and the number of trips on links are established. Those links with the concentration of trips have to receive special treatment (cycle ways, lanes, etc), and those routes which a lower level of occupancy, which have to be considered as potential routes for the future.

5-Proposal Methodology Application

A case study was developed in the Sobradinho City, located 24 km far from Brasilia – Brazil, with a population about 93,000 habitants (1996). It was identified on the aerial photograph mosaic 16 and 9 types of generation and attraction poles respectively. Only the traffic zone 237 was used in order to validate the proposal methodology. This traffic zone was selected due to verification of considerable external and internal trips. It was identified 3 and 5 types of generation and attraction poles respectively. The trip generation and attraction factors was computed using Eq.1 and showed on Table 1.

Table 1: Factors of trip estimation

Generation Poles	Generation Trip Factor/m²
G1	0.000408
G2	0.000603
G3	0.000239

m^2 – square meter

Attraction Poles	Attraction Trip Factors/m²
AE1	0.001575
AE2	0.002202
AC3	0.000515
AC4	0.004332

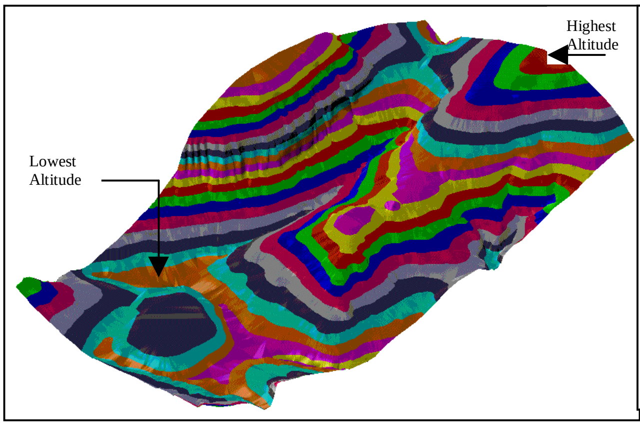


Figure 2 – Digital Terrain Model for Sobradinho City

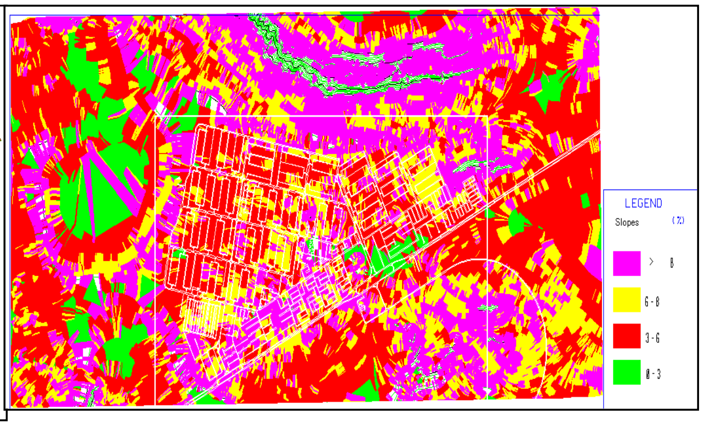
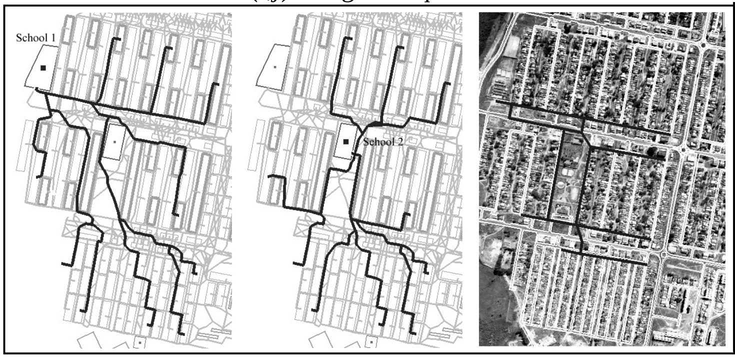


Figure 3 – Slope patterns for Sobradinho City

Next, we built a bicycle network using Network Analysis module of the MGE GIS software and the aerial photograph interpretation principles. All the network links were loaded with their respective distances *dp(i,j)*. Using the MGE Terrain Analysis module with a cartographic database provided by the development government agency (CODEPLAN), the DTM was constructed. It is presented in Figure 2. From the DTM, it was generated four slope patterns considering the city characteristics, that are from 0 to 3%; from 3.1 to 6%; from 6.1 to 8%; and greater than 8%, that are represented on Figure 3. These slopes were transferred to GIS and then each $\alpha\ (i,j)$ is attributed to all the network links, using the Grid Analysis MGE Module. Then, it was calculated the $dr(i,j)$ using the Eq. 2.



4a 4b 4c

Figure 4 – Trips Assignment

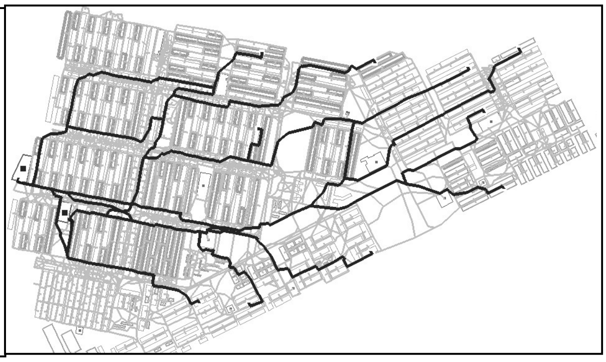


Figure 5 – External Trips Assignment

Finally, it was developed the route definition process. It was applied the procedure detailed on item 4-c and the Eq. 3 and was implemented in the MGE Network Analysis module. The allocation process started with the internal trips assigned to the first attraction pole (school 1), as it can be seen in Figure 4a. In the following, the same procedure was used to the second attraction pole (school 2), that can be verified in Figure 4b. In addition, the external trips were allocated, considering centroide of the Traffic Zone as the starting point (see Figure 5). So, it was possible to identify the concentration of trips using in a combination way both paved links (for motorized vehicles) and shortcut routes. Specifically to the 237 Traffic Zone, the final flow assignment indicates those links that necessarily have to receive a special planning. In order to develop such an activity, we proposed the actions that will give priority to the routes represented in Figure 4c. Those routes are located along local and collectors streets, but it is necessary to express the importance of the shortcut route in the network context. It was possible to verify clearly that in some cases, especially for external trips, the influence of surface profile in the shortest path optimization.

6 – Conclusion

The theoretical development for bicycle planning is an important step to contribute for the achievement of urban transportation solutions. We believe that a well-defined bicycle route could attract more users contributing to a sustainable transportation. However, the process has to be faced as a whole system that aggregates not only infrastructure definition but also bicycle trip pattern knowledge that is fundamental to process improvements for this mode.

In this paper, it was described a methodology to treat bicycle as a real transportation mode. It was mainly motivated by the inexistence of specific methodologies and models that consider the peculiar characteristics of bicycle displacements. We intended to insert variables that directly affect cyclist behavior and consequently the route choice. The proposal methodology evaluates bicycle displacement from generation / attraction (analyzing potential users and destinies), through out the definition of a particular and complex network (considering all the possible routes and slopes) to the definition of a special assignment process. This new conception was possible due to the use of the GIS and RS integration, which provides the wide consideration of geographical – spatial variables in bicycle planning.

Finally, this research is just starting point to carry out technical approach to consider bicycle such as transportation problem. It can be verified by application of the methodology that some additional studies are necessary in order to improve this research. In this sense, it is suggested some particular points that could be developed such as a sensitive analyze of slope range pattern and automation of network building technique.

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