GEOGRAPHICAL INFORMATION SYSTEM & REMOTE SENSING IN BICYCLE PLANNING

by Yaeko YAMASHITA **, Andre DANTAS ***, Pastor TACO **** and Koshi YAMAMOTO *****

1 – Introduction

Pollution, congestion, accidents, no parking space and increasing of public transportation fares are some of the problems usually related to urban transportation. 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 him/herself and consequently does not generate pollution. In addition, it can be used anytime and 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 patterns, which are important elements related to the analysis of bicycle mode characteristics. However, these patterns are related with the geographical – spatial reality due to bicycle mode characteristics and cyclist behavior. In this sense, distance minimization and route conditions which generates lower human energy consummation are the main aspects to be considered. Hence, in order to develop the analysis of trip patterns, information about the geographical – spatial reality has to be obtained and updated periodically. Nevertheless, it is verified that planning agencies have suffered with the absence of a good theoretical formulated methodology, for this transportation mode, that incorporates such information. Throughout this approach, a more realistic evaluation can be achieved and consequently, cyclist requirements can be more precisely defined.

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 where those data and information are decisive, once they can eliminate the problem of reliability and updated information about cyclist displacements easily. The use of GIS and RS can also provide a new perspective for the bicycle planning, once it can work 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, which intends to incorporate significant geographical – spatial data. Specifically, it is focused on the application of Taco's model [7] in order to evaluate travel demand from the analysis of land use patterns and the development of a special bicycle network. The GIS provides the identification and quantification of generation / attraction trips georeferenced to specific land use (residential, commercial, etc), that is fundamental to understand the unique nature of bicycle displacements. The RS technique becomes possible to represent and simulate more realistic such complex mode through the establishment of an aerial photo-interpreted network, which generates a great variety of links as shortcuts, roads, avenues, streets. The slope, that is the most relevant physical impedance for the cyclist is considered in the network. It is represented by increasing the plane distance in order to consider the energy consumed by the cyclist.

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.

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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 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 more frequently this 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)[5] 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 to generate new information.

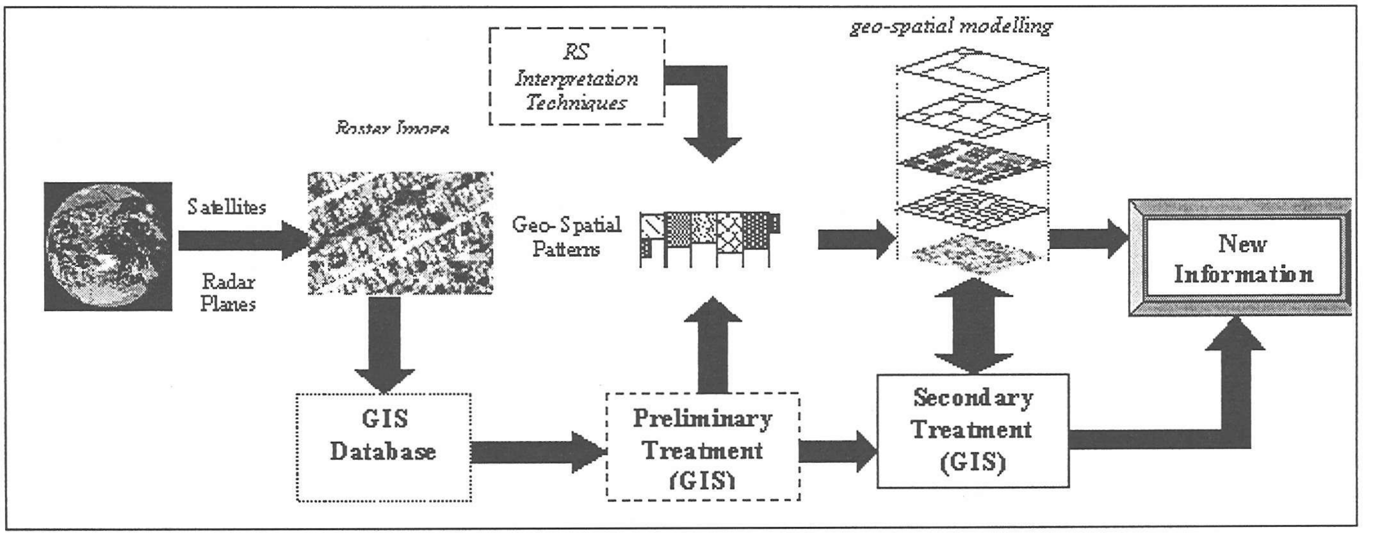


Figure 1 – GIS & RS integration Process

Recently, results of this integration can be observed in some transportation studies. There are already some experiences developed by Taco [6] about trip generation analysis using the identification of land uses patterns; Brown [7] worked with corridor analysis and Dantas [8] 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 to the solution of the traditional transportation problems.

4 – Proposed Methodology

The proposed methodology aims to analyze cyclist movements in urban areas incorporating the geographical-spatial dimension. It intends to define cyclist routes from the generation to the attraction pole and quantify trips. In this sense, the methodology focus on the incorporation of geographical – spatial data generated by GIS and RS integration (see item 4). The main data source is a mosaic of aerial photographs, which are used to obtain generation / attraction demand related to land use patterns and to create a specific bicycle network by considering shortcuts and slopes. In order to achieve such objective, it is presented a methodology composed by three phases, that is described in the sequence:

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 in identification of the objects and conditions presented on aerial photographs (see Avery and Berlim)[9]. This identification process consists of hierarchical properties that generates photo-interpreted classes. Depending on the identified characteristics of the photo-interpreted classes, it is possible to define the trip generation or attraction poles. Once the trip attraction and generation poles are defined, it is possible to estimate the number of trips generated or attracted by analyzing each type of land use identified on the photo-interpreted classes in a traffic zone. Generated and attracted trips are estimated by Taco's model [6] represented by following equation:

$$V^{ZT} = u + f_1 A_{f1} + f_2 A_{f2} + \ldots + f_3 A_{fn} + U \qquad \text{(Eq.1)}$$

Where V^{ZT} is the number of trip generated or attracted from a traffic zone;

f_k is the factor of photo-interpreted class k, $\forall\ k \in \{1, 2, 3, 4, \ldots, n\}$;

u is the constant of regression; U is the random component;

A_{fk} is the area of photo-interpreted class k, $\forall\ k \in \{1, 2, 3, 4, \ldots, n\}$;

n is the number of class photo-interpreted;

b) Bicycle transportation network building:

The procedures for identification and construction of bicycle network are described in this phase. It is a special network since it is consisted not only by avenues, streets and roads used mainly by motorized vehicles. Considering bicycle mode characteristics, it is fundamental to incorporate those ways that exist in no-constructed areas generally using green spaces without pavement or any special treatment. They are called shortcuts, especially because they are used to minimize displacement distances. In order to obtain such complex network, aerial photographs must be interpreted using RS techniques (see Avery and Berlim)[9] and GIS software to identify pixel color variations that indicates green areas transformed in shortcuts. After this recognition, the network has to be traced considering principles developed by Kovacs and Galle [10]. These principles define that pedestrian displacements always happen in a very smooth way connecting two points into the urban space looking for a minimum distance.

The energy requirements affecting cyclist movements, such topographical slope factors are incorporated to the network. These slope factors are applied to obtain an increased distance (called here representative distance) in order to simulate the consumed energy by the cyclist. It is the correction of the plane distance considering the observed inclination on the displacement surface. Evidently, there are many factors that affect cyclist movements such as psychological perception and pavement conditions but distance is the most important impedance and easy to be quantified, especially when using GIS capabilities. Thus, for each network link represented by *(i,j)* with the equivalent distance on plane surface (*dp(i,j)*), it is attributed the correspondent slope (α *(i,j)*) that is considered to compute the representative distance (*dr(i,j)*) by applying the following equation:

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

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

This process starts with the creation of the Digital Terrain Model (DTM) using specific GIS tools. Slope factors are calculated from DTM, which are related to areas with similar surface characteristics. After, using Overlay operations the whole network is updated with the equivalent slopes generating a new layer related to representative distance.

c) Routes definition:

In this phase, the trip demand computed for each photo-interpreted classes (item 4-a) are assigned to the bicycle network (item 4-b). In this step is intended to identify those links with high trip concentration where indicate the necessity to receive special treatment (cycle ways, lanes, etc) or could be a potential routes in the future. It is not the objective of this methodology to evaluate why and how natural barries generates changes in cyclist routes, in opposite, it intends just analyze links identified using GIS in order to find the shortest path route.

The assignment is done from each generation to attraction pole separately. Given a connected graph G (V, E) representing the network, a cost function defined by *dr* (equation 2) and a fixed vertex generation pole (*gp*) in V, find a shortest path S {*gp*, *ap*} from *gp* to vertex attraction pole (*ap*) in V. For this problem Dijkstra`s algorithm (Whitehouse and Wechesler)[11]; Khisty [12] ; Cormen et ali [13]) is frequently used. In the sequence, basic steps are described:

1 - Set i =0, S_0= {u_0=*gp*}, L (u_0)=0, and L(v)=infinity for v <> u_0. If |V| = 1 then stop, otherwise go to step 2.
2 - For each v in V\S_i, replace L (v) by minimizing {L (v), L(u_i)+d_{v} "$_i$}. If L (v) is replaced, put a label (L(v), u_i) on v.
3 - Find a vertex v which minimizes {L(v): v in V\S_i}, say u_{i+1}.
4 - Let S_i+1 = S_i cup {u_i+1}.
5 - Replace i by i+1. If i=|V|-1 then stop, otherwise go to step 2.

After defining the shortest path between *gp* and *ap*, all the trips are assigned to such path (All – Nothing Allocation). Considering a GIS environment, applying network analysis tools without any programming this procedure can be carried out. The above description intends just to establish a theoretical basis (Dijkstra`s algorithm) to this methodology, however depending on the GIS software the network algorithm may varies.

5 – Proposal Methodology Application

A case study was developed in 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 4 types of generation and attraction pole respectively. The generation pole is represented by different residential land use pattern. The attraction poles considered in this study are 2 schools and 2 different commercial land use pattern. The trip generation Gf_1 and attraction factors represented by school AS f_1 and commercial area AC f_1 were computed using Eq.1 are showed on Table 1.

Table 1: Factors of trip estimation

Generation Poles	Generation Trip Factor/m^2
Gf_1	0.000408
Gf_2	0.000603
Gf_3	0.000239

m^2 – square meter

Attraction Poles	Attraction Trip Factors/m^2
AS f_1	0.001575
AS f_2	0.002202
AC f	0.000515
AC f_2	0.004332

A bicycle network was built using Network Analysis module of the MGE GIS software and the aerial photograph interpretation principles according to the proposed methodology in item 4-b. All the network links were related with their respective representative 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 that can be shown in Figure 2. From the DTM, it was generated four slope patterns considering the city characteristics, that are 0 to 3%; 3.1 to 6%; 6.1 to 8%; and greater than 8%, that are represented on Figure 3. These slopes were transferred to GIS database and then each α *(i,j)* was attributed to all the network links, using the Grid Analysis MGE Module. The representative distance *dr(i,j)* was computed using the Eq. 2.

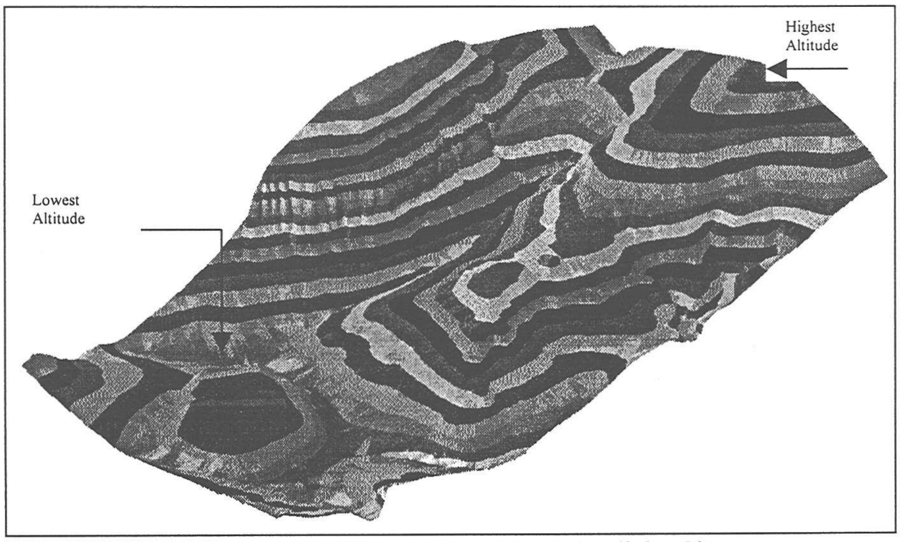
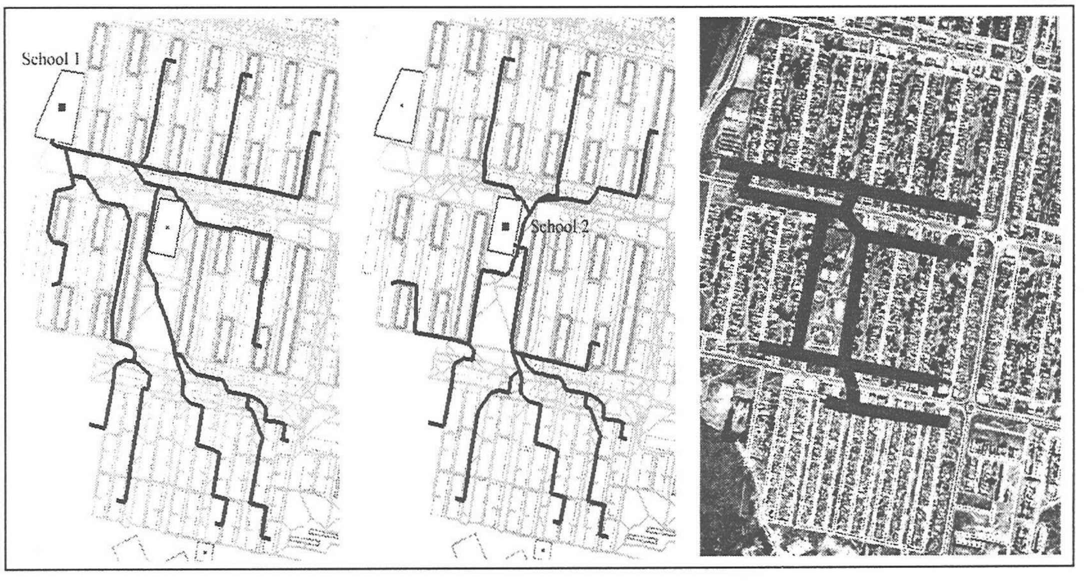


Figure 2 – Digital Terrain Model for Sobradinho City

Figure 3 – Slope patterns for Sobradinho City

Finally, it was developed the route definition. It was applied the procedure detailed on item 4-c that 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. 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). It was possible to identify the concentration of trips using in a combination way both paved links (for motorized vehicles) and shortcut routes. Specifically for 237 Traffic Zone (area in detail), the final flow assignment indicates those links that have to receive a special consideration on the cicleway definition. In order to develop such activity, it is proposed some considerations that will give priority to the routes definitions, represented in Figure 4c. Those routes are located along local and collectors streets, but it is necessary to express the importance in considering shortcut routes in the network context. It was possible to verify in some cases, especially for external trips, the influence of surface profile in the shortest path optimization.



4a 4b 4c

Figure 4 – Trips Assignment

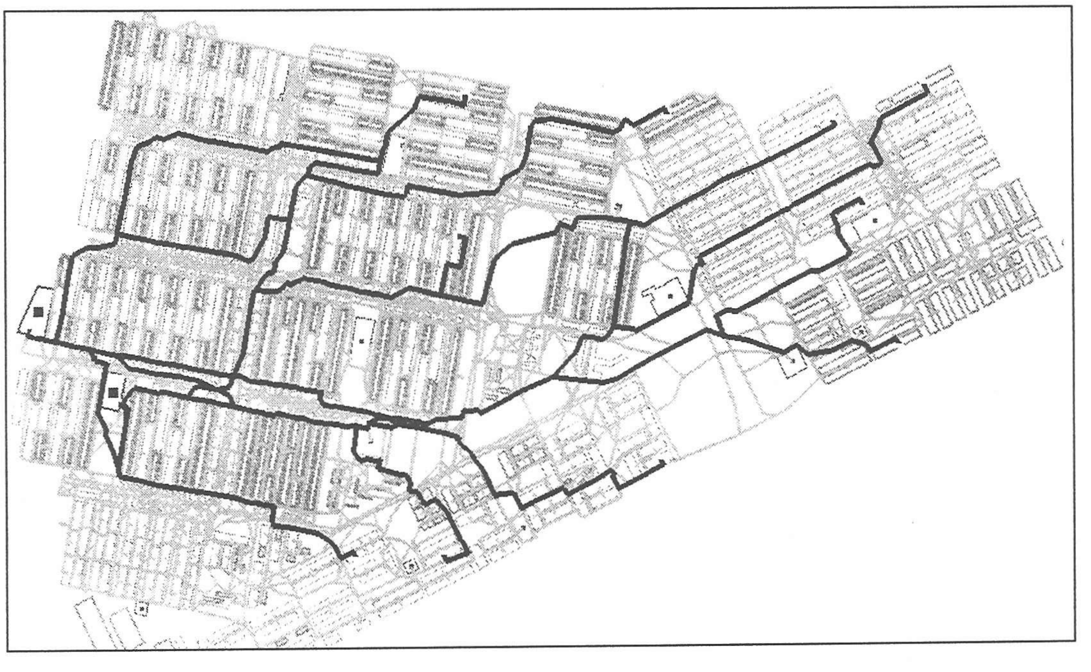


Figure 5– External Trips Assignment

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 based on geographical – spatial data generated from GIS and RS integration. It was mainly motivated by the non-existence of specific methodologies and models that consider the peculiar characteristics of bicycle displacements. In this sense, the proposed methodology concerns about the special nature of this mode and establishes a framework to analyze main characteristics affecting bicycle trips. It concentrates on the evaluation / incorporation of travel demand, bicycle networks and slopes generating more realistic comprehension of the route definition problem. Surely, such characteristics do not represent all the factors in cyclist movements, however they can be verified as the most important and representative. It has to be clear that it was not intended to cover all the characteristics but contribute to bicycle planning, since the successfully incorporation of geo-spatial reality can not be observed until now in the scientific literature. Hence, this research is just a 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, such as a sensitive analyze of slope range pattern, automation of network building technique and verification of the converted distance function is representative to the reality

Nevertheless, this new conception was possible to develop due to GIS and RS integration. It is remarkable its contribution to create information that can express the cyclist problem. This integration explored aerial – photographs as the main data source, which represents benefits in terms of time / money economy and a large variety of data / information representing the urban reality that hardly can be achieved by other sources. Transportation planning was limited by computational capabilities that concentrated only in storage/ organization / mathematical manipulation. In opposite, recent developments in computational systems such as GIS create the conditions to establish a new frountier that has a great potential to be explored. This paper tried to present a application for bicycle mode, which that has suffered without suitable instruments to evaluate specifically this mode as well its characteristics. Hence, starting from this spatial – analysis approach it is expected that advance would be achieved in a new future.

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Abstract: This paper presents a new methodology in order to give support to analyse the cyclist routes using a Geographical Information System (GIS) and Remote Sensing (RS). This methodology focus some specific cyclist travels characteristics that usually can not be considered by the measure difficulties. The topological elements such as land slope are identified from digital terrain model defined using GIS. These variables are considered in the definition of the cyclist route. In this context, GIS plays a fundamental role, fulfilling the gap of the transportation models.