MODELLING OF ACCESSIBILITY FIELDS

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Summary

The accessibility, according to distance or time-distance constitutes a variable essential to many models relating to urban planing and socioeconomic studies. Standard methods make use of graph theory and traffic engineering to work out the nodal accessibility in a transport network. The method proposed in this paper consists in the transposition of the task in raster mode in such a way : on the one hand, the accessibility can be computed at every point (pixel) belonging to the network and not only at nodes; on the other hand, an accessibility value can be attributed to any pixel in the image according to its shortest weighted distance to the network. It results from this approach of the problem a continuous field of accessibility which can be introduced in a large range of analyses using spatially continuous data and surface modelling.

1. Introduction

Fixing the accessibility is a standard issue of transport analysis which can be of interest to many socioeconomical applications. The computing of accessibility is solved by various algorithms, so called shortest path algorithms, resorting to graph theory. The transport network is considered as a graph and the origin is selected among its nodes. Then the accessibility of the other nodes from the origin is fixed by a shortest path algorithm (e.g. Dijkstra's algorithm).

The accessibility can be expressed in terms of connectivity, or distance, or time-distance or generalized costs. The choice depends of the application and of the availability of data allowing the weighting of the edges of the graph. Simple connectivity and distance weighting don't pose any particular difficulty [5]. The weighting by journey time resorts to the numerous parameters of traffic engineering [6, 2] while the weighting by generalized costs supposes to set down socioeconomical hypotheses concerning the user of the transport network [1]. The literature is particularly rich in this field, so the references are only mentioned for examples.

The research of the shortest path between two nodes in a graph constitutes an application frequently implemented in GIS softwares. The issue fits in with geographical data available in vector format. Even if the weighting capabilities often are limited, this kind of implementation has its uses, at least at the regional scale of analysis. Nevertheless, two major restrictions feature the "vector" solution of accessibility. On the one hand, the accessibility is solely computed at the nodes of the network. The accessibility of intermediate points on one edge can only be solved by interpolation between its two ending nodes, which is just valid for edges laying radially from the origin. On the other hand, the accessibility of the points located away from the network is completely ignored by the vectorial approach. Consequently the drawing of contour lines (iso-distance or isochronous lines), which often is one important aim of the application, is subjective and not reliable.

An overall solution consists in considering accessibility as a field, i.e. a spatially continuous geographical variable. Then the accessibility can present a actual value at every point in the region of interest, a minimum value at the origin and a maximum value inside the meshes of the network if accessibility is expressed in terms of distance or time-distance. The handling of an accessibility field presupposes a transcription of the problem in raster format. This can introduce some restrictions on data but it offers new processing possibilities concerning surface modelling.

2. Data preparation

The approach proposed in this paper is illustrated with a simple example processed at regional scale. It concerns the main road network covering the urban region of Liège (Belgium). The region of interest is framed by a rectangle of about 40 x 50 km (NS x EW) and only 3 road categories are used (table 1).

The accessibility is considered in terms of distance as well as in terms of time-distance. To fix the last one, the application just uses the maximum speed allowed on each road category, but not the full range of parameters required by complete applications resorting to traffic engineering. Nevertheless a speed limitation has been introduced inside urban agglomerations (table 1).

Road categories	**Maximum speed** km / h	**Urban speed** km / h
Highways and 4-lane roads	120	120
2-/3-lane main roads	90	50
2-lane secondary roads	60	50

Table 1. Road categories and maximum speeds used in the application.

The roads are digitally recorded in vector format from 1/100.000 topographic maps with two attributes : the road category and the corresponding maximum speed (figure 1). The boundaries of the urban agglomerations are separately recorded from special statistical maps.

Figure 1. Road network in the urban region of Liège (Belgium)

Then data are rasterized, that is to say they are converted into 3 images with a resolution (pixel size) of 100 m. The image resolution obviously influences upon the accuracy of the accessibility. Nevertheless, this broad example using the sole maximum speed criterion doesn't justify a better resolution.

Firstly, the road network is rasterized in an image where the pixels belonging to the network have an attribute fixed to (+1) while the background pixels present the value (-1).

A second image of the network is prepared to implement the time-distance application. In this second image, the pixels belonging to a road section have its maximum speed as attribute while the background value is fixed to (0) to allow further boolean operation. The urban agglomerations are rasterised in a third binary image where the pixels inside the agglomerations have (+1) value with a background fixed to (0). This mask of the urban agglomerations is used to modify the attributes of the road-pixels in the second image according to the urban limitations presented in table 1.

Finally, this modified image is reclassified in such a way the attributes of the road-pixels become the pixel crossing time (in seconds), which is a function of its size (constant) and of the maximum speed allowed in this pixel (table 2). During this step, the background value is set to (-1) indicating the crossing obstacle away from the network.

Maximum speed km / h	Pixel crossing time seconds
120	3
90	4
60	6
50	7
0 (away from the network)	-1

Table 2. Reclassification of maximum speed in pixel crossing time.

3. Accessibility on the network

We have to define now the origin with regard to which the accessibility will be computed. The origin is defined in a binary image, with the same position, size and resolution than the road network images. This image has a nil backgroung and it can contain only one or several pixel(s) having a (+1) value and corresponding to one or several dot(s) or polygonal origin(s) so long as the dot(s) and/or area(s) is (are) located over the network. This facility constitutes an original advantage of the raster approach of the accessibility issue, and it fits with the requirements of many applications. However, in this simple example, the origin has been selected on one pixel belonging to the network, at the centre of the main urban agglomeration.

The distance accessibility uses the simplest image of the road network, where the road-pixels are set to (+1) and the others to (-1). An algorithm of propagation [4] is applied to get an accessibility value at each pixel belonging to the network with regard to the origin. The pixels located away from the network behave like obstacles forbidding propagation and they are set to zero at the end of the process. On the network, the result at each road-pixel corresponds to the minimum number of crossed pixels needed to link the origin to the current pixel. To obtain an accessibility value expressed in kilometers, it only takes to multiply all the pixels of the resulting image by the pixel size.

The time-distance analysis uses the same origin and the image of the road network weighted by the pixel crossing time as discussed above. The algorithm is slightly different because the propagation from one pixel now is dictated by the minimal weighted neighbour. The resulting value, at each road-pixel, corresponds to the cumulated crossing time of all the pixels located on the shortest path linking the origin to the current pixel. The pixels away from the network receice the value (0) at the end of the process.

The couple of resulting images provides accessibility values, in distance or time-distance, to all pixels belonging to the network, and not only to the nodes as did the vector approach. Consequently no more indecision occurs on the edges whatever is their spatial arrangement with regard to the origin (figure 2).

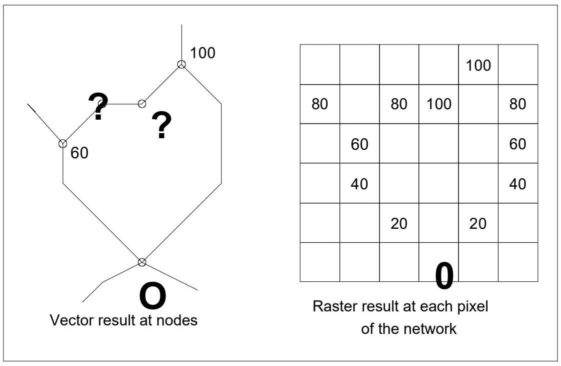

Figure 2.

4. Accessibility away from the network

To obtain an accessibility field, we now have to fix an accessibility value to each pixel located away from the network. This kind of accessibility can be broken up in two terms (figure 3) :

- the distance or time-distance between the current pixel (P) away from the network and its nearest pixel (V) belonging to the network;
- the distance or time-distance between this pixel (V) and the origin (O).

We notice that the second term corresponds to an accessibility value along the network as it was computed at the last step.

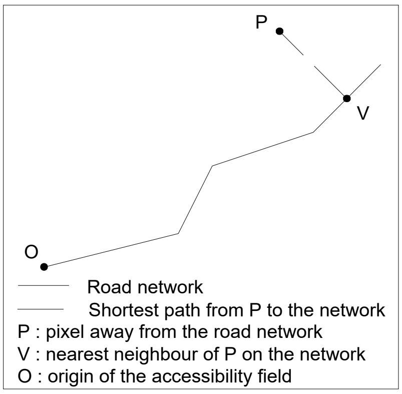

Figure 3.

Inside the meshes of the road network, the friction function of the distance can be constant or, on the contrary, it can change according to exogenous variables such as the land uses, the relief, etc.

When the friction function is constant or isotropic, the distance between a pixel away from the network and its nearest neighbour on the network is easily computed in raster mode with a dilatation of the network. If time-distance is needed, a speed of propagation must be fixed inside the mesh, in other words the distance get by dilatation must be multiplied by a constant.

When the friction function changes with exogenous variable(s), the problem is more complicated. Firstly, the various speeds of propagation must be fixed according to the kind of obstacles. Practically, it comes down to reclassify an image, with the same position, size and resolution than the road network image, but expressing the exogenous variable(s) : e.g. land uses stemming from the interpretation of a satellite image, a digital terrain model (D.T.M.) or one of its byproducts providing elevation or slope information, etc. Then the shortest path between each pixel inside the mesh and the surrounding network must be identified and evaluated in terms of distance and time-distance. This path is no more perpendicular to the network but follows the pixels presenting the minimum friction. The restricted space permitted for this paper doesn't allow to elaborate on the details of this procedure. Consequently, the example only uses the case of a constant friction function.

As mentioned earlier, the distances between the road network and the pixels located away from it are given by an algorithm of dilatation of the network. To express this in time-distance (in seconds), a uniform speed of propagation of 50 km/h is applied inside the meshes.The pixel size being 0.1 km, it comes down to multiply the distances get by dilatation by the constant (72).

To complete the accessibility away from the network, it remains to add to each pixel located inside the meshes, the distance or time-distance between its nearest neighbour on the network and the origin. For that a temporary image is built using again the dilatation algorithm. Nevertheless in this case the algorithm doesn't transfer step by step the distance to the network, but it propagates the accessibility values of the pixels on the network. The resulting temporary image is added pixel by pixel to the last image to obtain the accessibility of the pixels located away from the network with regard to the origin.

Figure 4. Distance accessibility field : from 10 to 10 km

Figure 5. Time-distance accessibility field : from 10 to 10 minutes

5. Accessibility field and surface modelling

The global accessibility field comes down to merge the two images recording respectivley the accessibility along the network and the accessibility away from the network, in terms of distance (figure 4) or time-distance (figure 5). The accessibility field can be transformed or can be submitted to further processing.

A straightforward transformation consists in the thresholding of the surface which provides contour lines (iso-distance or isochronous lines). The figures 4 & 5, thresholded for printing requirements, show such contour lines delineating the stepped surfaces of accessibility. More sophisticated analyses can be undertaken with a raster based GIS software where the accessibility field is considered as a layer of spatially continuous information. It can be related, or correlated [3], to other geographical variables naturally continuous (e.g. D.T.M.) or continuous after an adequate transformation. Two examples will illustrate this kind of analysis.

The first example concerns geomarketing. Density of population is initially available per census tract or district. When this information is converted into an image, in raster format, each pixel (which is not a point but an area) has an absolute figure of population as attribute. The availability of this population image and a co-registered accessibility field, for instance on a commercial centre, permits to compute the figure of population included in a hinterland delineated by an accessibility contour line.

The second example resorts to urban planning. Land values, initially available per parcel or district, can be converted into a spatially continuous field according e.g. to a convolution filter transformation. The availability of co-registered urban images of land value field and accessibility field provides the means to compare models relating to urban structure and/or urban growth. This second example using simultaneously two geographical fields lets glimpse the rich possibilities of the use of accessibility fields in surface modelling.

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