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# H2Network: A tool for understanding the influence of urban mobility plans (UMP) on spatial accessibility

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**Abstract:** We examine the impact of Urban Mobility Plans (UMP), imposed by the LAuRE law of December 30, 1996, on spatial accessibility to principal destinations, such as hospitals or schools. We use the open-source Geographical Information System OrbisGIS, paired with its Open Geospatial Consortium complaint spatial database H2 and its extensions H2GIS and H2Network, to produce accessibility indicators. We cross these indicators with demographical data to produce service area maps and numerical statistics. These indicators may be used to evaluate the effectiveness of UMPs.

**Keywords:** Urban mobility plans (UMP), spatial accessibility, shortest paths

## 1 Introduction

The Law on air and the rational use of energy (LAuRE), published on December 30, 1996, states that *everyone has the right to breathe air that does not harm their health*. In particular, it requires cities of more than 100,000 inhabitants to establish an Urban Mobility Plan (UMP[1]) in order to reduce the impact of public transportation on the environment. This law also requires the UMP to be reevaluated every five years, though it does not specify how.

In collaboration with Nantes Métropole, the *Institut de Recherche en Sciences et Techniques de la Ville* (IRSTV[2]), the French Research Institute in Urban Sciences and Techniques, initiated a research project known as Eval-PDU (2008-2012) in an effort to evaluate the environmental impacts of public policies on public transportation. The

[1] http://www.installationsclassees.developpement-durable.gouv.fr/Urban-Travel-Plan-PDU.html, retrieved April, 2014.
[2] http://irstv.fr, retrieved April, 2014.

methodology includes numerous approaches, including numerical simulations evaluating air quality, noise pollution, energy consumption, and greenhouse gas emissions with a chain of physically-based models, based on alternative and comparative scenarios.

In this paper, we examine how to evaluate UMPs geographically. In effect, changing the kinds of transportation offered to the public (e.g., introducing a new tram line or installing a public bicycle system) or modifying the structure of the road network to favor public transportation (pedestrianizing a street, introducing bus lanes) influences how people choose to get around on a daily basis. Everyday activities such as going to work can quickly become a burden if the changes introduced by the UMP are not sufficiently evaluated and their impacts anticipated (the distance from point $A$ to point $B$ could change; access to public services could decrease).

To address these issues, we propose a methodology and an open-source tool which, starting from geographic data representing the public transportation network of a city, allows one to produce indicators representing accessibility to principle destinations, such as train stations, airports, universities, hospitals, gyms, etc. We further clarify these accessibility indicators by crossing them with demographical data, thus quantifying the impact of a UMP on a city's inhabitants by studying their spatial distribution relative to principal destinations.

## 2 Methodology

The very definition of a UMP, by modifying public transportation options available to citizens as well as traffic flow, implies a restructuring in the way roads are shared. This reorganization has direct repercussions on citizens' transportation choices around and, by extension, on their quality of life. When we realize how much time people spend in public transportation—an hour and a half per day on average for inhabitants of the Ile de France region; over two hours for 20% of them—the vital necessity of tools for quantifying and characterizing the impact of UMPs becomes clear.

A number of travel-related problems can be cast in the language of graph theory, which examines relationships among discrete entities. The entities are represented as a set $V$ of *vertices* or *nodes* and the relationships as a set $E$ of *edges* (Newman 2003). The resulting graph is the ordered pair $G = (V, E)$. In a travel context, the edges are often road segments and the nodes are intersections or points of interest.

A variety of techniques and indicators for studying the structure of the graph are well-known. Some examples include degree distributions, clustering, network correlations, random graph models, shortest path calculations, and closeness and betweenness centrality. (Rodrigue et al. 2013, Newman 2003). In particular, Dijkstra's algorithm provides the solution to finding the most efficient travel route and the information that can be concluded from this calculation, such as identifying the closest facility or defining service areas based on travel time (Rodrigue et al. 2013). Yet these results are not widely implemented in Geographical Information Systems (GIS) or other cartographic contexts.

In this paper, we examine the notion of accessibility, defined as "the measure of the capacity of a location to be reached by, or to reach different locations. Therefore, the capacity and the structure of transport infrastructure are key elements in the determination of accessibility" (Rodrigue et al. 2013). In our case, we study accessibility via three different H2Network functions:

1. `ST_Graph`: From a table of geographical data, we construct a mathematical graph by assigning numerical ids to edges and nodes, resulting in two new tables. An edge may be enriched with additional information that controls how shortest paths are calculated, such as its orientation or weight. For example, one can specify whether a road is one-way or bidirectional, as well as its length or estimated travel time.
2. `ST_Accessibility`: We identify a subset of destination nodes (such as all hospitals). Fix any node $v$. Calculate the shortest distance from $v$ to each of the destination nodes. Take the minimum of these distances, and designate the corresponding destination as the closest destination. Repeat this for every node $v$ in the graph.
3. `ST_ShortestPathTree`: Calculate the part of the graph which can be reached starting from a given start node and limited by a given time or distance.

We use the information obtained during these calculations to produce a service area map, for various services such as train stations or schools. This map includes isolines whose intervals are expressed in metric or temporal units. Finally, the isoline map is crossed with demographical data in order to quantify the number of inhabitants affected by changes in the road network introduced by a UMP. Using this information, we can estimate, for example, the percentage of inhabitants situated at a distance of less than 500 meters from a train station, or at a travel time of greater than 20 minutes from a school.

## 3 Implementation in H2Network

The methodology described above is implemented in the open-source Geographical Information System OrbisGIS (Bocher & Petit 2012), which uses the relational database management system (RDMS) known as H2[3]. In 2013, the OrbisGIS team made the choice to switch to H2 from the previous database they had invented, called GDMS (Bocher et al. 2008). This choice brought greater modeling flexibility, improved performance and better interoperability with other databases. When the choice was made, H2 did not yet have a Geometry data type. The team collaborated with the H2 team to add basic support for Geometries, and eventually created their own open-source spatial extension of H2 called H2GIS[4].

H2GIS contains multiple spatial functions, including those specified by the OGC's Simple Features for SQL (SFSQL) 1.2.1 standards (Herring 2010, 2011). It includes additional spatial functions the team has developed that extend and complement the SFSQL functions. Examples include:

- `ST_CompactnessRatio`, which computes the perimeter of a circle whose area is equal to a given polygon's area, and returns the ratio of this computed perimeter to the polygon's perimeter (useful for urban morphology), and
- `ST_Delaunay` and `ST_ConstrainedDelaunay`, which calculate (constrained) Delaunay triangulations (useful in hydrology).

Both H2 and H2GIS are fully written in Java. They can be used in embedded mode in order to give spatial database capabilities to any Java application with a small mem-

[3] http://www.h2database.com, retrieved April, 2014.
[4] http://www.h2gis.org, retrieved April, 2014.

ory footprint. Moreover, H2GIS is based on a robust and well-known open source library known as the JTS Topology Suite[5], which provides an API for modeling and manipulating 2-dimensional linear geometry, as well as numerous geometric predicates and functions.

H2Network is the network analysis component of H2GIS. It provides functions for constructing a mathematical graph from geographical data representing a road network and performing shortest path calculations and other network analysis on the resulting graph. Some of its functions were mentioned in the previous section.

## 4 Case study

We take as study area the 24 municipalities of Nantes Métropole (566 500 inhabitants). The road network is modeled as 53,616 segments (polygonal chains); the data comes from the national topographical database BD TOPO® produced by the *Institut National de l'Information Géographique et Forestière* (IGN[6]), the French National Geographic Institute. The study area is divided into 229 IRIS zones, which are defined by the *Institut national de la statistique et des études économiques* (INSEE[7]), the French national statistics institute, to be statistical units comprising a population of 2,000 inhabitants. We represent them as polygons.

We study accessibility with respect to three scenarios:

1. Base case: The original road network as defined by the BD TOPO® data.
2. Busway: Scenario 1 with a new central bus line (the Busway) crossing Nantes from north to south and reducing light vehicles' access to the city center.
3. Bridge: Scenario 2 with a new bridge (the Eric Tabarly Bridge) which joins two major neighborhoods of Nantes, Ile de Nantes and Malakoff, otherwise naturally separated by the Loire river.

Overall, our results show a spatial redistribution of distances, which are notably more pronounced in Scenario 2. In effect, the accessibility calculations for light vehicles (cars) in this scenario show an increase in distances when approaching the center, as compared to Scenario 1. If we relate these distances to the inhabitants, our analysis shows that the number of inhabitants affected is relatively more important due to the fact that neighborhoods near the city center are more densely populated.

## Invitation

We would like to invite you to attend and participate in our workshop entitled *Road network analysis with H2Network: Applications of the spatial database H2GIS*. We will demonstrate and apply the various analyses evoked in this paper.

[5] http://sourceforge.net/projects/jts-topo-suite, retrieved April, 2014.
[6] http://www.ign.fr/, retrieved April, 2014.
[7] http://www.insee.fr, retrieved April, 2014.

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