

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/297738814>

LIMEWISE: A deterministic line-based interpolation methodology for a realistic multimodal accessibility representation

Conference Paper · July 2015

CITATIONS

0

READS

152

1 author:



[Patrick Palmier](#)

Centre d'études et d'expertise sur les risques, l'environnement, la mobilité et l'aménagement

13 PUBLICATIONS 10 CITATIONS

SEE PROFILE

LIMEWISE: A deterministic line-based interpolation methodology for a realistic multimodal accessibility representation

Palmier Patrick¹

¹ CEREMA – Nord-Picardie territorial division

Abstract

The representation of territorial accessibility need to combine two technical fields, transport modeling in order to calculate realistic and accurate multimodal travel times, and advanced GIS features to visualize the results through isochrones or other geographic indicators. Unfortunately results are too often produced by either transport or GIS specialists, ignoring each other. This paper proposes an original methodology, using free and geo open-source software to produce accurate indicators and realistic maps combining advanced techniques of both fields, in order to analyze territories accessibility, especially at a large scale. The article focuses on an implementation of a deterministic interpolation based on linear objects taking into account access times varying along polylines objects, and other criteria as impassibility, possibility of spread from linear objects, taking advantage of the open source geographic software Qgis to implement and validate the methodology through a plugin called "networks" available on Qgis repository.

Keywords

accessibility, multimodal, isochrone, interpolation, linear, transport

1 Territorial accessibility indicators

Generally, territorial accessibility maps based on isochrones are often produced to show accessibility inequalities. This mode of representation is attractive, especially for a non specialist public. Isochrones enable users to produce accessibility indicators, such as the number of inhabitants or jobs within a duration period a time, or based on gravity models (Hansen , 1959).

Transport modeling practitioners, generally used specific modeling tools from proprietary software which are designed to do efficient calculations, based on shortest path algorithms taking into account transport demand, and where the generation of isochrones is, when it exists, an optional layer, often based on simplistic rules for interpolation. In parallel, in most GIS software, isochrones are often produced with their own shortest path algorithms. Often they don't take into account the complexity of transport problem, especially inter-modality combining individual modes defined by arc-based travel times and timetable based-modes. Interpolation for isochrones generation, is in general based on kriging from travel times associated to point objects, located at junctions. But

kriging is designed to interpolate results from point objects where the spatial distribution of the variable we want to interpolate is not known "a priori". Kriging is then not well adapted to travel times, which are varying along the itineraries, and where time values outside lines don't fill with kriging variograms, but can be estimated with a deterministic approach

2 The multimodal issues

2.1 Road issues

Road accessibility calculation can be divided in two groups:

- Transport modeling group where accessibility is based on traffic assignment results. This approach needs a trip demand matrix in order to take into account road congestion defined by volume-delays functions on links. As traffic assignment is a converging iterative process, generally to reach Wardrop equilibrium (Wardrop, 1952), the road network taken into account isn't exhaustive to be adapted to the demand zones and for calculation speed. Transport modeling software are proprietary software where pricing is depending on the number of zones or links, which also limit the size of the network. Thus, if travel times at equilibrium reflect correctly real travel time conditions, this method can't estimate times for local network, which could be problematic for isochrones visualization at large scale. Static models are also based on peak hour to take into account road congestion, which is not adapted for long trips exceeding 1 hour, where only part of the trip is occurring at peak hour.
- Road accessibility based on GIS calculations are generally based on exhaustive with constant travel times on links defined by average speed on links depending on road and environment characteristics.

If, in order to calculate a particular itinerary between an origin and a destination, as in road navigator, A* like algorithms are adapted and powerful, Dijkstra or Graph Growth Algorithm like algorithms are more suitable for 1 to all destinations calculations as need for isochrones.

2.2 Timetable based networks

Public transport accessibility could be computed either on frequency based networks or timetable-based networks. Transport models are currently dealing with both approaches. Frequency based algorithms, as implemented in most modeling software, give an estimation of average travel times during a period, often based on strategies (Spiess & Florian, 1989). Timetable based algorithms give exact travel times or costs, but for starting or arriving at a precise time. These shortest path algorithms are different from road ones, and are subject currently of much research, in order to optimize public transport routing search engines (Delling, Pajor & Werneck, 2014) and (Dibbelt, Pajor, Strasser, & Wagner, 2013). Nevertheless, certain algorithms lose a significant part of their performance if they had to deal both timetable and road based networks.

2.3 Multimodal networks

Today, concerns related to inter-modality and modal shift, require accessibility

tools that combine different networks, either road networks (walking, cycling, driving) , timetable based ones (public transport, airplane), and hybrid ones as bike or car share services for example. These networks are built combining several networks connected in inter-modality points. Shortest path algorithms need to deal with characteristics of road and time table based algorithms. For planning purpose, and desktop tools don't need to have very quick algorithms as multimodal itineraries API need, but to be able to carry out complex studies with specific and multimodal options in order to evaluate complex public policies. Such algorithms as developed by IFSTTAR (Bousquet, 2010) in Tempus project or Musliw (Palmier, 2010) respond to these requirements. Multi-objective algorithms are designed to propose users several optimizations depending of their wishes, as implemented by Gräbener, Berro & Duthen (2010)

3 Multimodal calculations

3.1 The need of link based graphs calculations

For realistic accessibility maps visualizations, we need first powerful shortest paths algorithms which can manage several networks layers (road based and timetable based). In addition, the graph topology must be designed at a link level and not at a node level. It implied that the graph is composed of links with incoming and outgoing links, and not a succession of nodes connected with links. This prerequisite is essential to visualize access time, in particular at large scale, because access times are varying along links. It implies that the access time for at a particular node is generally not unique. It depends of the node in-comings link. This property allow to take into account in standard, specific turning movements, or transfer penalties. More complex algorithms are taking into account complete sub-path prohibitions or cost-addition as in Tempus (Bousquet), 2010. The accessibility calculator tool must provide detailed access times of general costs for every link in order to build accessibility maps.

3.2 The Musliw Tool

Musliw is a tool designed by CEREMA (Palmier, 2010) to compute multimodal itineraries calculation for planning studies. The network internal structure is based on nodes and links. Links are defined by a starting and ending node and a line identifier. Links could be either road links defined by a travel time which could be set for different time periods and calendar days, or either timetable links defined by a line identifier, and a set of services (days of services, starting time and ending time). The internal graph topology is link-based and produces complete statistics as detailed output as a result. These outputs concern generalized costs including in-vehicle times, individual modes travel times, waiting time and boarding times which can be set depending of a user-defined link attribute. The user can ask either for a date and a time of latest arrival or either a date and time of earliest departure, and can specify specific check-in delays for flight or Eurostar. The tool produces as outputs, generalized costs for every node and arc, detailed multimodal itineraries, link flows, transfer flows and trip summaries.

4 Isolines representation issues

4.1 Point-based interpolation

As access times are often only available at node level, the creation of isolines or iso-polygons has to be carried out with point objects. Many techniques are existing to predict a value at a given point by processing an interpolation. Several techniques are commonly used, inverse distance weighting, triangulated irregular network, nearest neighbors or kriging. If these techniques could be sufficient at small-scale with a high density of points, they are unadapted for analysis at large scale, especially for measuring the walking accessibility of a site. Even though, these techniques of interpolation are often used, because research in this area is very active and many interpolation algorithms are implemented in commercial and open-source GIS software and are easy to use. In addition, many of GIS users don't know the theoretical concepts of interpolation and kriging they are using and the set of algorithm parameters to be determined, so they use default ones. This implies that the produced maps could be wrong and it could be impossible to explain the represented access times.

4.2 Fixed grid or buffer around stations

Several other procedures are used to represent territorial accessibility, as generating a fixed grid and to extend the graph by creating virtual arcs from the center of each cell to the nearest arc orthogonally. This method gives a good representation of accessibility but has some disadvantages such as increasing the size of the network graph, being only adapted in a specific range of scales. A grid is necessarily associated to a networks graph that requires to build as many grid as different network graphs you have. Grids could be replaced by territorial zones or voronoï regions based on the node layer.

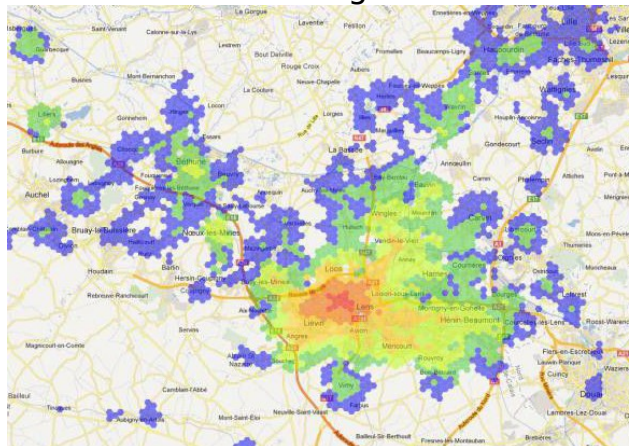


Figure 1: Example of PT and walking accessibility rendering with grid - Source CEREMA/DterNP – (Palmier 2014)

Instead of generating polygons, it could be sufficient in some cases to make a thematic map based on access times on nodes, represented by colored circles. Finally, we can mention the possibility of generating isolines concave hulls, which are subject of much research, but have the disadvantage of not being

unique.

4.3 Line-based interpolation

Two main methods are used to create iso-lines from polylines objects. The first, which is the default method used by ArcGis called "polygon based networks buffer" (Frank, Schmid, Sallis, Chapman & Saelens, 2005) consists in building polygons from vertices which are exactly at a specific access distance of time from an origin. Generally, this implies that the shortest path calculations are made with the software algorithm, which doesn't enable most of the time complex multimodal networks mixing timetable based and individual mode networks. This method is disputed because of the importance of the buffer type which influences significantly the precision of walkability measurement. Oliver, Schuurman & Hall (2007) prefer introduced the "buffered line-based network buffer" which corresponds to create a buffer of 50m wide around every road that can be reached in a predefined distance or time. But this method don't perform very well to take into account data which is not point data, as density or public space areas. The limits of these different methods to build isolines for multimodal accessibility highlight the need of a method that leverage the best of, on one hand, the quality of multimodal calculation, and on the other hand, a specific interpolation method that answer completely the objectives of multimodal accessibility specifics.

5 The LIMWISE method

5.1 Presentation

Limewise (Linear Interpolation Method With Impassability and Spread for Evaluation) method origin, was designed to define, in the mobility plan of Lille Metropole, high walking access areas around public transport stations (at 5 minutes and 10 minutes).

Basic principles of the Limewise method were implemented in ZAP maps in Lille (Palmier, 2001). The methodology has been constantly improved since 2001, to reach its current state of development, including the consideration of lateralized spread and impassability. Here is a comparative of three different methods (Chatalic 2012).

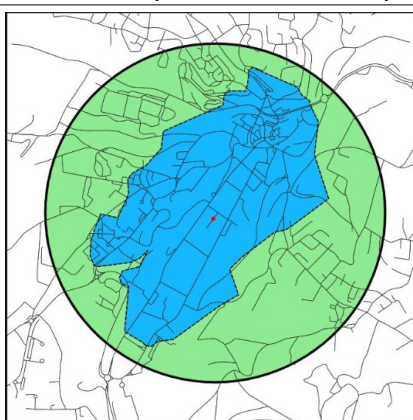


Figure 2: Buffer line-based network (Chatalic 20112)



Figure 3: Buffer line-based network buffer (Chatalic 2012)

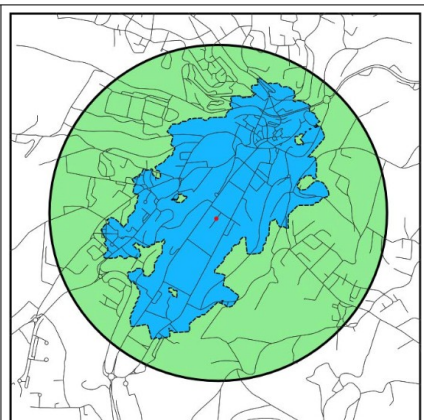


Figure 4: Zap method (Chatalic 2012)

5.2 The questioning of some assumptions

First, multimodal accessibility specificities encouraged to question some assumptions. Common methods supposed that accessibility is universal (defined everywhere), continuous, isotropic and permanent.

5.2.1 Universal

Multimodal accessibility is not defined everywhere, because some places are inaccessible, as rivers, lake, prohibited places,... This property should be taken into account in a realistic method

5.2.2 Continuous

Multimodal accessibility isn't continuous everywhere, because some roads are impassable. It implies that access time on one side of the road isn't the same as the one on the other side. For example, from either side of a motorway access time could be very different, if we suppose that we can't cross the lanes. In addition, even if you consider that where you're in a car you can park everywhere on the side of the road, it's no more true in highway, and you can't jump out of a bus, a metro or a train until it stops at a station. Public transport accessibility is by nature discontinued, as you can access or egress only at stops or stations.

5.2.3 Isotropic

In parallel, multimodal accessibility isn't always isotropic. First, concerning public transport the frequencies and travel time may vary from a bus stop to another depending of the service direction. Even, for individual modes, when you're walking on the sidewalk of an avenue with many cars, you can spread on the same side of you sidewalk, but not on the other side, because you need to cross the road, and it's impossible except at junctions due to heavy traffic.

5.2.4 Permanent

The accessibility of individual modes is permanent, that is it is defined all day-long and any day, even if travel time may vary during the day, as by car in peak hours. Public transport are discontinuous along the day, because people have to wait for the bus in order to board in. In addition, frequencies varies along the day, and often there is no service available at night between 1am and 4Am. The level of service also depends of the type of the day (school, period, holidays, sunday,...)

5.2.5 The need of an adapted methodology

The questions raised require a methodology that can deal with an oriented graph to take into account travel times which could be different depending of the flow direction. In addition, the methodology has to take into account impassability of links and the possibility to define if people can spread form the road either to the left, to right, in both directions or not.

5.3 Description of the method

The LIMWISE method is based on the key idea that in order to represent realistic multimodal accessibility, you need an efficient an adapted multimodal

shortest path algorithm combined with an line-based interpolation algorithm which interact each other to take advantages of the best of both techniques.

5.3.1 Access times for any link at start and end nodes

The multimodal shortest path algorithm should provide access times for any link of the multimodal oriented graph. It means that each reachable link has an access time (or cost) from origin. This access time corresponds to the endpoint, if the query was to start from origin at a certain time, or it corresponds to the start point, if the query was to arrive at the destination a a certain. In both cases, you need to calculate the time at the other end, by subtracting the link travel time or cost.

This implies that access time at a node is not unique. They are as many access times at a node as incoming links.

5.3.2 Limewise necessary link attributes

In order to create realistic isochrones maps, you need to fill to each link three attributes

- Flow direction: This field is necessary to know if each link is one-way , two-ways, or prohibited

'0'	Prohibited link
'1'	One way link in the same direction of digitizing
'2'	One way link in the opposite direction of digitizing
'3"	Two way links

- Side of spread: This attribute indicates if when you are traveling in a certain link, you can spread in adjacent blocks, left or right, or not. For example, if you are circulating on a motorway you can't spread because you need to reach an interchange to exit. It's the same thing when you are traveling in a bus, a train or a metro, your need that the vehicle arrives at a stop to alight. If you're walking on a street with heavy traffic, you can spread only in one side, because you can't cross the street, except at a junction.

'0'	Spread is prohibited in both sides
'1'	Spread only to the right side
'2'	Spread only to the left side
'3"	Spread allowed in both sides

- Impassability: This field indicates whether you can cross the link or not. For example, if you are on a side of a river, your can't access the other side directly, you need to go to a bridge that crosses. Conversely, I you are on a side of an underground metro line at a ground level, you can cross easily as you are not on the same level. In theory, you can imagine barriers that you can cross only in one direction, for example at a border or to enter in some areas where entrance are not in the same place as exit.

'0'	You can cross the link from any side
'1'	You can cross only from left to right

'2'	You can cross only from right to left
'3'	You can't cross the link

5.3.3 Examples of network links codification

The next table gives examples of links codification.

Type of link	Flow direction	Spread	Impassibility
Bus (on road)	'1'	'0'	'0'
Metro (undeground)	'1'	'0'	'0'
Train (road level)	'1'	'0'	'3'
Highway	'0' or '1' or '2' or '3'	'0'	'3'
Streets (low trafic)	'1' or '2' or '3'	'3'	'0'
Streets (high trafic)	'1' or '2' or '3'	'1' or '2'	'0'
River or railways	'0'	'0'	'3'
Bridge or tunnel	'1' or '2' or '3'	'0'	'0'

5.3.4 Method of interpolation

- Firstly, you have to grid your study area.
- Secondly, you had to fetch each link in your study area where you can spread from.
- Then for each grid cell in a search radius distance from the link, you find the closest point on link from the center of the cell. In Qgis, this is done with the closestSegmentWithContext API function. It corresponds to the orthogonal projection of the cell center on the link. If this projection isn't on the link, the closest point is either the link starting point or ending point.
- If the distance between the grid cell and the link is lower than the smallest distance between the grid cell and all previous links, and the if the line between the link and the grid cell doesn't cross a link which is impassable, then the grid cell minimum distance is updated and the cell access time is calculated as follow.

$$T_{i,j} = (1-\lambda)t_{k,endpoint} + \lambda t_{k,startpoint} + v_{spread} \cdot d_{(i,j),k}$$

i, j :refers to cell i,j

k :refers to link k

λ :refers to fraction of line length defined from the link startpoint to the orthogonal projection of the grid cell

$t_{k,startpoint}$ and $t_{k,endpoint}$:refers to acces times

for link k at startpoint and endpoint

v_{spread} :refers to the speed of spread

can be a constant or a link attribute

$d_{(i,j),k}$:refers to the shorstest distance

between the grid cell and the link

- After having fetched all links, you have a geographic grid representing access times, which can be either displayed as a raster or either as

isolines with contour generation algorithms as proposed in Qgis or Grass.

6 Application

6.1 Implementation in Qgis

Limewise method in Qgis is implemented in networks plugin, available in the Qgis repository. This plugin also proposes a set a tools to help users to prepare networks or graphs. As Limewise method works with oriented graphs, users have to choose between dealing only with one-way links or two-ways links. Working with two ways links requires that user use four access time fields, two for each direction (end node and start node times). Dealing with one-way links only, needs to duplicate two-ways links and reverse the direction (for example using the "reverse" plugin command) in order to facilitate its use.

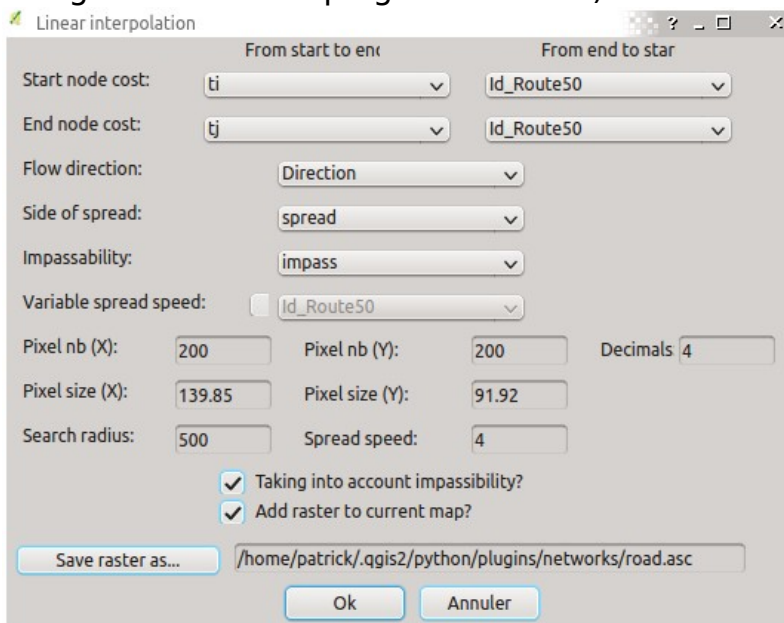


Figure 5: Limewise dialog in Qgis

6.2 Examples

The following examples shows differences using different settings in Limewise algorithms. They are related to a road accessibility from an origin in the center of Lille

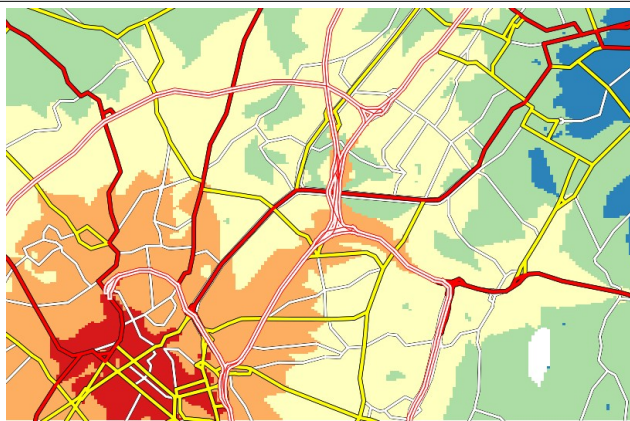


Figure 6: Limewise with basic settings (Palmier 2015)

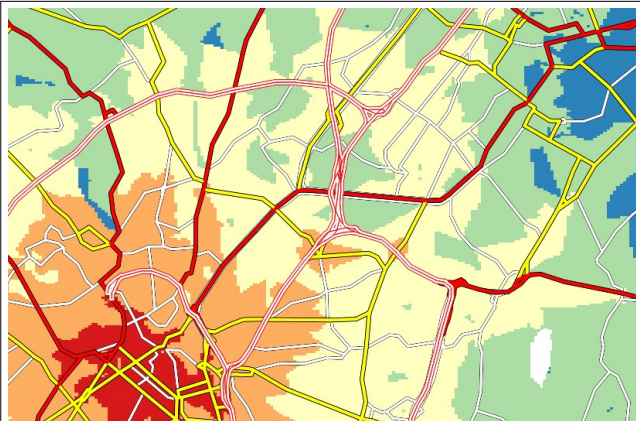


Figure 7: Limewise with user defined settings (adapted to local environment) (Palmier 2015)

On the left, the map shows Limewise basic settings, where spread is possible on each side for every link. On the right, spread is prohibited for motorway links, and only allowed on right side for primary links (in red). In the same time, motorway links are impassable. Color gradient from red to blue, is divided by steps of 10 minutes with a spread speed of 20km/h.



Figure 8: Limewise with user defined settings (adapted to local environment) Palmier (2015)

The map above shows the LimeWise method applied to the Tourcoing station which is only north-oriented. Streets are colored in black, and railways corridors limits in red, are considered as impassable. Color gradient from red to blue describes the walking accessibility to the station by steps of 100m. This method points out very clearly dead ends (in the bottom middle of the map) where accessibility to the station is very poor. A map analysis, shows the

advantages provided by the Limewise method. First, access times on links are realistic, and those inside blocks are easy to explain or interpret as rule of spread are well known and set by the use.

6.3 Variability over a time period

The remaining question, about accessibility concerns the variability over a time period, as public transport accessibility strongly depends on timetables, especially with low frequencies lines. (Richer & Palmier, 2011) propose a method called TIP to represent multimodal accessibility over a time period defined by a combination of three indicators (travel time, intensity, hardness). These indicators are build by simulating 60 departures in an hour, by steps of a minute. Travel time is defined by the average of the every travel times, intensity by the number of different alternatives and the standard deviation on travel times, and hardness by the average number of boardings. These indicators are synthesized in a statistical classification.

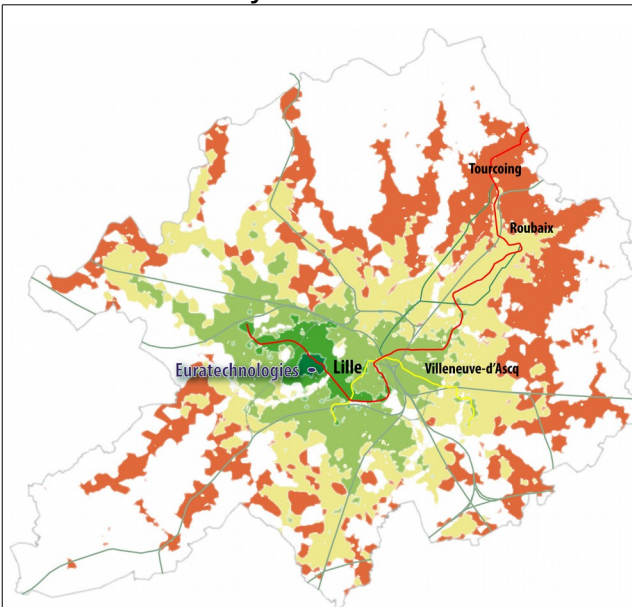


Figure 9: minimum travel time method (Richer – Palmier 2011)

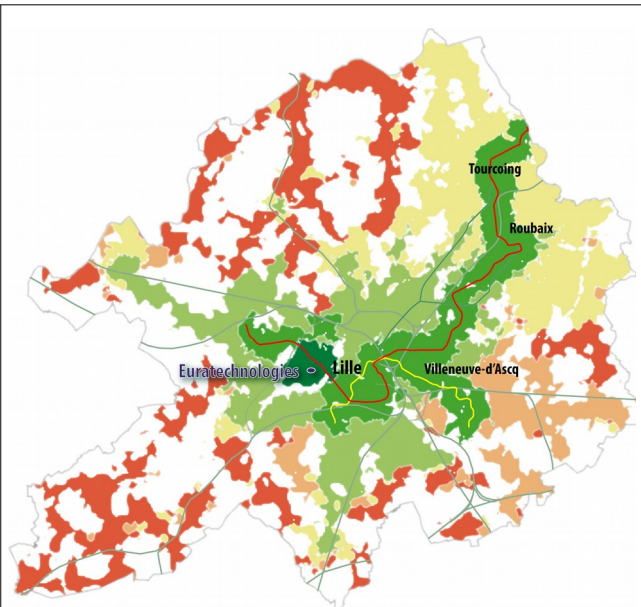


Figure 10: TIP method (Richer – Palmier 2011)

The TIP method on the right shows that the minimum travel time indicator is not very adapted for public transport accessibility. The TIP method shows the huge impact of VAL metro lines, which with a frequency between 1 and 2 minutes, give a high accessibility level compared to some areas, which could have a smallest access times, corresponding to a quick service with low frequency, therefore with poor access time during the rest of the period.

7 Conclusion

This article outlines the need for strong interactions between multimodal routing calculation processes and isochrone generation algorithms, while today each one works in a rather separated way. Isochrone creations algorithms must take advantage of all the information that can provide multimodal routing algorithms, and routing algorithms must adapt their output to produce indicators that are designed for the generation of accessibility maps, which will

be precise, accurate and easy to interpret for decision makers. The implementation in Qgis of the Limewise methodology associated with the free Musliw tool provides a set of tools that fully responds to these requirements. These tools are part of a regional project in Nord - Pas de Calais region, where CEREMA has developed a database of theoretical multimodal transport supply. This database is provided with free tools as Qgis, and Musliw, in order to allow users to exploit the database without the need to purchase expensive software they can't afford. Several training sessions were conducted with local authorities and agencies, so that they can take full benefit of their own data, which was unfortunately, most of the time, dedicated to the operator.

References

- ✓ Bousquet, A. (2010). Optimisation d'itinéraires multimodaux fondée sur les temps de parcours à l'échelle d'une agglomération urbaine dense (Doctoral dissertation, Ecole Nationale des Travaux Publics de l'Etat).
- ✓ Chatalic, V. (2012) Université Paris1-Panthéon Sorbonne Master 2 aménagement du territoire et urbanisme Mémoire de recherche.
- ✓ Delling, D., Pajor, T., & Werneck, R. F. (2014). Round-based public transit routing. *Transportation Science*.
- ✓ Dibbelt, J., Pajor, T., Strasser, B., & Wagner, D. (2013). Intriguingly Simple and Fast Transit Routing. *SEA*, 7933, 43-54.
- ✓ Frank, L. D., Schmid, T. L., Sallis, J. F., Chapman, J., & Saelens, B. E. (2005). Linking objectively measured physical activity with objectively measured urban form: findings from SMARTRAQ. *American journal of preventive medicine*, 28(2), 117-125.
- ✓ Gräbener, T., Berro, A., & Duthen, Y. (2010). Time dependent multiobjective best path for multimodal urban routing. *Electronic Notes in Discrete Mathematics*, 36, 487-494.
- ✓ Hansen, W. G. (1959). How accessibility shapes land use. *Journal of the American Institute of Planners*, 25(2), 73-76.
- ✓ Oliver, L. N., Schuurman, N., & Hall, A. W. (2007). Comparing circular and network buffers to examine the influence of land use on walking for leisure and errands. *International journal of health geographics*, 6(1), 41.
- ✓ Palmier, P. (2001). Cartes ZAP: mode d'emploi. Lille Métropole Communauté Urbaine.
- ✓ Palmier, P. (2011). Musliw. Logiciel de calcul d'accessibilité multimodale. SETRA
- ✓ Richer, C., & Palmier, P. (2011). Mesurer l'accessibilité en transport collectif aux pôles d'excellence de Lille Métropole. In *Mobilités spatiales et ressources métropolitaines: l'accessibilité en questions/11ème colloque du groupe de travail "Mobilités Spatiales et Fluidité Sociale" de l'AISLF.c*
- ✓ Spiess, H., & Florian, M. (1989). Optimal strategies: a new assignment model for transit networks. *Transportation Research Part B: Methodological*, 23(2), 83-102.
- ✓ Wardrop, J. G. (1952, June). ROAD PAPER. SOME THEORETICAL ASPECTS OF ROAD TRAFFIC RESEARCH. In *ICE Proceedings: Engineering Divisions (Vol. 1, No. 3, pp. 325-362)*. Thomas Telford.