DECISION SUPPORT FOR IMPROVING PUBLIC TRANSPORT NETWORK

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ABSTRACT

When dealing with accessibility in a public transport network, isochronous maps are the common rule. Those maps are based on shortest distance algorithms run over simple or simplified networks. This contribution aims at representing the actual spatial distribution of the public transport offer in order to improve the usefulness to the urban community and to predict the evolution of the network according to the expected development of the agglomeration. The study combines the street (walking distance) and public transportation (buses) networks. The analyses rely on timetables and road maps completed by the public transportation company (TEC). Moreover, it makes use of built-up areas derived from satellite imagery. The processing requires raster- as well as vector-based procedures which have been achieved notably with the IDRISI software. Nevertheless the implementation of the decision rule relies on an original routine written by the authors. The area of interest concerns a part of the agglomeration of Liège (Belgium), including two secondary poles, highlighting their relation with the centre of the city and with each other. First the paper presents the typology of the public transport routes. Then the methodology elaborated for each transportation type is analysed; the shortest distance routes and their alternatives are extracted and combined within a raster process. The obtained results and their operationality are finally presented and the paper concludes with possible improvements of the methodology.

1. INTRODUCTION

For a few years public transportation is a question that has been much debated in urban management. The increasing motor car traffic and its pressure on urban life have led urban decision-makers to pay attention to alternative solutions where public transport is inescapable (MET, 1996). Before improving the offer in public transport, it must be studied in its actual form in order to highlight its forces and weaknesses. This paper attempts to set out the real spatial distribution of the public transport offer. This offer is expressed as the time required to go from any point within the area of interest to a final destination (or from one selected origin to all the other locations in the area).

Travelling implies a cost (CANCALON and GARGAILLO, 1991; ROY, 1991) which is a function of the travelling time. Therefore shortest time-cost route should have to be chosen according to the decision rule. The search for the shortest time-cost route is justified by the travellers’ wish to minimise their travelling cost. Such routes can be found with different algorithms such as the Dijkstra’s algorithm (DIJKSTRA, 1959, in CANCALON and GARGAILLO, 1991; DONNAY, 1983; ENGELEN and BRANS, 1980; ROY, 1991). However, the full trips are not necessary made via these routes due to the nature of the public transport itself.
In order to visualise the spatial distribution of the public transport offer, isochronous maps are often prepared (DUSSART, 1939 et 1959; AUGUSTE, 1977; BAUDOT et LALOUX, 1980; VANCRAEYNEST, 1986; KUMMERT et VANDERMOTTEN, 1975). The length of the route must take into account, not only the travelling time, but also the waiting time, the connection time, etc. To draw an isochronous map it is necessary to find the shortest time-cost route. This is the key issue because many authors only consider the fastest line which, in most cases, does not correspond to the reality. Sometimes the paths of several lines are superimposed and the speed is supposed to be identical for all the lines even though it is rarely the case (id.). Another problem is the evaluation of the walking time beyond the stops: should the distance be considered along the roads or as the crow flies? On the other side, such maps generally rely on a mean travelling time, ignoring peak and off-peak periods.

This contribution first defines the features of public transport networks and establishes a typology of the public transport routes. Afterwards, the methodology used for the two parts of the public transport journey is developed. Finally, results obtained on a concrete case are discussed and possible improvements are presented.

2. PUBLIC TRANSPORTATION NETWORKS

2.1. Distinctive features of public transport networks

Public and private transport modes cannot be strictly compared. A trip done with a private transport mode is almost realised with only one vehicle, while walking must be considered at the beginning and at the end of a public transport trip, and possibly for intermediate connections. Different services (e.g. express vs. regular bus) can be offered on the same link and services are changing according to the hour in the day and the day in the week. Travelling by public transport is not possible at any time (ROY, 1991). The travellers have to wait for the passage of the vehicles at the stop. All these reasons, and some others, explain why the fastest line is not always available.

2.2. Typology of the public transport routes

What should be established at the very outlet is that the complexity of a public transport network increases when the vehicles are not attached to tracks. This, in turn, introduces essential differences in the methodology used to solve applications relating to bus routes vs. railway, subway or tramway. The present application only concerns buses.

Even though the routes remain simple in the dense city centres, this is not generally the case in the suburbs. Those areas are characterised by a greater
population scattering and thus they develop a more complex network. As a consequence buses mostly serve such areas since they have more flexibility in their routes.

Various public transport networks have been analysed through the maps delivered by transport companies to their users. A typology of the different configurations of the public transport routes has been achieved [Figure 1] (Vanraes, 1997). This typology demonstrates the complexity of public transport networks.

Figure 1. Typology of public transport routes (1 to 8) and combination of public transport routes (9 to 13).


2.3. Network under study

The method was applied to a part of Liège, third urban area in Belgium (about 600,000 inhab.). The area under study is triangular in shape. The top of this triangle is located in the centre of the town while the triangle stretches to the outskirts. Two sides of the area of interest are limited by motorways which constitute major obstacles for pedestrians since they can only be crossed at limited places.

The network covering this area is made out of twenty-one bus lines. Two major bus roads link the centre and two secondary poles of the urban area: Ans and
Rocourt. High frequency lines follow those roads. The two poles are only linked to each other by two low frequency lines (one vehicle per hour).

3. PUBLIC TRANSPORT TRIP

A public transport trip can be split in different parts:

- the walking trip to the stop of the public transport vehicle (bus stop, station); it will be detailed later;
- the waiting for the vehicle to come;
- the journey in the vehicle, from the origin stop to the destination stop;
- eventually a connection will be necessary to reach the destination.

3.1. The waiting time

The waiting time, the journey and an eventual connection are specific to the public transport network itself. Passage frequency at a stop, $v$, is the quantity of vehicles passing at a stop in a given interval and period, $T$, is the time passing between two halts of a vehicle at a stop. The mean waiting time for a traveller will be: $w = \bar{T} / 2$ with $\bar{T} = [\text{time interval}] / v$. If the time interval is equal to one hour the mean waiting time will be: $w = 30 / v$.

The used period is a mean period, which means that the time between two passages of a vehicle at a given stop is considered to be constant ($\bar{T} = T$). If such equality can be accepted for important bus routes, which present regular time schedules, it is not the case with less important lines. However the mean period is often accepted as a good approximation, but we have to keep in mind that the precision will decrease with the regularity of the periods. In fact, even for important bus routes, the period does not remain constant during the whole day. Different phases can be observed: peak, off-peak, evening phases, and so on (ORFEUIL J.-P. and TROULAY P., 1989). The mean period measured over a whole day will not reflect the reality: many lines have a short period in peak hours and a long period during the rest of the day. Hence a serious study should only consider a precise part of the day.

3.2. The journey in the vehicle

The journey in the vehicle from the origin stop to the destination stop is available in the timetables of the public transport companies. Such timetables are not often complete in the sense that the information is not available for all the stops of a bus line. In this case, the passage time must be interpolated between successive stops where the time, and the distance between them, are known.
3.3. Connections

When travelling by public transport one or more connections are often necessary to join the destination stop. As a consequence, the travellers will be submitted to the frequency of the other lines. It is commonly estimated that at least two minutes are necessary to make a connection (KUMMERT and VANDERMOTTEN, 1975): if the second vehicle arrives at the same time as the first one at the connection stop, it will be difficult for the users to make the connection because, for instance, the road must be crossed, the platforms are not on the same level, etc…

So far, the global time for a journey from a starting stop to a destination stop can be expressed as:

\[
time = 2c + \sum_{i} \left( \frac{30}{v} + R_i \right)
\]

with:
- \(c\): the number of connections;
- \(v\): the frequency
- \(R\): the time passed in the vehicle from the origin stop to the destination stop.

3.4. Multiple services

One of the difficulty peculiar to the public transportation network is that there are often more than one line joining two stops. Those lines can have different routes, number of stops, frequencies, route times, etc. To solve that issue, the contribution of each line joining the stops and respecting specific conditions was taken into account.

The mean waiting time for a vehicle is \(30 / \sum v_i\) and the mean route time is a weighted mean \(\frac{\sum v_i R_i}{\sum v_i}\). But those multiple service formulas cannot be applied in every case. Let us consider, for instance, a line needing thirty minutes to join the destination stop and another line requires forty-five minutes to reach the same stop. Will the traveller take indifferently the first vehicle passing at the stop independently of the line or will he/she chose a specific line regarding the route time? This question can be expressed as: “if the traveller misses the vehicle of the first line (30 min.) to join his/her destination, will he/she take a bus of the second line (45 min.) passing at the stop before the next bus of the first line ?”. The answer is considered positive if the vehicle of the second line arrives at the destination stop before the next vehicle of the first line.
Table 1. Multiple service examples in the studied network (units: decimal minutes)

<table>
<thead>
<tr>
<th>Lines</th>
<th>W1</th>
<th>W2</th>
<th>R1</th>
<th>R2</th>
<th>Total1</th>
<th>Total2</th>
<th>Line 1x2</th>
<th>R1+T1</th>
<th>R2&lt;R1+T1</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 and 75/G-88</td>
<td>16</td>
<td>75</td>
<td>2.73</td>
<td>12.00</td>
<td>18.73</td>
<td>19.52</td>
<td>21.46</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>75/ et 75/G</td>
<td>18</td>
<td>30</td>
<td>30.00</td>
<td>30.00</td>
<td>48.00</td>
<td>60.00</td>
<td>39.00</td>
<td>78.00</td>
<td>yes</td>
</tr>
<tr>
<td>88 and 75/</td>
<td>27</td>
<td>15</td>
<td>10.00</td>
<td>30.00</td>
<td>37.00</td>
<td>45.00</td>
<td>31.50</td>
<td>47.00</td>
<td>yes</td>
</tr>
<tr>
<td>70-70/ and 74</td>
<td>16</td>
<td>16</td>
<td>7.50</td>
<td>30.00</td>
<td>23.50</td>
<td>46.00</td>
<td>22.00</td>
<td>31.00</td>
<td>yes</td>
</tr>
</tbody>
</table>

Hence the decision rule will be: the multiple service can be calculated if \( R_2 \leq R_1 + W_1 \) [table 1]. This decision rule expresses that the traveller tolerates a greater difference in the route times if the frequency of the connections between the origin and destination stops are weak. This reaction is logical if we remark that most public transport users don’t know the exact passage time of the vehicles but have an idea of the frequency and of the time required to reach their destination stop. They chose their line(s) with these parameters in mind.

3.5. Global route time

If the global route time is measured in minutes and if the interval is one hour, the global route time, \( G_t \), will be:

\[
G_t = 2c + \sum_{i} 30 + \sum_{i} v_i R_i / \sum_{i} v_i
\]

With the condition \( R_i \leq R_{(fastest \ line)} + T_{(fastest \ line)} \).

4. FINDING THE SHORTEST ROUTE AND ITS ALTERNATIVES

4.1. Stops, boarding points and nodes

The nodes of the network were defined in function of the boarding points. Those points are located at the places where users get on/off the vehicles. Physically they correspond to a station, or to a signpost on a side of the street, with the names of the stop and of the lines serving it. A stop is thus made of one or more boarding points sometimes located at a not insignificant distance. When digitising the network, nodes have been created. The different possible cases can be represented as [Figure 2]:

6
Figure 2. Stops, boarding points and nodes

- The stop is made out of two boarding points (one for each direction of the line for instance). Those points are in front of each other. One node has been created.
- A stop is only made out of one boarding point (when the stop is only served in one direction for instance).
- The boarding points for each direction are located at a significant distance of each other. In this case we created a node for each boarding point.
- Stops located where different lines cross are particular cases. Generally such stops present more than two boarding points and they must allow connection between lines. Only one node is created (connections involving walking are not considered) and a time of two minutes is imposed to make a connection.

4.2. Missions and sections

A line can have different routes [Figure 3]. The public transport lines have been divided in “missions”. A mission corresponds to one and only one route covered by a bus line from an origin stop to a destination stop.
On the other hand, the lines have been divided into sections. The attributes of a section is: its origin node, its destination node, the identifier of the mission using it and the time required by this mission to cross the section. The sections are thus directive and can be stacked [Figure 4].

4.4. Database

The network is implemented in the database by two tables: the nodes table with their name and coordinates and the section table with their code, the mission code, the origin and destination nodes and the crossing time by the mission. As the frequency is required to calculate the waiting time, a table with the missions and their frequency has also been created.

Figure 5. Database

<table>
<thead>
<tr>
<th>Nodes</th>
<th>Sections</th>
<th>Missions</th>
</tr>
</thead>
<tbody>
<tr>
<td>name</td>
<td>code</td>
<td>code</td>
</tr>
<tr>
<td>coordinate x</td>
<td>mission code</td>
<td>frequency</td>
</tr>
<tr>
<td>coordinate y</td>
<td>origin node</td>
<td></td>
</tr>
<tr>
<td></td>
<td>destination node</td>
<td></td>
</tr>
<tr>
<td></td>
<td>covering time</td>
<td></td>
</tr>
</tbody>
</table>

The studied network is compounded with 183 nodes, 853 sections, 21 lines divided in 53 missions.

4.5. Finding for the shortest route and its alternatives

The search for the shortest route and its alternatives is achieved according to a specific routine written in Pascal. The program can solve the following problems:

- Search for the shortest route and its alternatives (responding to the multiple service condition) between a fixed origin and a fixed destination, an origin and all the destinations and a destination and all the origins.
- Search can be done at three degrees of complexity: direct links, direct links plus links with one connection, and direct links plus links with one and/or two connections. Obviously the search time increases with the degree of complexity of the request.

The program exploits a couple of relations from the database. First, a table is generated which records, for each node, all the missions which cross it. Similarly a second table maintains, for each mission, its frequency and the list of all the served nodes, together with the accumulated time to reach them from the origin of the mission.
The simplest exploitation of the database consists in the selection of the shortest straight link between an origin and a destination. This comes down to the selection, in the adequate table, of the mission(s) crossing both the origin and the destination. If more than one mission are selected, the program applies the multiple service condition and sorts the selected missions according to their global route time.

If one connection is permitted between the origin and the destination, a second search is performed, looking for the missions crossing the origin or the destination, and which present a common node. These “one connection” links are only kept if their cumulated route time is less or equal to the global time of the fastest straight link. Lastly, when two connections are allowed, an additional search keeps the mission which simultaneously present a common node with a mission crossing the origin and another common node with a mission crossing the destination. It is worth noting that, in order to obtain a complete accessibility survey from one origin or towards one destination, the previous procedures must be repeated, in turn, for all the nodes identified in the region of interest.

At the end of the procedure, a file is generated with all the kept links. This file mentions the total route time, the sum of the mean waiting times, the global time of each mission used to reach the destination, the mean waiting time of each mission, the origin node, the destination node, the connection nodes and the missions compounding the link. Such files can be quite bulky, notably when one or multiple connections are allowed.

This file is post-processed to sort the indirect links. First, the multiple service is computed for all parts of links with the same origin and destination nodes. The multiple service is thus calculated on each piece of a trip (e.g. origin node to connection node and connection node to destination node). This provides a way to select the “best” connection nodes and finally to keep the fastest links. If a complete accessibility survey is achieved, this stage allocates, to all the nodes, their shortest time from the common origin or to the common destination. This time is the mean global route time from the origin to the destination [table 2].

<table>
<thead>
<tr>
<th>Origin</th>
<th>Name</th>
<th>X</th>
<th>Y</th>
<th>Dest</th>
<th>Name</th>
<th>Con</th>
<th>Name</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Al Trappe</td>
<td>231.5507</td>
<td>153.3931</td>
<td>47</td>
<td>Saint-Lambert</td>
<td>143</td>
<td>Français</td>
<td>41</td>
</tr>
<tr>
<td>2</td>
<td>Arsenal A</td>
<td>233.2845</td>
<td>152.7424</td>
<td>47</td>
<td>Saint-Lambert</td>
<td>32</td>
<td>Principale</td>
<td>31</td>
</tr>
<tr>
<td>3</td>
<td>Limbourg</td>
<td>234.7392</td>
<td>150.3085</td>
<td>47</td>
<td>Saint-Lambert</td>
<td>0</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>4</td>
<td>Lohest</td>
<td>233.0917</td>
<td>152.6292</td>
<td>47</td>
<td>Saint-Lambert</td>
<td>0</td>
<td>0</td>
<td>24</td>
</tr>
<tr>
<td>5</td>
<td>Lonay Ecoles A</td>
<td>233.3722</td>
<td>150.4124</td>
<td>47</td>
<td>Saint-Lambert</td>
<td>74</td>
<td>XIV Verges</td>
<td>53</td>
</tr>
<tr>
<td>6</td>
<td>Lonay Ecoles B</td>
<td>233.2577</td>
<td>150.4438</td>
<td>47</td>
<td>Saint-Lambert</td>
<td>20</td>
<td>Nicolay</td>
<td>31</td>
</tr>
<tr>
<td>7</td>
<td>Lys</td>
<td>233.8151</td>
<td>149.7507</td>
<td>47</td>
<td>Saint-Lambert</td>
<td>147</td>
<td>Henri Baron</td>
<td>21</td>
</tr>
<tr>
<td>8</td>
<td>Maison de retraite A</td>
<td>229.9982</td>
<td>151.4485</td>
<td>47</td>
<td>Saint-Lambert</td>
<td>141</td>
<td>Fort de Loncin</td>
<td>47</td>
</tr>
<tr>
<td>9</td>
<td>Maison de retraite B</td>
<td>230.0310</td>
<td>151.4373</td>
<td>47</td>
<td>Saint-Lambert</td>
<td>0</td>
<td>0</td>
<td>21</td>
</tr>
<tr>
<td>10</td>
<td>Makro A</td>
<td>231.6581</td>
<td>152.1255</td>
<td>47</td>
<td>Saint-Lambert</td>
<td>134</td>
<td>Expansion</td>
<td>62</td>
</tr>
</tbody>
</table>

Table 2. Extract of the result file
5. WALKING TRIP

The beginning and the end of a public transport trip are generally done walking. Travellers have to follow the shortest way, from the origin or the destination, to the nearest bus stop or, more exactly, to the most interesting bus stop for their trip. The time needed for this walking trip depends from one person to another but 5 km/h is mostly used. In order to take the walking trips into account, it is necessary to digitize the complete road network, co-registered to the nodes of the bus lines. In this application the source is provided by a topographic map at the scale of 1/25,000.

Moreover, because the built-up area, containing the actual origins and destinations, is not only located along, but also between the roads, it can be necessary to add a complementary walking trip inside the city blocks, at the same speed but perpendicular to the road network. This application makes use of a classified and co-registered high resolution satellite image to delineate the built-up area and, in turn, to calculate the distance from any built-up location to the road network.

From this step, the rest of the process will be carried out on a three meters resolution grid, making an extensive use of the raster-based procedures offered by the Idrisi software (Eastman, 1997). A surface of accessibility (Donnay and Ledent, 1995) will be produced by adding the walking time from any built-up pixel to its nearest bus stop, to the global route time characterising this stop versus the selected origin/destination. The visualisation of this surface can be seen as a map of the public transport offer with respect to one origin or destination.

The Idrisi/CostGrow algorithm is used to calculate the distance between the road pixels and the node pixels. This algorithm creates a distance or proximity surface where distance is measured as the least effort in moving over a friction surface. The distance is measured in "grid cell equivalents", but a diagonal moving increases the distance by a factor of 1.41 grid cell equivalents. In this case, the friction surface incorporates barriers (in fact, all the pixels which do not belong to the road network are classified as barriers) in order to restrict the propagation to the network. Then the distance surface is multiplied by the constant 2.52 corresponding to the time, in seconds, required to cross a pixel at the selected walking speed.

As a follow-on to the distance surface, the Idrisi/Allocate algorithm assigns each pixel of the road network to the nearest bus node from which the distance was calculated. Owing to a substitution of the original node identifier by its global route time, each pixel on the road network will therefore end up with the global route time from its nearest bus stop to the origin/destination. This image added to this featuring the walking time on the network fix the accessibility of the pixels belonging to the road network.
A similar operation is performed for the pixels located out of the road network, but the target is now any road pixel characterised by its attribute of accessibility. The resulting image is multiplied by the boolean built-up image, restricting the accessibility map to the built-up area. The complete processing, mentioning Idrisi functions and parameters, is illustrated in the figure 6.

6. RESULTS

6.1. Case studies

This section details a couple of concrete cases applied to a part of the urban area of Liège. The maps are “from all the points to a specific destination stop”. In the first case (figure 7), the destination point is the most important bus terminus located in the centre of the town and the chosen phase is the morning peak period. In the second case (figure 8), the destination point is a bus stop in the centre of a secondary pole, while the phase selected for this map is the afternoon off-peak period.

It should be stressed that, in the elaboration of such maps, the processing time is significantly reduced if the nodes located on directive missions are flagged to avoid useless investigations from a “nearest” node leading to the opposite direction of the destination.
Figure 7. Time of the routes to the Saint-Lambert square at the morning peak (7-9 o'clock)
Figure 8 Routes time to the Astrid square at the afternoon off-peak (14-16 o’clock)
6.2. Accessibility of the main central terminus

The main central terminus is located at the Saint-Lambert Square. This square is the core of the public transport system of the urban area. Most of the bus lines covering the study area have their terminus on this square. A lot of other lines not included in this area start from there or from other nearby places. The accessibility of this square is thus fundamental. Since this place is in the downtown area, measuring the square accessibility is measuring the accessibility of the town centre.

The map shows clearly the radial disposition of the network and the good connection from the secondary poles to the centre. Two axes are highlighted: the Liège-Rocourt axis and the Liège-Ans axis. Many bus lines run along those axes, with in several cases a high frequency. Hence, the mean waiting time do not exceed seven minutes.

6.3. Accessibility of a secondary pole

In this case study the bus stop concerns the Astrid Square in the secondary but commercially important pole of Rocourt. This map highlights the consequence of a radial arrangement of the network. The areas located in the surroundings of the Liège-Rocourt axis are at less than twenty minutes from destination. Areas located along the axis connecting the couple of secondary poles, Ans-Rocourt, are at less than thirty minutes. But the largest part of the secondary pole, Ans, is more than thirty minutes away. The reason is that from this area the links reaching the Astrid Square have to pass through the main terminus in the town centre, where a connection must be made.

Surprisingly, other areas which seem not far from the destination are not reachable in less than thirty minutes. Two reasons can explain this situation. First, only one connection has been allowed to define the different links. This is justified by the fact that most of the users generally accept one connection maximum during their trip. Secondly, it has been assumed that the user goes to the nearest node to take the public transport, but in some circumstances it is preferable to join a more distant bus stop to benefit from a faster link or, in the utmost case, to go on foot to the destination. Anyway this case study has demonstrated that two bus lines could be extended to the Liège-Rocourt axis to improve significantly the accessibility to the destination.

7. IMPROVEMENTS AND FUTURE RESEARCH

The objective was to establish a method that allocates a cost-time to all the locations within a given area. This time corresponds to the mean time from the locations to a
specific destination or from a specific origin. Maps were conceived with this method and an analysis of the actual public transport offer has been achieved.

However, the method in its actual state presents some limitations that could be overcome. Two issues are illustrated hereafter.

Future developments of the algorithms would have to solve the problem resulting from comparing the connection speed of two routes to a third one (figure 9). In its present form, if the fastest line is line 1, the trip from the origin to the destination uses line 1 until the node 1 where a connection is realised with line 3. The algorithm compares line 1 and line 2 between the origin and the node 1, ignoring the opportunity of a connection from line 2 to line 3 at the node 2. This situation systematically gives a not proved advantage to line 1.

Figure 9. Illustration of two routes connecting to a third one where the advantage is given to line 1

A second issue appearing in the case studies results from the calculation of the walking distance. Until now this computation relies on a simple buffering process applied on the road network (figure 10 A). Consequently neighbouring pixels might present unrealistic differences when the accessibility of the road network is allocated to the pixels within the buffer. Figure 10 C illustrates the correct solution to identify the closest bus stop. Such a solution requires a deep modification of the allocation algorithm, but it can be partially approached by filtering the distance surface.

Figure 10. Accessibility to the closest bus stop by buffering the road network (in grey).
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