Modeling and simulating Accessibility within the Luxembourg cross-border area

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Abstract: With the favourable context of economic growth, Luxembourg has encountered for several decades a steady growth of its internal employment. The majority of the workers travel by private vehicle. It results in an important congestion during the morning peak hours. A traffic model was developed over a cross-border area of Luxembourg with a combination of intra-urban scale (Luxembourg City) and an interregional scale. Its main objective is to model travel time values. Because no transport survey is available, we try to build a model based on a home to work matrix. This matrix is built for the morning peak hours and private vehicle on the base of administrative data and updated according to the last available statistics. Finally we discuss the limits of the estimation of travel times in a congested network with a static traffic model and theoretical speed-flows curves.

Keywords: traffic modelling, accessibility, speed-flow curve, static assignment, Luxembourg, congestion

1. Introduction

Luxembourg encounters since more than 15 years a steady growth in its internal employment, as well as an important number of cross-border workers living either in France, Germany or Belgium. This growth is expected to continue in the decades (Statec 2010) and leads to an increase in the traffic road towards Luxembourg as the majority of the home to work trips are done by car (Carpentier, Gerber, 2009). These issues, involving land-use management and accessibility evolution, are addressed in the MOEBIUS project, international project co-funded by the Luxembourg National Research Fund. It seems essential to evaluate and simulate the performances of the different modes of transportation by 2025 accounting for the forecasted number of the work trips evolution. This would be investigated by the mean of several accessibility models aiming at calculating the travel times at the scale of Luxembourg cross-border area.

At the scale of Luxembourg City, the ICMA project aims at estimating the accessibilities according to the transportation mode. This implies the model to have precision inside Luxembourg City.

At first, we discuss the issues raised in this modelling in a detailed methodological part. In a second part we analyze the first results of our traffic model. Finally we open the discussion on the validation of this modelling for the assessing of accessibility and the improvements planned.

2. Modelling accessibility in MOEBIUS

2.1. Objectives of modelling accessibility in MOEBIUS and ICMA

The main objective of the Moebius (Mobilities, Environment, Behaviours, Integrated in Urban Simulation) project is to assess the sustainability of various planning policy scenarios using a land use and transport interactions (LUTI) modelling platform. The mid-term perspective is to build a decision support tool for planning policy makers and other stakeholders in Luxembourg. There are a lot of researches about models which integrates land

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use and transport planning and the literacy provides several analysis and state of the art of the models developed (Timmermans, 2003). This paper will focus on the transport model of the Moebius project, called daily mobility,

![Figure 1: MOEBIUS Project](image)

It is first necessary to define precisely the expectations and objectives of the daily mobility model in Moebius (Figure 1), to avoid the classic problem of the misuse of models and especially transport models (Gudmundsson, 2011).

The aim of this model is to allow the estimation of different accessibility measures, especially accessibility to jobs and to local services. These measures interact with the residential mobility model to estimate the consequences of the evolution of accessibility for the residential location choices. The model is supposed to estimate accessibility, based on travel time estimation, for peak hours and off peak hours and for all modes of transport. In this article we will focus on the estimation of the travel time for private car.

If the objective of our model is to calculate precisely travel time, it doesn’t necessarily imply the precise estimation of traffic counts on the network, despite of their relationship when approaching the network congestion. The two main tasks in the model design are the network definition and the transport demand. Considering the congestion of the road network of Luxembourg during the peak hours, the main challenge is to calculate travel time which reproduces the impact of congestion.

Moreover our transport model has to fulfil a constraint about its precision level in Luxembourg City in order to be used in a European INTERREG project called ICMA (Improving Connectivity and Mobility Access). The general aim of ICMA is to provide attractive and effective alternatives to private car for the “first and last miles” of journeys. One of the actions consists in designing an alternative accessibility map, in the city of Luxembourg, for all the modes of transport. Therefore the zoning system of the transport model has to be very detailed in the city, to make relevant comparison with public transport or bike.
2.2. Choice a modelling approach

There are different types of model which can be used in the Moebius project. We chose to work with an aggregate and static model, for several reasons:

- In this kind of models, the road network codification requires fewer data than for micro simulation models, especially for a large area like in our project,
- The team has already developed a static model for another project (Klein et al., 2011), so it was an opportunity to use this experience,
- The planning model in Moebius uses multi agents systems and cellular automats, the experiences of other research project (Antoni, 2011) showed that it is possible to combine desegregate model with aggregate model (at some points),
- This model can be easily developed to take into account new research perspectives or new survey data,
- This kind of model is operational on a large area with lots of trips, and despite of its limits, gives consistent results which can be sufficient in quality to be integrated in spatial planning model, contrary to some microsimulation models (Wegener, 2011).

In a first stage, we decided not to model the trip generation and the trip distribution, but to use a static OD matrix, and to focus on assignment. We seek to know if the model is able to calculate relevant time travel in a congested network.

3. Methodology

3.1. Multi level zoning system

The area on which the travel times should be reproduced encompasses Luxembourg country. The zoning is defined according to the disaggregation level needed for the travel time modeling in Luxembourg and Luxembourg City. It is not necessary to disaggregate the municipalities of residence of the cross-border workers. Indeed, in order to model the private vehicle traffic at the border crossing, it is sufficient to model the origin of the trips at the municipality level. On the contrary, at the scale of Luxembourg, where we expect the precision at the municipality level, it is necessary to disaggregate the employment and the residence zones. In the case of Luxembourg City, for which we would like to build a road accessibility model for mode comparison in ICMA project, an infra-municipal zoning is necessary.

Regarding these constraints, 409 zones were created on a locality base in the country of Luxembourg. In Luxembourg City, a 200 Meters grid of 826 zones was created. The 1101 outer zones were designed with a decreasing size according to their distance to Luxembourg borders (Figure 2). This should allow the analysis we would like to perform in the MOEBIUS project at the country level and for the ICMA project at Luxembourg City level.
3.2. Network design

The Luxembourg City network includes all the streets and avenues and comes from OpenStreetMap (12.10.2010). The Luxembourg country network is the state road network (Ponts et Chaussés) and includes secondary roads. In the other countries, the network includes fewer details when going away from the Luxembourg borders. There is a total of almost 30 000 links in the model.

The road types distinguish highways, primary and secondary roads. Furthermore, in Luxembourg, the roads sections crossing an urban zone got new types of smaller speed and capacity. The speed-flow curves were specified for each road type. We used BPR functions with parameters values according to the literature, and, for the highways, different speed flow relationship when flows exceed capacity. This could be further improved by the use of the traffic counts. We also coded the junctions in Luxembourg city to calculate the average delay for each turning movement.

3.3. Simplified transport demand model

3.3.1. Why using only trips to work in Luxembourg?

In order to estimate the travel demand in peak hours, and in absence of other data, we suppose the home-to-work trips represent the majority of the traffic in the morning peak hours on the Luxembourg road network.

According to the national transportation survey in France of 2008 (Quetelard, 2010), in the morning peak hours (7 to 9 am), 45% of the trips realized by private vehicle (as driver) and 68% of the travelled distances are related to work. We think that this ratio is even higher in
Luxembourg, due to the large number of cross-border commuters and the high number of jobs (360,000) compared to the population (500,000). The inner trips in Luxembourg by private vehicle are estimated with administrative data. We also assume that the trips for other purposes than work are negligible in the morning peak hours. So, it is important to estimate precisely the home to work trips matrix between the municipalities, insofar as they represent the most of the trips in the morning peak hours.

3.3.2. Design of the home to work trips matrix by car

The construction of the home-to-work matrix (Table 1) is built with the help of several data sources. The first one comes from the population census of 2001. This source allows us to distribute home to work flows at the municipality level. It was also possible for Luxembourg City to localize this flow at the address (the postal code) level. It was therefore possible to build a matrix at the grid level. The second source is an estimation of the municipal employment in Luxembourg for 2005 (Statec). This permits an update of the distribution for 2005. Finally we use the figures of the inner employment of 2009 (Statec), after deduction of the cross-border workers, to update the Luxembourg demand matrix at this date. The calculated margins of the matrix are similar to the occupied working people figures of the municipalities for 2009.

<table>
<thead>
<tr>
<th>Origin\ Destination</th>
<th>Luxembourg City</th>
<th>Rest of the country</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luxembourg City</td>
<td>35,000</td>
<td>10,000</td>
<td>45,000</td>
</tr>
<tr>
<td>Rest of the country</td>
<td>70,000</td>
<td>103,000</td>
<td>173,000</td>
</tr>
<tr>
<td>Greater Region</td>
<td>50,000</td>
<td>95,000</td>
<td>145,000</td>
</tr>
<tr>
<td>Total</td>
<td>155,000</td>
<td>208,000</td>
<td>363,000</td>
</tr>
</tbody>
</table>

Table 1: Home-to-work matrix estimation (2009) between Luxembourg City and the rest of the country

Source: IGSS, Statec, authors calculation, CEPS/INSTEAD Luxembourg

The part of the matrix of the cross-border workers living outside Luxembourg comes from a cross-checking of administrative files of 2009 (Tax Administration, Social Security). The amount of the cross-border workers outside of Luxembourg represents 1,000 workers. Their contribution to the traffic will be neglected. The internal trips of the outer zones haven’t been estimated either.

After the building of a home to work matrix, it is necessary to determine the proportion of the trips done by car as driver. For the working people living in Luxembourg this share is available in the 2001 census. We suppose this share remained the same in 2009. For the cross-border workers, we use a 2007 survey from Statec & CEPS/INSTEAD about the cross-border workers expenses. The sample (5,000 people) doesn’t allow us to reconstitute a modal share matrix per municipality. So we grouped the destinations in 3 zones: Luxembourg City, Luxembourg agglomeration and the rest of the country which show the most significant differences in the shares. For the twelve municipalities with the most cross-border, we used the share from the survey. For the rest, the share could in a first approximation be applied on the base of the destination zone to all the origin municipalities and in a second step refined according to the proximity of a train station. The car-sharing is estimated to 10 % for all the municipalities.

We have then to determine the proportion of the people who travel to work during the morning peak hour. This can be determined on the base of road counts. The main roads
crossing the border have traffic counts. Some of the secondary roads don’t have traffic counts. We can postulate, since these roads are located in the North of the country where less jobs are located that this will not underestimate the cross-border counts during the peak-hours. With the help of an O-D survey at the French border in 2003, we can estimate that 80% of the traffic in direction Luxembourg was related to work between 7 and 8 am. With the raise of the cross-border workers number from 55,900 in 2003 to 72,800 in 2009, we can suppose the cross-border traffic between 7 to 8 am to Luxembourg to be very close to the total one. The road counts show the highest values between 7 and 8 am. They represent 17% of the estimated cross-border workers from France, 22% of those from Belgium and 29% of those from Germany.

We use the same method for the workers from Luxembourg, with the counts of Luxembourg City which give the number of vehicles entering in the city between the peaks hours. We estimate a ratio of 31% of the workers of Luxembourg on the roads during 7 and 8 am. This estimation will be improved by further survey data.

3.3.3. Assignment of the travel matrix on the network
The travel matrix is assigned on the network with the OmniTRANS software. We used an algorithm leading to user equilibrium of Wardrop. The freight is manually preloaded on the links on the base the available traffic counts.

4. First results: accessibility during peak hours
The first results are represented on Figure 3 for Luxembourg City. We present here the average access time to the zones of the city from each other zone of the city. We can observe the effects of the congestion within the city. The best values can be observed in the valley of Alzette, directed North-South, Grund and Clausen, on the East of the centre. These places actually have poor job density. On the other side, the centre, the European institution locations in the South of Kirchberg appear to be less accessible than expected according to their position.
Figure 3: Average travel time (min) to places in Luxembourg City during the morning peak hours

On Figure 4, we represent an interpolation of the travel time to the South of Kirchberg during the morning peak hours. The congestion seems to affect the motorway A3 (from Thionville, Lorraine) more than the A1 (from Tier, Rhineland-Palatinate) or the A6 (from Arlon, Walloon Region). A second result is that most congestion is met in Luxembourg City, since it lasts around 15 min from the limits of the city to reach the destination.
In our study about public transport accessibility in Luxembourg we were able to build a travel time matrix. These travel times by modes can be compared.

<table>
<thead>
<tr>
<th>Zone of residence</th>
<th>Zone of employment</th>
<th>Total of the trips</th>
<th>Number of trips by car</th>
<th>Number of trips by Public Transport</th>
<th>Percentage by car</th>
<th>Percentage by public transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>City of Luxembourg</td>
<td>City of Luxembourg</td>
<td>34 700</td>
<td>34 700</td>
<td>24 900</td>
<td>100%</td>
<td>72%</td>
</tr>
<tr>
<td>City of Luxembourg</td>
<td>Rest of the country</td>
<td>10 200</td>
<td>9 400</td>
<td>1 200</td>
<td>93%</td>
<td>12%</td>
</tr>
<tr>
<td>Rest of the country</td>
<td>City of Luxembourg</td>
<td>69 300</td>
<td>54 600</td>
<td>14 300</td>
<td>79%</td>
<td>21%</td>
</tr>
<tr>
<td>Rest of the country</td>
<td>Rest of the country</td>
<td>103 000</td>
<td>94 300</td>
<td>49 500</td>
<td>92%</td>
<td>48%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>217 100</strong></td>
<td><strong>193 100</strong></td>
<td><strong>90 000</strong></td>
<td><strong>89%</strong></td>
<td><strong>41%</strong></td>
</tr>
</tbody>
</table>

Table 2: Comparison of the percentage of trips that can be done by car or by public transport within 30 min during the morning peak hours

In Table 2, we represent the ratios of trips that can be done in 30 min by car or by public transport. Most of the trips are possible by car in 30 min, whereas only 41% can be done by...
public transport. With 93% of the trips, compared to 79%, a greater proportion of the trips to work can be done in 30 min by car from Luxembourg City to the rest of the country than in the other direction. This shows the effect of the congestion. Conversely, a greater proportion of the trips are possible by public transport in the direction of Luxembourg City than in the direction of the rest of the country.

Of course this comparison could be refined taking into account the time to access the public transport network and the parking delay, but also as we will discuss below by refining the calculation of the travel time by car by a better calibration of the model.

5. Discussion: travel time estimation in a congested network

5.1. Model calibration with the traffic counts

The calibration and the validation of the model are two different steps, which are sometimes mixed. We will focus on the calibration, which consists in checking the model’s ability to represent correctly the observed situation. The validation consists in testing the model with data which were not used to build the model (another OD matrix).

In a first time, we compare the assignment results with the available counts. As the objective is to represent the mobility during a normal day during the week, we calculate the average value of each count only for the private cars by excluding the weekends and the holidays. The OD matrix is only based on trips to jobs for people working in Luxembourg. Although those trips are predominant in the road network during the peak hours, it is clear that they cannot reproduce the entire volume of the observed traffic, particularly the traffic outgoing the country. Thus, for the calibration, we select only the counts (N=100) oriented towards the employments areas (Luxembourg City and other secondary cities). The analysis of the counts shows that the non-oriented traffic flow to the big employment areas is relatively small and that it is largely under the capacity of the network. This validates the use of a home to work matrix in the model to calculate the travel time, as, where there is few of trips, there is no congestion and speed flow during peak hour is similar to free speed.

We use the GEH statistic to compare the counts and the results of the models (named after its inventor Geoffrey E. Havers). There is total of 100 road sections with available traffic counts.

<table>
<thead>
<tr>
<th>GEH</th>
<th>0 - 5</th>
<th>5 - 10</th>
<th>10 – 15</th>
<th>&gt;15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of sections</td>
<td>23%</td>
<td>33%</td>
<td>20%</td>
<td>24%</td>
</tr>
</tbody>
</table>

Table 3: GEH statistic comparing the traffic counts and the results of the model

The Table 3 shows that the model could not be used to make classic traffic studies, as the GEH statistics in average are too poor: 45% of the sections where a traffic count is available have a GEH superior to 10, which is not acceptable. Nevertheless as the highways sections have a better GEH (5 of 7 have a GEH inferior to 10) and in general all the sections with high traffic volume (Figure 5), for the objectives of the model (time travel calculation), we consider that the model is acceptable, for a first step.
Without the access to other data, we believe that we can improve these results, first by calibrating the OD matrix at peak hours with different coefficient depending on the origin of the trips (for instance traffic coming from Germany is underestimated) and by improving the speed-flow curves for the highways. At the end, these results show that it is possible to get a plausible estimation of the traffic flows during peak hours, with the use of a home to work OD matrix. This is probably due to the high number of jobs in Luxembourg compared to the population, and may not be reproducible in other areas.

5.2. Model calibration with the travel times

The comparison between the estimated travel time and the observed travel time is essential, as it allows checking the quality of the model outputs. Contrary to the traffic counts, we cannot have easily access to a set of observed travel time during peak hours. We are currently studying the possibilities to use GPS measures or information from the traffic management system in Luxembourg (CITA), based on several detectors on the highways. We also consider the use of the declared travel time from the Luxembourg EU-SILC survey (PSELL 2007). As it is difficult to obtain a set of reliable and detailed observed travel time, we can suppose that, if the model is calibrated with the traffic counts, the average speeds and then the calculated travel times are similar to the observed travel times, thanks to the speed-flow curves. Unfortunately these curves (and in general this method) have, at least, two inconveniences.

5.2.1. Limits of static modelling
Firstly, static modelling represents poorly congested network, where traffic flows are very complex, especially when it comes to calculate travel times. It does not take into account the queues building, for instance when the speed on a freeway ramp is very low due to the huge volume of traffic, there is no consequence on the highway before the ramp. As the speed on a link is independent to the volume of traffic or the speed on other links, the model cannot represent congestion due to queue building. Then it underestimates the effects of congestion generated by isolated bottleneck, which could significantly increase the travel times.

5.2.2. Limits of general speed-flow curves
Secondly, we use general speed-flow curves which do not take into account the particular characteristics of the highway network. The traffic measures show that the speed-flow
relationships are different depending on the location before or after a bottleneck, such as exit or access ramp (Hall, 1997). The data analysis from the CITA enables us to check the impact of the access ramp.

The Figure 6 shows the impact of the A13 ramp on the traffic of the A3: The graph A (before this ramp) reflects the situation whereby traffic had almost reached theoretic capacity before the added traffic from A13 caused the queue. There is a range of congested data of the lower part of the graph with very low average speed (50km/h). The data observed at B (after the ramp) are on the top portion of the theoretic speed-flow curve, with no congestion observed, and with high average speeds for high traffic flows. It corresponds to the queue discharge situation.

These differences are not supported by our model, where every highways section has the same characteristics (depending on the number of lanes and the maximal speed). We consider codifying some sections of the highways with different speed-flow curves based on the traffic data available. For example, before ramp access, the speed decreases quicker with the traffic flow and the capacity is lower than for the sections after. Then we will compare the results obtained with this method, to analyse if it improves the outputs.
5.3. Travel time variability as criteria of accessibility?

Day-to-day travel time can significantly vary in a road network, especially when the volume of traffic is close to the capacity. The variations can come from particular events (accident, roadwork) or from small changes of the transport demand. The first challenge is obviously to estimate this variability (both for cars and public transport), thanks to the data available and the literature reviews. Reliability of travel time is indeed an important factor for travellers, especially for trips to jobs, and travel time variability has an impact on behavioural reactions (Noland, 2002).

It seems to be difficult to use travel time variability for the assignment of the OD matrix, but we can consider and analyse the possibilities of using it in different ways:
- for the modal choice,
- for extending the average travel time calculated (average travel time is 30 minutes, with a high degree of variability)
- as a criteria of accessibility. The reliability of travel time to reach a certain zone is very low, what may decrease its accessibility.

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