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Projet de Fin d'Etudes

Establishment of the electric demand load curve required for the individual vehicles in an agglomeration,

supposing all- electric vehicles

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2014-2015

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FORMATION PAR LA RECHERCHE ET PROJET DE FIN D'ETUDES EN GÉNIE DE L'AMENAGEMENT

La formation au génie de l'aménagement, assurée par le département aménagement de l'Ecole Polytechnique de l'Université de Tours, associe dans le champ de l'urbanisme et de l'aménagement, l'acquisition de connaissances fondamentales, l'acquisition de techniques et de savoir faire, la formation à la pratique professionnelle et la formation par la recherche. Cette dernière ne vise pas à former les seuls futurs élèves désireux de prolonger leur formation par les études doctorales, mais tout en ouvrant à cette voie, elle vise tout d'abord à favoriser la capacité des futurs ingénieurs à :

Accroître leurs compétences en matière de pratique professionnelle par la mobilisation de connaissances et de techniques, dont les fondements et contenus ont été explorés le plus finement possible afin d'en assurer une bonne maîtrise intellectuelle et pratique,

Accroître la capacité des ingénieurs en génie de l'aménagement à innover tant en matière de méthodes que d'outils, mobilisables pour affronter et résoudre les problèmes complexes posés par l'organisation et la gestion des espaces.

La formation par la recherche inclut un exercice individuel de recherche, le projet de fin d'études (P.F.E.), situé en dernière année de formation des élèves ingénieurs. Cet exercice correspond à un stage d'une durée minimum de trois mois, en laboratoire de recherche, principalement au sein de l'équipe Ingénierie du Projet d'Aménagement, Paysage et Environnement de l'UMR 6173 CITERES à laquelle appartiennent les enseignants-chercheurs du département aménagement.

Le travail de recherche, dont l'objectif de base est d'acquérir une compétence méthodologique en matière de recherche, doit répondre à l'un des deux grands objectifs :

Développer toute ou partie d'une méthode ou d'un outil nouveau permettant le traitement innovant d'un problème d'aménagement

Approfondir les connaissances de base pour mieux affronter une question complexe en matière d'aménagement.

Afin de valoriser ce travail de recherche nous avons décidé de mettre en ligne les mémoires à partir de la mention bien.

THANKS

Throughout this final project, some people have participated to its and I would like to thank them.

First and foremost, I would like to give my special thanks to Mindjid Maïzia, Professor in “Aménagement de l’espace et Urbanisme”, who mentored me and for his precious guidance all along my project.

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Last but not least, I thank all the people who were there for helping me.

1. Environmental stakes

In Europe, transportation is one of the main sources of air pollution. NOx, PM, CO, and VOCs, harmful particles for human health and environment are rejected in high quantity by different vehicles. More than 30% of the energy consumption is due to transportation in France. Among the transportation-related air pollution, more than 80% is caused by road transports and 61% is generated by individual cars[1]. In this way transportation highly participates in global warming.

Therefore, the European Union is working on reducing the greenhouse emissions to contain at 2°C the increase of the Earth temperature (compared to 1990-temperature[2]). After the Kyoto Protocol, the 28 European countries are still involved in the "Climate and energy package" with three objectives for 2020: reducing by 20% their greenhouse gas emissions compared to 1990, reducing the energy consumption by 20% and having at least 20% of renewable energy in the total energy consumption. It is called the "3*20". France has an ambitious environmental policy: the government is committed to divide by four its greenhouse emissions between 1990 and 2050.

It is why an energetic transition is necessary to reduce carbon emissions, which cause the global warming. It means controlling the energy consumption, increasing its efficiency and finding alternative technologies. As research is fundamental for an effective energetic transition, France consecrated 447 M€ in 2012[3] for the new technologies of energy, which is considered as an important effort regarding the average of European countries.

2. Technical stakes

Electric vehicles can be viewed as a solution to this energetic transition, according to most scientists. This type of vehicle accounted for 0.57% of the French sales in 201[4]. Three main reasons explain this very low number: its cost, its low autonomy and the need for dedicated infrastructures to plug in the vehicle. That is why, with the decrease of prices or/and an improvement of the electric technologies, it is easily to imagine that electric vehicles could gain a significant market share in the next years.

3. Urban stakes

Assuming the electric vehicles-use is generalized, electric needs will be higher. This implies knowing exactly the electrical consumption of vehicles at each moment and each place. The electric production is known, the electric consumption has to be as well. It is important to establish the most relevant network of charging points across an agglomeration since the driver needs to kwon where plug in his car.

[1] Les chiffres clés 2013 Climat, air et énergie, ADEME
[2] According to the Intergovernmental Panel on Climate Change (IPCC)
[3] « Panorama Energie-Cimat", Ministère de l'Ecologie, du Développement Durable et de l'Energie, http://www.developpement-durable.gouv.fr/IMG/pdf/Panorama-energies-climat_2014-COMPLET-leger.pdf
[4] Comité des Constructeurs Français d'Automobiles - http://www.ccfa.fr/

1. Electric vehicles

To begin with this paper, it is important to quickly focus on electric vehicles. Different kinds of electric vehicles exist: the hybrid vehicle (combining an internal combustion engine and an electric battery) and the fully electric vehicle. This paper will focus only on this last one.

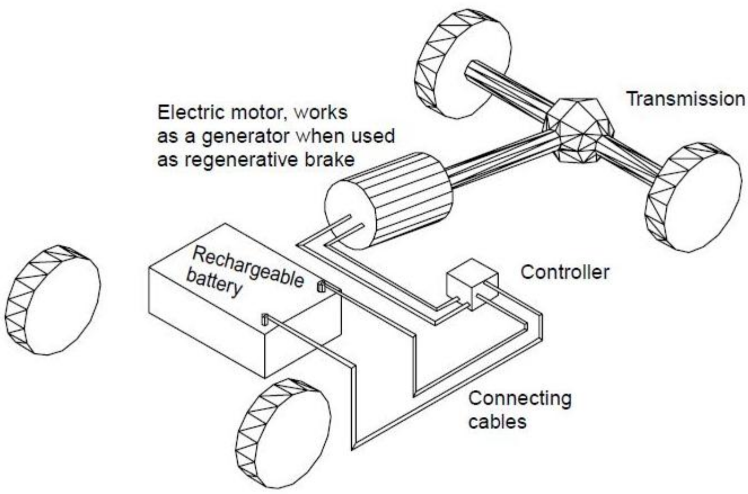


Figure 1 : Concept of the rechargeable battery electric vehicle (*LARMINIE James and MOWRY John, 2003)*

An electric car is propelled by an (or more) electric motor(s). This electric energy is stored in rechargeable electric batteries. Most of these batteries use lithium-ion technology.

The battery powers the motor to create its rotation and the torque is transmitted to the wheels.

Nowadays, the highest autonomy is attributed to the Tesla Model S with 350 to 500 km, according to the manufacturer. But most of electric cars have 150 to 200 km of autonomy, depending on a lot of parameters. It is obvious that the autonomy will be lower if the car goes uphill than downhill: the required power is different.

Electric batteries account for for 100 to 600 kg of the vehicle mass (between 750 kg and 2100 kg), depending on manufacturers. This mass is much higher than the mass of petrol necessary for thermal motor. Indeed, considering that one liter of petrol weights 0.755 kg and assuming a 6 L/100 km petrol-consumption, a gasoline car needs to carry about 9 kg of fuel to travel 200 km. That is explained since these two energy-sources do not have the same energetic density. Burning 1kg of petrol provides between 10 000 Wh and 15 000 Wh of energy compared to batteries lithium-ion which, provide between 150 to 200 Wh for the same mass. The energetic density of batteries is at least 50 times less than petrol energetic density, even if it is still six times more than the lead batteries. This explains the mass of the batteries in the electric vehicles[5]. Besides, it shows that this technology has to be improved. Another field to improve concerning batteries is their time of recharge. Currently, eight hours are required to totally charge up the battery.

[5] La voiture électrique populaire: http://www.voiture-electrique-populaire.fr/enjeux/technologie/batterie

2. Power calculators

ADEME[6] created the "Calculette Éco déplacements"[7] (Figure 2). This calculator allows to estimate the environmental and economic impacts of the pendular trip during one year according various means of transport (individual car, bus, tramway, bike, carpooling, train, etc).

It works easily with only two needed pieces of information: the length of the pendular travel and the means of transportation. It is worth noticing that the calculator does not propose a calculation for electric cars and does not make any difference between either a diesel and a gasoline car or a small and a large car. The results are based on the average consumption, determined by ADEME experts in 2007.

Figure 2: Screenshot of the « Calculette Éco Déplacements"

A second calculator has been developed by the ADEME, called "Car Labelling"[8]. This calculator gives energy consumption and cost for more than 6000 vehicles, recorded in this database, including electric vehicles. Nevertheless, the results (Figure 3) propose the consumption in liters/100 km for diesel, gasoline and superéthanol-E85 and in m3/100 km for GPL vehicles. The consumption is not expressed in kWh/100 km. There is no denying that this calculator does not suit for the electric vehicles.

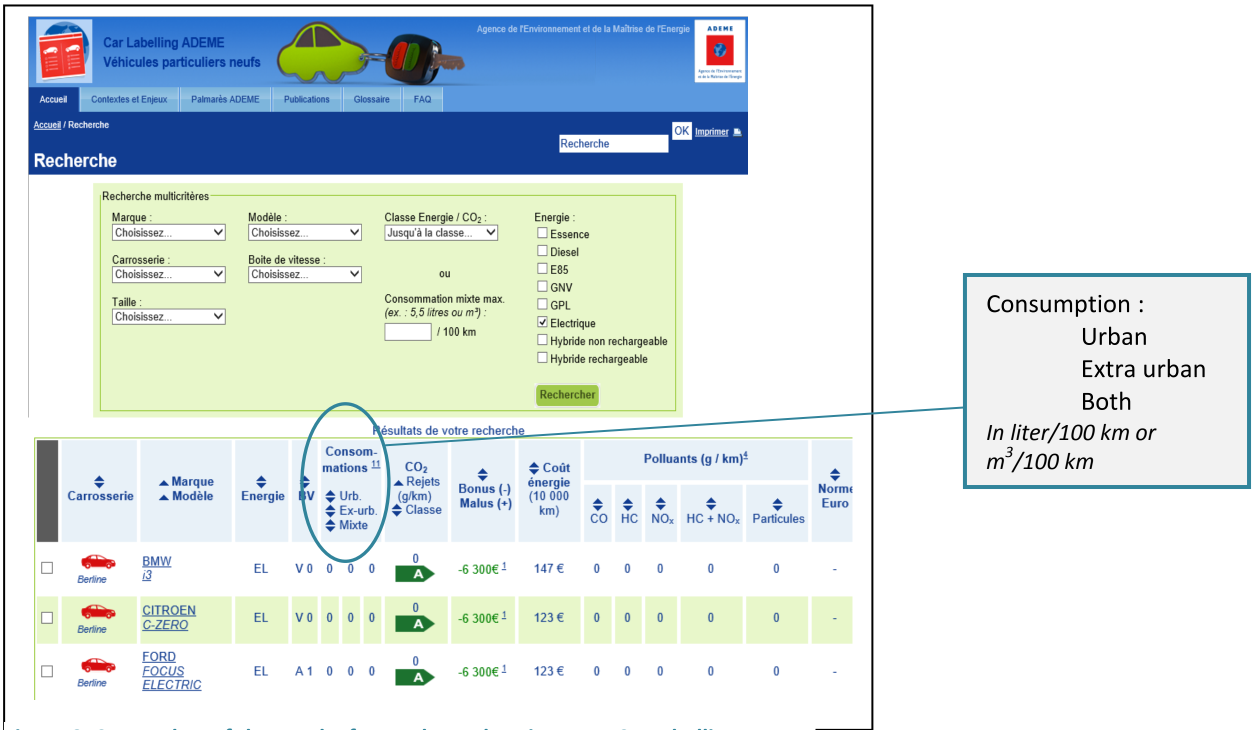


Figure 3: Screenshot of the results for a saloon electric car on CarLabelling

Through these two examples based on the ADEME website, it has been demonstrated that it is not an easy task for an average citizen to find his own consumption with an electric vehicle. The electric vehicles are not yet integrated in these calculators, even if the energy consumption per 100 km is known (between 10

[6] Agency for the Environment and the Control of Energy, a scientific reference in France for the sustainable development

[7] ADEME: http://www3.ademe.fr/eco-deplacements/calculette/

[8] ADEME: http://carlabelling.ademe.fr/index/

and 14 kWh/100 km according theoretical data[9] and between 18.5 and 21 kWh/100km according to driving tests[10]).

All this goes to show that the knowledge about electric consumption is less accessible than the classic vehicles. It is obvious that there is a lack of information concerning electric required power.

3. Scientific researches

For some years, more and more scientists have focused on electric vehicles. However most of them deal with the mechanical aspects (how to overcome the low autonomy of batteries for instance). Few of them treat the electrical consumption and the electrical transportation system.

Various parameters can be taken into account in order to calculate the energy consumption: mechanical parameters such as the aerodynamic of the vehicle, urban parameters such as topology, and human parameters like the behavior of the driver.

Most of the consumption studies base their researches on empirical data. Indeed, the scientists collect data (speed, travelling distance, grade, power…) from one or several electric vehicle(s) using captors and making readings. This data serves as a foundation for the analyze and allow to establish links between different parameters and the electrical consumption. It is the case of a study led by four scientists *(Wu Xinkai, Freese David, Cabrera Alfredo, Kitch William A., 2015).* They collected data from an electric vehicle which travelled for approximately 5 months. Next, they calculated the instantaneous required power based on theoretical formulas and used their empirical values to obtain the instantaneous power. Finally they compared the results from the data collection and from the theoretical prediction in order to check if the model is pertinent.

In order to know the influence of parameters in consumption, some studies focus on only one parameter and neglect others. In their research (*S.C. Yang, M. Li, Y. Lin, T.Q. Tang, 2014*), these Chinese scientists focus on the influence of the grade taking into account the driver's behavior but neglect some mechanical forces.

Nowadays, scientists begin to have significant results – it is worth noticing that the quoted studies are very recent - and succeed to establish links between parameters influencing the electric consumption.

There is no denying that the study of electrical consumption requires various knowledge in different fields such as in mechanic, electronic, modelisation and even sociology (if the driver's behavior is observed). It must be recognized it is a complex issue with high stakes. The future scientific researches promise to bring new useful knowledge and tools for developing the use of electrical vehicle and improve a significant smart grid of recharge points.

[9] http://www.technologicvehicles.com

[10] United States Environmental Protection Agency: http://www.epa.gov/.

In this paper, a method is developed to obtain the required instantaneous power as a function of travel time (Figure 4) in order to provide all the vehicles (assuming they are electric) in an agglomeration with theoretical data, unlike the other researches which are based on empirical data.

Contrary on consumption calculators, this project will introduce the notion of "time" to calculate the electric consumption. Indeed, calculators obtain it only by basing their results on a trivial multiplication of the travel distance and consumption per km.

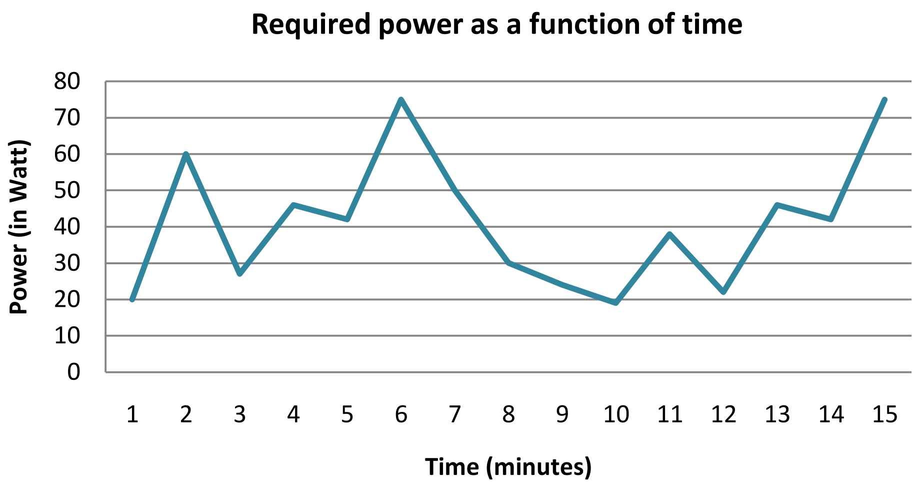


Figure 4: Required power as a function of time

After obtaining the load curve, the required energy will be compared with the average theoretical and empirical consumption (10-14 kWh/100 km - 18.5 and 21 kWh/100km).

Besides, it will be interesting to vary different parameters in order to determine their influence in the electrical consumption.

1. Graph theory

The base of this work is a roadway network. Working with a roadway network requires to know the bases of the graph theory. This science clearly represents "the structure, connections and the possible movements of a roadway network emphasizing the relations and dependence between its elements" (*Caloz Régis and Collet Claude, 2011*).

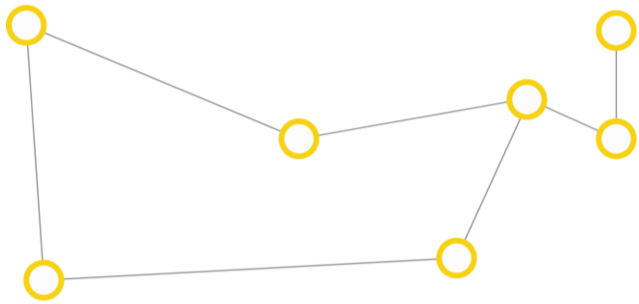


Figure 5 : Representation of a roadway network

First of all, a network is a group of links, called edges. An edge is the portion of road between two intersections. An oriented edge has a sense of circulation. A node represents an intersection. In general, they are represented as shown in the Figure 6.

Figure 6 : Representation of the graph theory elements

Each oriented edge is described by its coordinates (x, y, z) at the beginning and the end, its length, a sense of circulation and a nature of the roadway (highway, secondary-road, etc).
A node also has coordinates x, y and z and a name (equivalent to a number).

An itinerary is a succession of nodes and oriented edges,
It begins with a node and ends with another one (Figure 7).

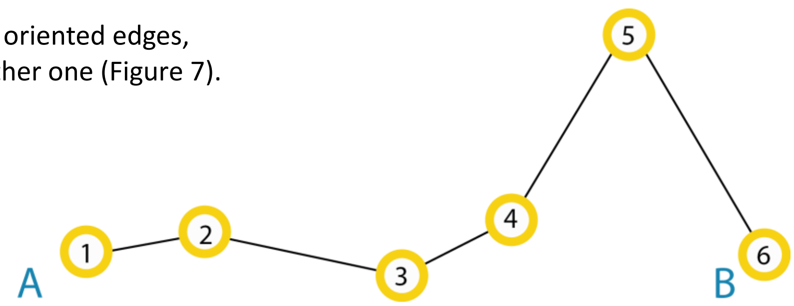


Figure 7: The composition of an itinerary from A to B

An itinerary between A and B can be calculated by the S.I.G. software depending on different criteria such as the lowest cumulative distances or time, the less dangerous way, etc. Nevertheless, the most common way is based on the lowest cumulative distances, realized with the Dijkstra algorithm (used by the Global Position System GPS). This algorithm, conceived by the computer scientist M. Dijkstra in 1959, travels all the possible paths from A to B and selects the lowest cumulative distance one.

French cities' roadway networks are furnished by the TOPO_V2 database from IGN[11]. The nature of the edge is indicated (highway, path, bicycle path, etc) as well as its length, its coordinates, its sense of circulation and administration information.

After this summary about graph theory, the method for the establishment of the load curve can begins. First of all, the significant parameters on the electric consumption during a travel need to be established.

2. The Fundamental Dynamic Principle (FDP)

A vehicle in movement along an inclined plane (Figure 8) is subject to various mechanical forces: the tractive force F_{trac} (the required force to move the vehicle), the aerodynamic resistance force F_{aero} due to the friction of the vehicle and the air, the rolling resistance force F_{rl} due to the friction of the tyres on the road and the grade force F_g due to the gravity. Other forces taking place are neglected such as the inertia of the rotating wheels.

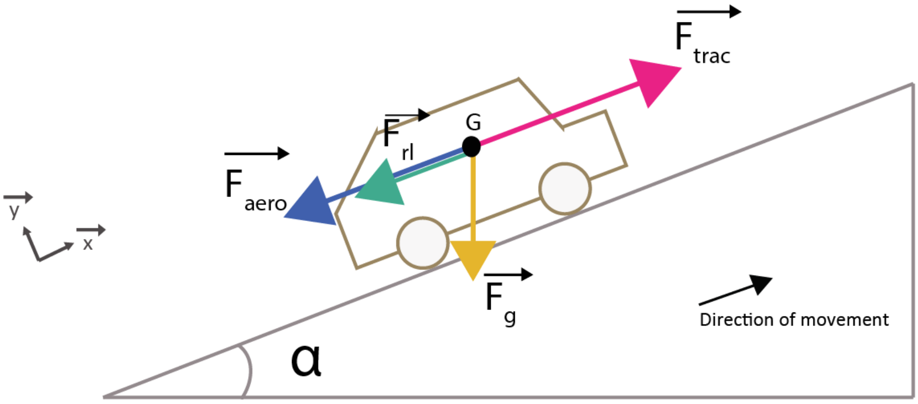


Figure 8 : Summary of forces applied on a vehicle in movement

With :

$$\overrightarrow{F_{aero}(t)}\Big|_x = 0{,}5 \cdot \rho \cdot C_d \cdot A_f \cdot \overrightarrow{v(t)}\Big|_x^{\,2} \quad (1)$$

$$\overrightarrow{F_g(t)}\Big|_x = m \cdot \sin\alpha(t) \cdot \vec{g}\Big|_x \quad (2)$$

$$\overrightarrow{F_{rl}}\Big|_x = f_{rl} \cdot m \cdot \vec{g}\Big|_x \quad (3)$$

where m is the vehicle mass (in kg), g the gravity acceleration (g=9.81 m/s²), α the roadway grade (in degrees), f_{rl} the rolling coefficient (no unit) depending on the surfacing, the width, the composition and the pressure of tyres, ρ the air density (in kg/m^3), C_d the coefficient of drag (no unit), A_f the frontal area of the vehicle (in m²), v the vehicle speed (in m/s) *(Wu Xinkai, Freese David, Cabrera Alfredo, Kitch William A., 2015)*.

The Newton's second law is applied on this vehicle in intertial frame of reference and allows to determine the tractive force F_{tract} (in Newton):

$$\sum \overrightarrow{F_{external}(t)}\Big|_x = m \cdot \overrightarrow{\Upsilon(t)}\Big|_x \quad (4)$$

where ϒ is the acceleration (in m/s²)

The combination of equations (1), (2), (3) and (4) gives:

$$\overrightarrow{F_{tract}(t)}\Big|_x + \overrightarrow{F_{aero}(t)}\Big|_x + \overrightarrow{F_g(t)}\Big|_x + \overrightarrow{F_{rl}}\Big|_x = m \cdot \overrightarrow{\Upsilon(t)}\Big|_x \quad (5)$$

[11] Institut National de l'Information Géographique et Forestière

Projecting this vectorial equation on the *x*, the tractive force is expressed as follows:

$$F_{trac} = m.\Upsilon + F_g + F_{rl} + F_{aero} \qquad (6)$$

Υ and F_g can be negative, respectively during a deceleration phase or a slope.

Regarding the power P_{out}, the mechanical power given out by the electrical motor, it is expressed as follow in Watt:

$$P_{out}(t) = F_{tract}(t) \,.\, v(t) \qquad (7)$$

The electrical power supplied to the motor is:

$$P_{in}(t) = \frac{P_{out}(t)}{\eta} \qquad (8)$$

with η the electric motor efficiency (no unit)

The equation allows to calculate the required power according to the vehicle speed, acceleration, grade, mass and mechanical parameters.

3. Calculation method

As a result, three parameters appear to be dependent on the time: the vehicle speed, its acceleration and the grade. The other parameters are fixed for one vehicle along a travel.
The power depends on where the vehicle is on the roadway network. In graph theory, this means that it is depending on which edge the vehicle is.

Thus, the power will be, in a first step, calculated for each edge of each itinerary and for one vehicle. That is why this method involves knowing the itineraries travelled by the vehicles and the three parameters for each edge. After that, the power for each itinerary is calculated, before calculating the power required by the wholeelectric vehicles fleet.

Five main steps described below (Figure 9) have to be performed in order to calculate the total required power.

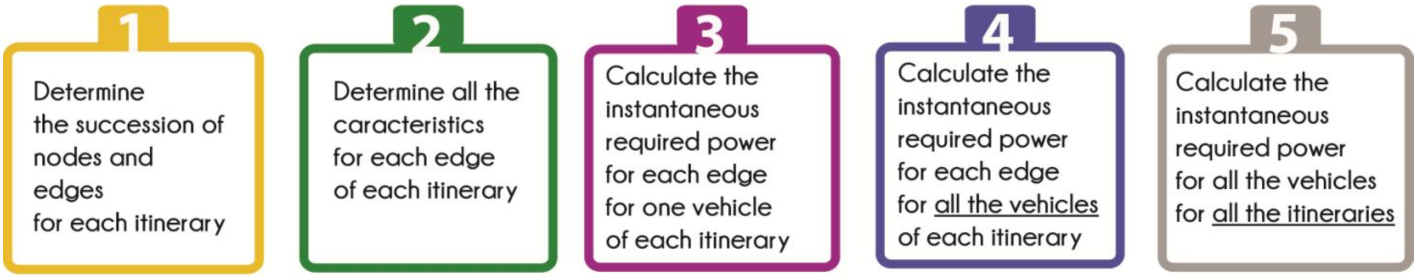


Figure 9: Main steps for calculation of the required power

In most cases, speed varies constantly during a travel. As the simulation of this phenomenon is quite difficult, the speed (*vtype*) is assumed to be constant for each edge, meaning a null acceleration (*ϒ)*. Thus, a speed is affected to each edge (according to reasons developed in *Vehicle speed affectation* part).Nevertheless, in order to be more accurate, a phase of acceleration is set up: it is a phase at the beginning of each edge allowing to reach the constant speed for this edge. The phase is expressed thanks to a distance of acceleration (*dtype*).

To simplify, edges have a *type* (an integer) which refers to a couple of speed and distance of acceleration.

For example, for two random consecutive edges: the type of the first one is 1, referencing to a 50 km/h–speed and a 25-meters of distance of acceleration, and the type of the second edge is 2, referencing to a 90 km/h-speed and 80-meters of distance of acceleration. A vehicle needs a phase of acceleration to go from 50 to 90 km/h; this phase takes place during the distance of acceleration of the second edge (dtype 2). In this paper, the acceleration depends on the speed of the edge, not on the speed of edges before and after.
An edge has a length named *ld*.
This schema illustrates what is said above Figure 10.

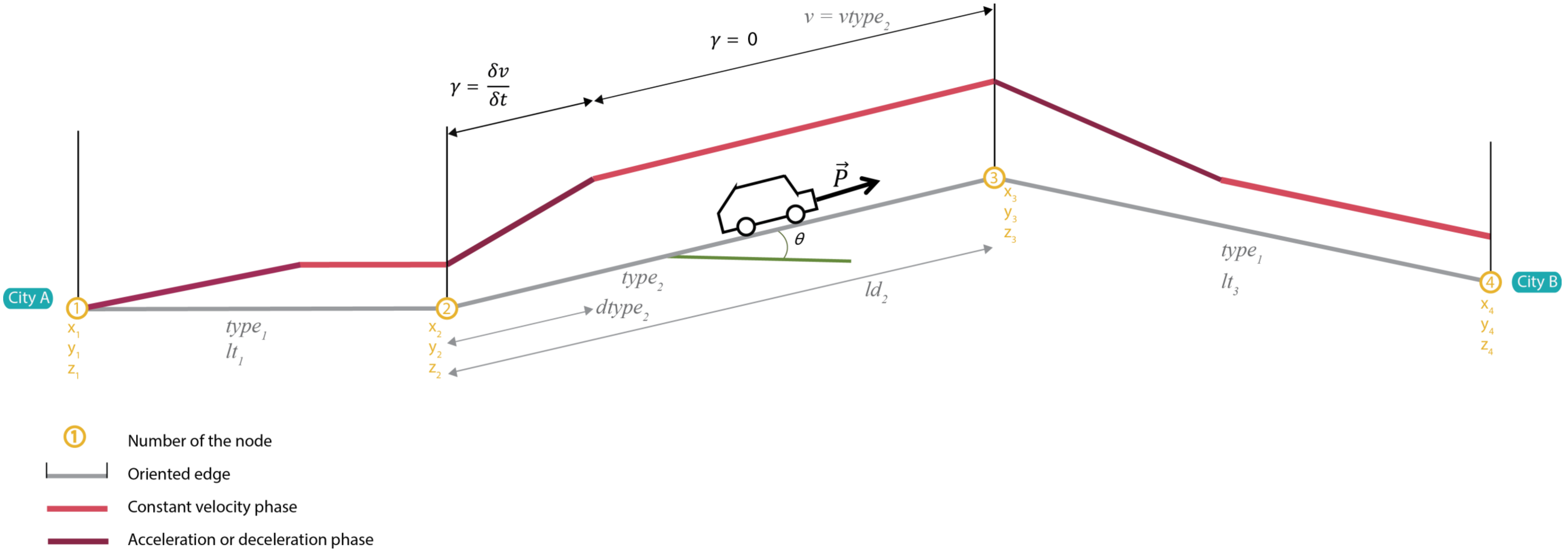


Figure 10 : One Itinerary divided into edges and nodes

The execution of this method is divided into three main parts. The first one consists of affecting parameters (grade, speed, distance of acceleration) for each edge of the roadway network. The aim of the second one is to build the roadway network and acquire all these parameters for each edge of each itinerary. This work is based on ArcGis® treatments. Finally, the last step is to calculate the necessary power as a function of time for each edge in order to have the power for each itinerary for XX vehicles, performed by a MatLab® program.

4. Parameters affectation

Grade affectation:

Each edge is described by its initial node, there (Figure 11) node number 1. The coordinates (x_1, y_1, z_1) of this node is known. It is the same for the next node, number 2 (x_2, y_2, z_2). These data are enough to calculate the grade. Therefore, its determination is easy:

$$\sin \alpha\,(t) = \frac{z_2 - z_1}{lt}$$

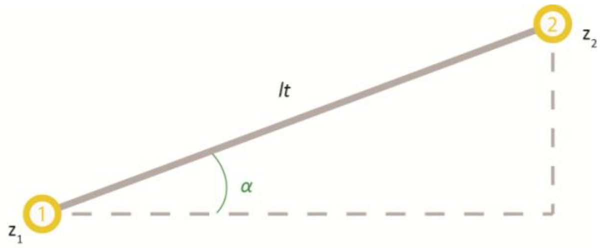


Figure 11 : Nodes et edge of the grade affectation

Therefore, sin α is positive when the vehicles goes up and negative when it goes down.

Vehicle speed affectation:

At each edge, a type (an integer) has to be affected in order to refer a speed and an acceleration distance. This means the type depends on the speed and the acceleration distance.

Generally, the speed depends on the nature of the road (highway, two-lanes road, slip road, etc) - and so, its speed limit- and the traffic jam. Since no database about speeds exist in France for free, a method needs to be designed for having the speed for each edge.

There are different approaches to affect a speed to an edge.
The first possibility of the speed attribution consists in giving a speed according to the observed average speed on the different natures of road in different urban networks (urban, peri-urban, rural network). It looks like a pertinent solution, nevertheless it highlights a striking issue: how to define what is an urban area, a peri-urban one and a rural one?
The second method is to simply attribute the speed limit to the edges. This solution does not reflect the true conditions of circulation (congestions for instance) in urban center. Indeed, the speed in big city centre is lower than the speed limit because of the traffic. However, maximizing the speed maximizes the electric required power, which is a good point for this paper. That is why this method will be used. The process is based on the French Professor M. SERRHINI's work (Tableau 1).

Method of speed affectation:

As said previously, there is no data base for free which informs about the speed limit network. Because of that, M. Serrhini's work is based on several years of studies, observations in the field and on the Cyril Ray[12]'s work. He has cross-referenced information on building linear density and nature of the road in order to obtain the speed limit.

Why taking into account the speed limit ?

The speed limit gives the speed which drivers are allowed to go. This means that if the road is free (no congestion, no obstacle), the driver probably reaches this speed. Observations realized by the « *Observatoire national interministériel de la sécurité routière* » show that the real average speeds are close to the speed limits[13]. For instance, on highways with a 130 km/h-speed limit, the real average speed is 127 km/h. Thus, this is relevant to suppose that the effective speed is the same that the speed limit.

The data presented above are national averages, excluding cities with more than 100 000 inhabitants. But in the centre of these highly populated cities, it is well-known that the circulation is more difficult because of the higher traffic.

The speed limits aim to drive safely and efficiently. They are established according to various criteria such as the nature of the road, its danger (curve, buildings), the presence of pedestrians, bicycles, schools or others public institutions, etc.

Why taking into account the building density ?

« The main parameter describing the shape of a city is its density », exposed Newman and Kenworthy (*Peter Newman and Kenworthy Jeffrey, 1989*). Since then, density is integrated in urban planning documents as a way to consume less energy and less area. Besides, M. Levinson[14] and M. Kumar[15] pointed out that high density and congestions are linked, leading to lower automobile-speed (*POUYANNE Guillaume, 2004*). It is worth noticing that this affirmation creates debates in the scientific community.

Besides, "among buildings, in order to optimize the security, the speeds have to be reduced"[16] . This proves that building density along edges influences the speed limits.

How to determine the influence of the building linear density ?

The building density is the linear density of building along each edge, expressed by building surface per meter (m^2/m). The building surface corresponds to the floor area, the height and the numbers of floors of each building.

M. Serrhini developed a method to determine the influence of the density. A buffer area of 50 meters is created around all the edges (Figure 12). This value allows to take into account all the buildings along the edges. The surface of building in each buffer is calculated and divided by the length of the edge in order to obtain the linear density.

Figure 12: 50-meters buffer

Knowing the building linear densities, the speed limits in place and with observation, M. Serrhini succeeded in doing a link between these two data. He established a threshold of linear density, according to the nature of the road, to affect the speed to the edges (Tableau 1).

[12] French researcher and professor at École Navale

[13] « Observatoire national interministériel de la sécurité routière : résultats de l'année 2011»

[14] American Professor at the University of Minnesota, as a civil engineer and transportation analyst

[15] Indian Professor at the Georgia Tech

[16] Guide de détermination des limites de vitesse sur le réseau Routier, Direction de la sécurité des infrastructures routières, 2009

Acceleration affectation:

As said above, an acceleration distance has to set up. A time of acceleration could have been chosen as well. In spite of it, this acceleration phase is determined by an acceleration distance.

How to estimate the acceleration distance*?*

The acceleration distance is calculated according to the acceleration of the Renault Zoé ZE car. This car reaches 50 km/h from 0 km/h in 4 seconds, and 100 km/h in 13.5 seconds, according to the car manufacturer.

Based on this data, the acceleration distance is deduced:

$$v_{acc} = \frac{d_{acc}}{t_{acc}}$$

$$d_{acc} = v_{acc} \cdot t_{acc}$$

with v_{acc} the average of the initial and final speed and t_{acc} the required time to go from the initial speed to the final speed.

The previous methods allow to attribute a type, with a speed and a distance of acceleration, for each edge.

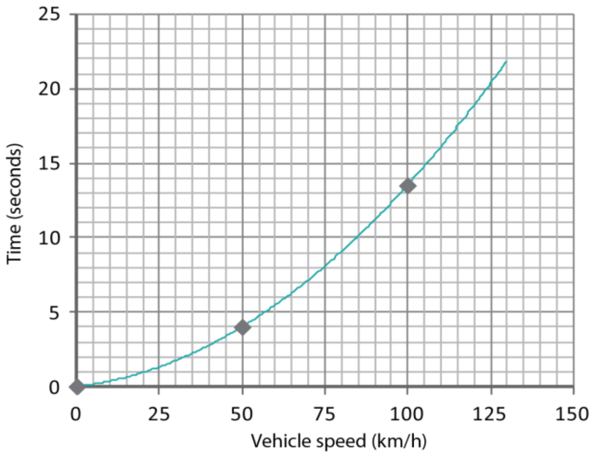


Figure 13: Acceleration of a Renault Zoé ZE

Tableau 1: Speed and acceleration distance affected according to the edge characteristics

Nature of roadway	Linear density of buildings (m²/m)	Type of the road	Speed (km/h)	Distance of acceleration (meters)
Highway	< = 0.7	1	130	183
Highway	>0.7	2	90	80
Quasi-highway	< = 0.7	3	110	139
Quasi-highway	>0.7	2	90	80
Two-lanes road	< 105	4	70	50
Two-lanes road	> = 105	5	50	25
One-lane road	< 105	5	50	25
One-lane road	> = 105	6	30	7
Slip road	--	6	30	7
Gravel road	--	7	20	1.4

Calculation of the required power:

Thus, all the itineraries, from each city to each other city, are created thanks to a network data set (on a S.I.G. software). After some treatments, the ordered succession of all the taken nodes and edges for each itinerary is created. As a consequence, the type (hence the speed and the acceleration distance) and the coordinates are known across all the itineraries. Those data are the inputs in MatLab® programs, realized by Mindjid Maïzia available in Appendixes 1 to 4, in order to calculate the instantaneous required power for all the electric vehicles in an agglomeration.

In order to be closer to the reality, a margin of error has been instituted for different parameters: vehicle mass, speed and distance of acceleration. Their value can vary between these margins of error.

Besides, a delay (in minutes) is introduced, meaning it is supposed that cars of one itinerary do not leave at the same time. This action still aims to better simulate the reality.
A chart (Appendix 5) summarizes these explanations.

The method described above is applied to the Tour(s) Plus agglomeration. Tour(s) Plus is an agglomeration of more than 295 000 inhabitants[17], distributed across twenty-two cities in Indre-et-Loire (Region Centre, France). The main one is Tours with about 135 000 inhabitants[18]. The agglomeration has the particularity to be crossed by the highway A10 (North to South) and A85 (East to West) (Appendix 6).

The present case study only takes into account the commuting travels – also called "pendular travels" - (from home to work) in the agglomeration in order to simplify the problem. Indeed, the necessary data for this type of travels – that is road flows between each city - are easily available for each agglomeration, contrary to the other types of travels (for leisure, shopping, etc).

On a daily basis, more than 66 000 commuters drive its own car to go to work[19], in the agglomeration. Since there are twenty-two cities, 484 pendular itineraries can be done. The flow of commuters from one city to another one is available on the INSEE Website.

1. Selected roadway network

The paper focuses on the commuting in Tour(s) Plus. That is why the selected roadway network integrates the Tour(s) Plus'one but also the network of the cities next to this agglomeration. Indeed, the roads outside of Tour(s) Pus can be used to reach one city of Tour(s) Plus from another one. This whole network integrates only carriage roads, meaning that pathways, bicycle paths and stairs are excluded. The roadway network data comes from the IGN database (BD_TOPO_V2).

2. Application

The linear density is calculated (Appendix 7) and the type of each edge is attributed. The map in Appendix 8: represents the affected speed on the roadway network.

In order to create the 484 itineraries, ArcGis® needs to have a departure and arrival points for each city. In this case study and in order to only focus researches on the objectives of this paper, these points are the centroid (spatial center) of each city. A better solution would have been to take the highest concentration of living places for the departure points and the highest concentration of working places for the arrival points. Finally, the 484 itineraries are generated (Appendix 9:). The 22 itineraries from a city A to this city A are logically considered as inexistent: no power will be calculated even if pendular travels happen. This is not a big deal since it represents very small distances, that is to say only a low required power has been neglected.

After treatments on ArcGis®, Access and Excel, the data necessary to calculate the consumption is gathered, that is to say the succession of the taken nodes number (from the first one to the last one) with their coordinates and the type of each edge, for each itinerary. Besides, a matrix containing the vehicles flow between each city is set up. The MatLab® program can finally be used.

Many program inputs are constant for one vehicle but can vary between different vehicles. It is the case for mechanical values. This case study is realized with the following intervals or constants (Tableau 2):

[17] Tour(s) Plus : http://www.agglo-tours.fr/index.php?idtf=178

[18] Insee : http://www.insee.fr/fr/themes/dossier_complet.asp?codgeo=COM-37261

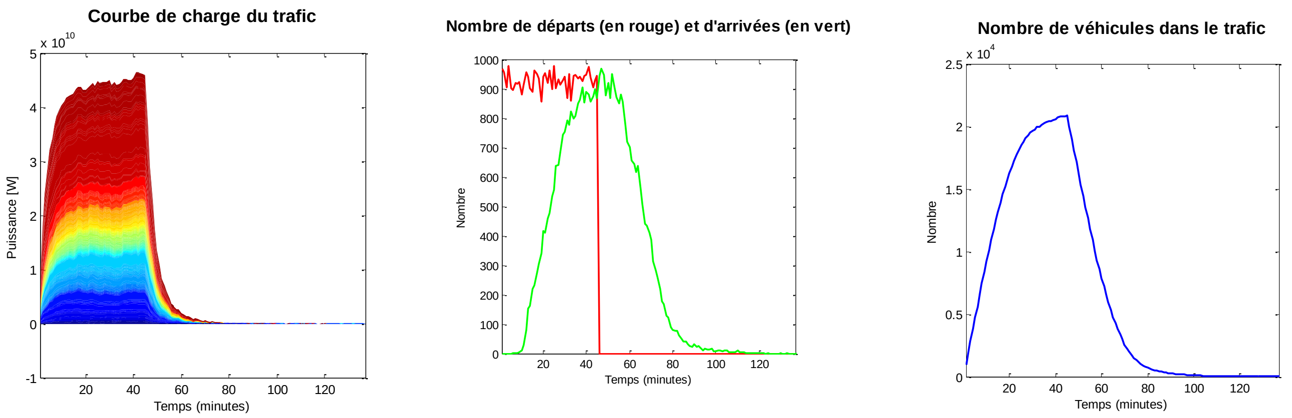
[19] Base de données MobPro, INSEE – http://www.insee.fr/fr/themes/detail.asp?reg_id=0&ref_id=fd-rp2010&page=fichiers_detail%2Frp2010%2Ftelechargement.htm#RP2010_MOBPRO

Tableau 2: Chosen values for constant parameters

Parameters	Min – Max for vehicle	Chosen value
g	9.81 m/s²	9.81 m/s² [17]
ρ	1.25 kg/m³	1.25 kg/m³ [17]
C_d	0.19 - 0.4	0.25 [17]
A_f	1.7 – 3.5 m²	2.5 m² [17]
f_{rl}	0.005 – 0.015	0.008 [18]
m	750 – 2100 kg	1 400 kg [19]
η	0.85	0.85[20]

[17] *(VAZ Warren, NANDI Arup K.R., LANDERS Robert G., KOYLU Umit O., 2014)*
[18] According to the tyres manufacturer Michelin, http://toutsurlepneu.michelin.com/pneu-michelin-ultimate-energy
[19] According to the weight given by the manufacturers of electric vehicles sold in France in 2014
[20](*YANG S.C., LI M., LIN Y., TANG T.Q., 2014)*

The simulation made thanks to MatLab® provides three graphs.
First, the load curve is generated, giving the value of the consumption peak (in W) and the total consumption (in Wh).
Secondly, the simulation also represents the numbers of vehicles which leave from the origin and arrive to their destination as a function of time.
Thirdly, the number of vehicles still in the traffic is available as a function of time.



vitesse par type de route [+|-20 %] : 130 90 110 70 50 30 20 km/h
distance d'accélération par type de route [+|-0.0001 %] : 183 80 139 50 25 7 1 m
Masse des véhicules [+|-0.2 kg] : 1400 kg
Durée de la période des départs : 45 minutes

Résultats :
Pic de consommation (W) : 46389724755
Consommation totale (Wh): 2033293535609

Figure 14: Summary of one simulation

1. First observation

It is worth noticing that the curve of the number of arrivals seems following a normal distribution (or Gaussian distribution). This well-known curve stands for many daily situations in statistics and probabilities. Indeed, "when a phenomenon is caused by a superposition of many random factors, the result follows a normal distribution" (*KAHANE Jean-Pierre, 2009*). The interpretation of the curve is as follows: the probability for a random quantity to do not take away from more than two standard deviations of the average is 95%. Graphically, the average value of the quantity is equal to the abscissa of the top (the peak) of the curve.

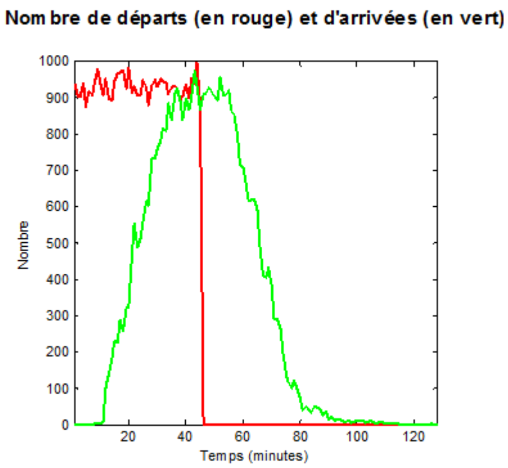


Figure 15: Departures and arrivals number for a departures-interval of 45 minutes

In this paper, this means there is a 95%-probability that a vehicle arrives in two standard deviations of the average time.

Supposing that the whole vehicles left between an interval of 45 minutes (with *dtype* and *vtype previously defined)*, the average time is also at 45 minutes according to the simulations.

So, there is a 95%-probability that a vehicle arrives 45 minutes after the departure of the first vehicle, more or less one standard deviation. That implies that a vehicle needs 45 minutes or less to reach its destination (still with a 95%-probability), no matter when it leaves from origin.

It is important to observe that the average of 45 minutes matches with the interval of time in which vehicles can leave.

The graphs in Appendix 10 represent numbers of departures and arrivals as a function of time for many simulations.
Observations can be formulated:

- A normal curve is always observed. However, after an interval of 90 minutes for the departures, the curve tends to flatten itself.
- More the interval of departure time is long, more the standard deviation is big, less a probability on the arrival can be done.
- The lowest standard deviation seems being for a 30 or 45 minutes-interval.

The explanation of the phenomenon is hard and it should be interesting in focusing on it in another study.

2. Tour(s) Plus electric vehicles-consumption simulation

The required electric power is calculated to the whole vehicles fleet in Tour(s) Plus only for the pendular travels (one way).

Due to incorrect results (wrong order of magnitude) when the acceleration is taking into account, this acceleration force is unfortunately assumed as null. It signifies that vehicle goes from the speed 1 to the speed 2 without any acceleration.

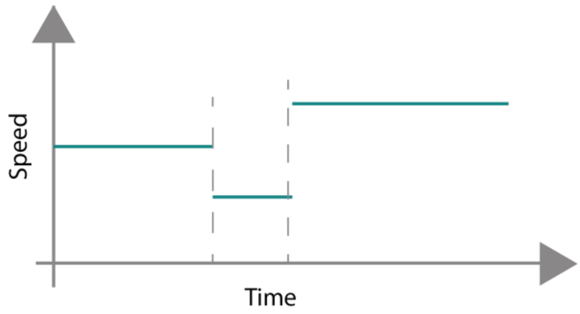


Figure 16: Value of speed without acceleration phase

A simulation for a random vehicle mass between 750 and 2100 kg with random mechanical parameters (Tableau 2), with speeds as defined in Tableau 1 and a departures interval of 45 minutes, was studied (Results on the Figure below) .

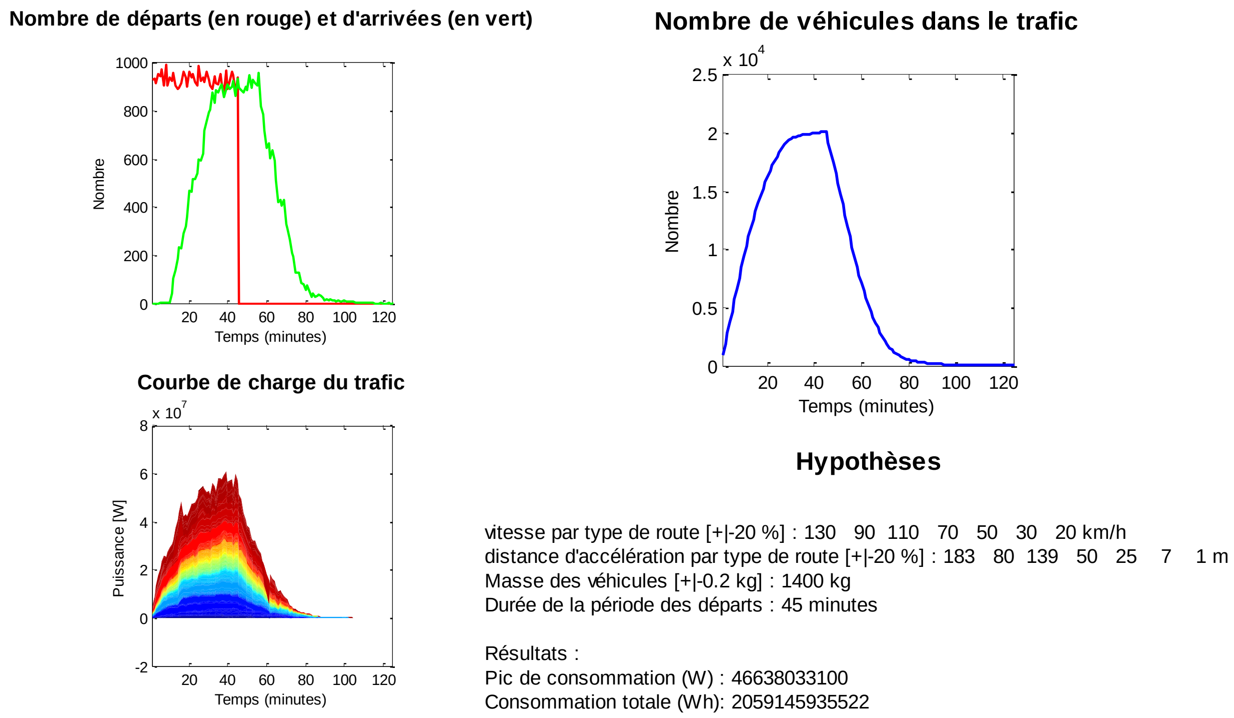


Figure 17 : Results of the simulation for pendular travels in Tour(s) Plus

After various simulations, the average consumption peak and total consumption can be defined:

Tableau 3 : Average results for simulations in Tour(s) Plus

Average peak (kW)	**6.1 * 10^4**
Average total consumption (kWh)	**2.6 * 10^6**

In the simulation, according to database, 375 858 km are travelled by 41 890 vehicles.

Calculation of the consumption per 100 km:

The unit consumption for 100 km (kWh/mh) CU is calculated to check if it fits with the theoretical values:

$$CU = \frac{\text{Total consumption}}{\text{Distance}}$$

$$= \frac{2.6 * 10\hat{}6}{3.8 * 10\hat{}5}$$

= 6.8 kWh/km
= 680 kWh / 100km

The total consumption per 100 km is 400 kWh. This result does not fit with the theoretical consumption neither with the empirical one. Indeed, the consumption here is twenty times bigger than the average, without taking into account the acceleration. It is obvious something is wrong.

The error search:

In order to find the mistake, a simulation has been done without taking into account the acceleration and the grade force, with a 50-km/h speed for all the edges, without departure delays, no margins of error and no random for all the mechanical parameters. All this aims avoiding sources of mistakes. The required power for each minute and for each itinerary is available on MatLab®: the orders of magnitude are correct. The consumption results are below:

Tableau 4: Results for a no random and 50km/h-speed simulation in Tour(s) Plus

Consumption peak (kW)	**1.26 * 10^5**
Total consumption (kWh)	**2.8 * 10^6**

Applying the same formula as previously:

$$CU = \frac{\text{Total consumption}}{\text{Distance}}$$

$$= \frac{2.8 * 10\hat{}6}{3.8 * 10\hat{}5}$$

= 7.4 kWh/km
= 740 kWh / 100km

Once again, the unit consumption is false.

In order to know when the error occurs, those data will be compared with theoretical values.

Theoretical calculation:

Tableau 5: Theoretical values

Instantaneous power (W) for one vehicle	**3 027**
Number of vehicles	**41 890**
Instantaneous power for all the vehicles (W) = consumption peak	**1.26 * 10^8**

Next, the theoretical calculation of the power is done, based on equations (1) and (2). For a 50km/h-speed, with the parameter values in Tableau 3, the power required is 3 027 Watts for one vehicle.

Since there is no delay, all the vehicles leave in the same time (at the same speed). The required power is the same for each vehicle, that is why the peak of consumption is reached at the beginning (before some cars arrive to their destination). There are 41 890 vehicles, so the required power is 1.26 * 10^5 kW. This result is exactly the same as the result gives by the MatLab® simulation. The consumption peak on MatLab® is right.

The problem does not result from a mistake during the calculation on the instantaneous power.

Secondly, the total consumption has been calculated. For each itinerary, the travel time (minute) and the number of vehicles are known. The instantaneous power (W) is always the same across all the itineraries.

The energy is the multiplication of the travel duration (in hours) by the instantaneous power. The total consumption – or total energy - is the sum of each itinerary energy.

Tableau 6: Theoretical energy calculation

Itinerary number	Duration (minutes)	Duration (hour)	Unit power (W)	Number of vehicles	Power for all the vehicles (W)	Energy (Wh)
1	18	0,3	3 027	8	24 216	7 265
2	26	0,43	3 027	29	87 783	38 039,3
3	48	0,8	3 027	4	12 108	9 686,4
4	0	0	3 027	0	0	0
…	….	….	….	….	….	….
462	41	0,68	3 027	5	15 135	10 342
					Total consumption (Wh)	**46 829 809**

Finally, the total consumption is about 4.7 * 10^7 Wh, two hundreds time lower than the total consumption provides by MatLab®.

$$CU = \frac{\text{Total consumption}}{\text{Distance}}$$

$$= \frac{4.6 * 10^\wedge 4}{3.8 * 10^\wedge 5}$$

= 0.13 kWh/km

= 13 kWh / 100km

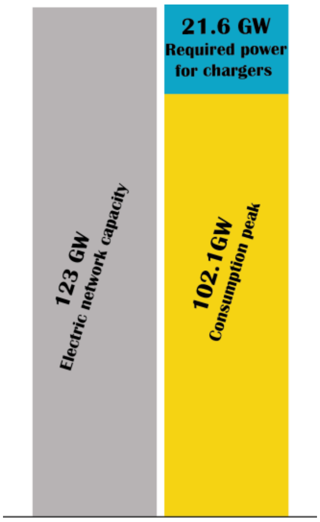
This theoretical result fits with the theoretical consumption per km given by bibliography. This means the mistake is probably in the calculation of this total consumption.

It is worth noticing this is below the empirical consumption (18.5 to 21.5 kWh/100 km) given by scientific papers. It can be explained because in this calculation, the grade and acceleration are neglected. As Tours is almost flat, the required grade force should not be high and 90% of the taken edges have a speed equal or lower than 50 km/h (Appendix 12), so it looks as if the acceleration phases are not long and are most of the time inexistent. If these two forces were taken into account, the consumption per km was higher, probably closer to the empirical values.

From now, the considerate total consumption will suppose to be the one found thanks to theoretical calculations because it has a possible order of magnitude, contrary to the MatLab® result.

The electric consumption of Tour(s) Plus in 2014 was 1 679 GWh[21].
A pendular travel is made twice a day, meaning the daily electric consumption due to individual vehicles should be 94 * 10^6 Wh. Supposing 226 worked days, the annual electric consumption reaches 21 GWh. If all the individual vehicles in Tour(s) Plus were electric, its annual consumption will increase of 1.25%.

In Tour(s) Plus, 15% of the greenhouse gas emissions provides from transportation of passengers. Among these 15%, a third is due to transportation of inhabitants[22]. Supposing that pendular travels represent the half of the whole travels, electric vehicles avoid 2.5% of the greenhouse gas emissions.
This is a low emissions saving but it represents more than one tenth of the 20% reducing-objective from the Climate and energy package. If all the individual travels are made in electric vehicle, this number rises to 5% (a quart) with a rise of 2.5% of the electric consumption. Electric vehicle can participate to reducing to greenhouse emissions but it will not be enough.



But a total consumption is not the only important data to check. The electric consumption peak can be a real issue. Indeed, an electric demand peak causes technical issue: the electric network has to be able to provide this electric quantity. The use of electric vehicles emphasizes this issue, especially if all the drivers plug their electric vehicle at the same time, probably after the end of the work day or during the night. The highest electric peak in France occurred on the 7th February 2012 at 7 p.m. with 102 100 MW[23] while the national network is able to provide 123 000 MW. In France, electricity comes from 63% of nuclear, 13% from hydroelectricity. If the electricity consumption is high, the production of electricity is completed by a production based on fossil fuels such as coal (5%), heating oil (5%) and gas (4%). Electricity can also be bought to other countries (7%). For the highest peak in 2012, France bought electricity from Germany, most of it provided from coal and heating oil plants.
In France, there are about 38 millions of individual vehicles. Assuming there are electric and each driver puts its car to plug-in each day after work (about 7 p.m.) thanks to a 6kW-charger, they generate a demand of 21 600 MW. The national network becomes unable to provide this quantity of electricity. This means the electricity will need to be produced by other polluting sources.

Electric consumption peak leads to the use of fossil energies and the actual electric network is not yet able to provide millions of electric vehicles. Consequently, electric vehicle can finally have a negative effect on the environment. This is why it is fundamental to better manage the production and distribution of electricity in the whole national network. The smart girds aims to improve it since they put in relation all sources of production and improve the electric distribution. Moreover, a dense network of charging points needs to be created, allowing to plug vehicles during the day, not only at home.

[21] According to the Renewable energy department of Tour(s) Plus
[22] Bilan Carbonne Tour(s) Plus, 2009
[23] RTE : http://www.rte-france.com/sites/default/files/bilan_electrique_2013_3.pdf

3. Limits and ways of improvement

Firstly, this work details a method to calculate the instantaneous power required for all vehicles in an agglomeration.
The method application could be improved. Indeed, the speed attribution deserves to be studied deeper in order to attribute the closest value to the real speed. Certainly it is a difficult but interesting point. Others solutions can be mentioned. One solution consists on measuring the speed of vehicle in the studied agglomeration. However, it is a heavy task which can be made by firms for thousands Euros. A second solution could have information of the average speed according to each type of roads and to urban network (urban, peri-urban and rural). That means to have a very clear definition of how to describe the urban network and another research can be consecrated to the point.
To be even more precise, it will be wise to cut each edge into many pieces and attribute a speed according to the previously developed solution. It tends to have the instantaneous speed. Higher the precision is, higher the computation time is.
These comments are also valid for the distance of acceleration.

Secondly, it would be pertinent to simulate the traffic lights, which cause stops or, at least, reduce the speed. It could be done by georeferencing most of the traffic lights of the agglomeration and transforming them into nodes. In these particular nodes, the speed should be equal to zero with a phase of deceleration during the previous edge. In the case, an edge has three speed phases. This is an interesting improvement which requires a longer research.

Thirdly, as said before, the required power for pendular travels inside a city is neglected. To avoid that, the centroid of the city should not be taken as both the point of departure and arrival of the itinerary. Indeed, it should be better to have two distinct points. For the study of pendular travels, it should be pertinent to determine the highest living places concentration as the departure point and the highest working places concentration as the arrival point. However, it requires unavailable data (for free) and causes only 22 travels no taking into account in the paper.

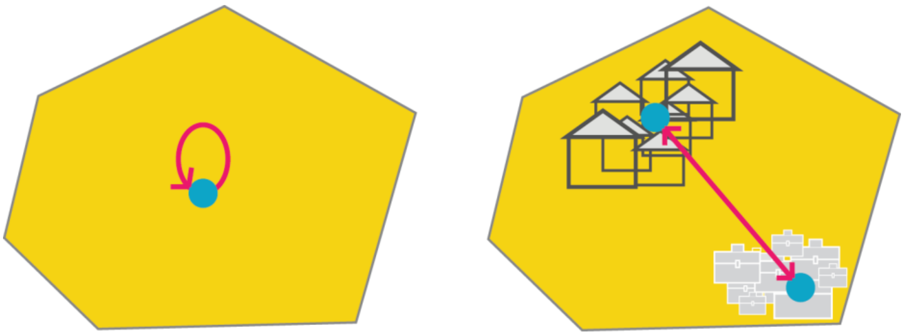


Figure 18: Departure and arrival points according two different methods

Moreover, the case study is based on data from IGN. Although IGN does its best to provide a metric precision for its data, some of them are erroneous such as the numbers of floors, the shape of buildings, and the coordinate z. A mistake on the coordinate z can create an important mistake of the grade so on the grade resistance and finally on the tractive force. It is worth noticing these mistakes are exceptions. Nevertheless, IGN stays a very reliable data source for free, that is why this database was chosen for this paper.

Finally, the data acquisition method works and fits with any agglomeration. Nevertheless a mistake still resides, probably in MatLab® programs. Obviously this mistake has to be corrected in order to obtain right results and allow their interpretations. Several urban studies could have been done such as how the acceleration influences the consumption, the reason of the higher consumption of the drivers comes from far (because of the higher distance or the higher speed?), etc.

Nowadays more and more citizens and policy pay attention to the environmental issues and campaign for living in a sustainable way. The European Union takes actions in this way and encourages an energetic transition both consuming less energy and improving its efficiency. Transportation causes a significant part of air pollution and consumption of fuel fuels. Furthermore, more and more vehicles are in circulation, its number has always increased. At that rate, pollution will never stop. This is why thermal vehicles are naturally one of the main targets for the energetic transition.

It looks as if electric vehicles can be the solution. During years, studies developed new technologies to improve the electric vehicle. Now, the use is growing and should reach 6.5% of the whole vehicles in France. Nevertheless, a difficulty of its expansion is due to the lack of infrastructures to welcome these vehicles. This work proposed a method for acquiring the load curve of the instantaneous power as a function of time and the whole consumption.

The student exercise did not succeed to generate right values of electric consumption. Nevertheless, it brings a reflection about the benefits of electric vehicles regarding the 3*20-objectives for an agglomeration, and on the other hand, it highlights the potential hazards of its generalized use.

This paper developed a method to calculate the instantaneous consumption for electric vehicles. It is based on topologic data, data which each GPS possess. Nowadays it gives the shortest cumulative distances or times path. Since the high necessity to save energy, it could be pertinent to revise these choices. Indeed, the GPS could always propose the lowest energy-consumption path to reach one point to another in order to reduce the consumption.

The huge stake is now to adapt electric network and cities to this new source of electric consumption in order to conserve all their environment benefits.

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Agence pour l'Environnement et la Maîtrise de l'Energie (ADEME):

http://www.ademe.fr/

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http://www3.ademe.fr/eco-deplacements/calculette/

Agglomération de Tour(s) Plus :

www.agglo-tours.fr/

List of figures

Appendix 1: Program « Required power » *Loading inputs and representation of the required power*

```
load('input')

%%Partie 1 : Importation du SIG et mise au bon format
t_i_j = input.t_i_j(:); % Flux entre i et j en nombre de véhicule
trajet = cell(length(t_i_j),1); % Ensemble de chemin entre i et j (cell) en
type = cell(length(t_i_j),1); % Ensemble de type de route pour chaque trajet (cell)
id(1:length(t_i_j),1)=false;
npoint=-inf;
   for i=1:length(trajet)
       tr=input.trajet(i,:);
       tr(tr==0)=[];
       trajet(i)={tr};
       if max(tr)>npoint, npoint=max(tr);end
       tr=input.type(i,:);
       tr(tr==0)=[];
       type(i)={tr};
          if isempty(tr), id(i)=true;end
      end
      trajet(id)=[];type(id)=[];t_i_j(id)=[];
      clear i id tr

      x = input.x; % Coordonnées en x des nœuds du réseau routier en m
      y = input.y; % Coordonnées en y des nœuds du réseau routier en m
      z = input.z; % Coordonnées en z des nœuds du réseau routier en m

      % Partie 2 :Paramètres des véhicules et des types de voies
      dtype = [20 30 40 50 60 70 80]; % Distance d'accélération ou de décélération
   par type de route en mètres
      mu_d = 0.2; % Marge d'erreur de la distance d'accélération par type de route
      vtype = [20 30 40 50 60 70 80]; % Vitesse par type de route en km/h
      mu_v = 0.2; % Marge d'erreur de la vitesse par type de route
      m = 1000 ; % Masse des véhicules en kg
      mu_m = 1; % Marge d'erreur en masse de la masse des véhicules en kg
      retard = 45; % Marge de retard des départs en minutes
      t_m_a_x = 60*24 ; % Durée maximale entre le 1er départ et la dernière arrivée
   minute (une journée pour être sûr)

      %% Partie 3 : Calcul de la puissance appelée, avec un appel un  programme
   « trafic »
      [ D , A , epsilon , P ] = trafic ( t_i_j , trajet , type ,... trajets,
   types de routes et flux
          x(:)' , y(:)' , z(:)' , ... coordonnées x,y,z
          dtype(:)' , mu_d , ... distance d'accélération
          vtype(:)' , mu_v , ... vitesse pratiquée dans les tronçons
          m , mu_m , ... masse du véhicule
          retard , t_m_a_x ); % intervalle de temps et durée de l'analyse

      %% Partie 4 : Représentation des résultats

      subplot(2,2,1)
      plot(1:length(D),D,'r',1:length(A),A,'g','linewidth',2)
      ylabel('Nombre')
      xlabel('Temps (minutes)')
```

```
    xlim([1 length(P(1,:))])
    axis square
    title({'Nombre de départs (en rouge) et d''arrivées (en
vert)';''},'FontSize',14,'FontWeight','bold')
    subplot(2,2,2)
    plot(1:length(D),abs(cumsum(A)-cumsum(D)),'b','linewidth',2)
    ylabel('Nombre')
    xlabel('Temps (minutes)')
    xlim([1 length(P(1,:))])
    axis square
    title({'Nombre de véhicules dans le
trafic';''},'FontSize',14,'FontWeight','bold')
    subplot(2,2,3)
    area(P','EdgeColor','none')
    ylabel('Puissance [W]')
    xlabel('Temps (minutes)')
    axis square
    title({'Courbe de charge du trafic';''},'FontSize',14,'FontWeight','bold')
    subplot(2,2,4)
    tx={['vitesse par type de route [+|-' num2str(100*mu_v) ' %] : '
num2str(round(vtype)) ' km/h'];
        ['distance d''accélération par type de route [+|-' num2str(100*mu_d) '
%] : ' num2str(round(dtype)) ' m'];
        ['Masse des véhicules [+|-' num2str(mu_m) ' kg] : ' num2str(m) ' kg'
];
        ['Durée de la période des départs : ' num2str(retard) ' minutes'];
        '';
        'Résultats :';
        ['Pic de consommation : ' num2str(round(max(sum(P))))];
        ['Consommation totale : ' num2str(round((sum(P(:)))))]};

    text(0,1,tx,'VerticalAlignment','top')
    title({'Hypothèses';''},'FontSize',14,'FontWeight','bold')
    ylim([0 1])
    axis off
```

Appendix 2: Program « trafic » Calculation of the required power for all the vehicles

```
function [ D , A , epsilon , P ] = trafic ( t_i_j , trajet , type , x , y , z ,
dtype , mu_d , vtype , mu_v , m , mu_m , retard , t_m_a_x )

[ C ] = F6(trajet,type)
;
[ T ] =
F5(C,t_i_j,trajet,type,x,y,z,dtype,mu_d,vtype,mu_v,m,mu_m,retard,t_m_a_x);

D=T.D;
A=T.A;
epsilon=T.epsilon;
P=T.P;

     function [ T ] =
F5(C,t_i_j,trajet,type,x,y,z,dtype,mu_d,vtype,mu_v,m,mu_m,retard,t_m_a_x)
        % T=\{D,A,epsilon,P\}
        if C==true
            P=zeros(length(trajet),t_m_a_x); % Puissance d'une voiture pour chacun
des t trajets sur tmax minutes
            depart=zeros(1,t_m_a_x); % Nombre de voitures qui partent
            arrivee=zeros(1,t_m_a_x); % Nombre de voitures qui arrivent
            energie=zeros(1,t_m_a_x); % Energie consommée à l'arrivée
            fWait=waitbar(0,'');
```

```
            for i=1:length(trajet)
                tj=trajet{i};
                waitbar(i/length(trajet),fWait,['Calcul des ' num2str(t_i_j(i))
' trajets entre les noeuds ' num2str(tj(1)) ' et ' num2str(tj(end))])
                Pt=zeros(t_i_j(1),t_m_a_x);
                for k=1:t_i_j(i)
                    vtypee=vtype.*(1+mu_v*(1-2*rand(size(vtype))));
                    dtypee=dtype.*(1+mu_d*(1-2*rand(size(dtype))));
                    me=m+mu_m*rand; % masse des vehicules
                    [ ti , vi , gammai , di , alphai ] = speed ( type{i} ,
vtypee , dtypee , trajet{i} , x , y , z );
                    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
                    %%Paramètres à faire varier
                    eta = 0.85; % Rendement
                    gamma = -10 + rand * (7 - (-10)); % Acceleration en m/s²
                    alphai = -0.7854 + rand(1,5) * (0.7854 - (-0.7854)); %
Roadway grade
                    me = 750 + rand * (2100 - (750)); % Vehicle mass  en kg
                    g = 9.81 + rand * (9.81 - (9.81)); % Gravitational force en
m/s²
                    f_r_l = 0.005 + rand * (0.015 - (0.005)); % Coefficient of
rolling resistance en
                    v = rand(1,5) * (60); % Vehicle speed en m/s
                    rho = 1.25 + rand * (1.25 - (1.25)); % Air density en kg/m^3
                    C_d = 0.19 + rand * (0.4 - (0.19)); % Drag coefficient
                     A_f = 1.7 + rand * (3.5 - (1.7)); % Frontal area en m²
                    [ Pi ] = car ( eta , gammai , alphai , me , 9.81 , f_r_l ,
vi , 1.25 , C_d , A_f );
                    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
                    dt=ceil(retard*rand);
                    ti=ti+dt; % chaque voiture part avec une incertitude de 20
minutes
                    Pii = interp1(ti,Pi,ceil(min(ti)):floor(max(ti))); % cette
fonction permet d'interpoler les Pi sur la base d'une minute
                    Pt(k,dt:length(Pii)+dt-1)=Pii;
                    depart(dt)=depart(dt)+1;
                    arrivee(floor(max(ti)))=arrivee(floor(max(ti)))+1;
                    energie(floor(max(ti)))=energie(floor(max(ti)))+sum(Pi)/60;
% en Wh
                end
                Pt=sum(Pt);
                P(i,:)=Pt;
            end
            id=sum(P)==0;
            P(:,id)=[];
            T=struct;
            T.P=P;
            T.D=depart;
            T.A=arrivee;
            T.epsilon=energie;
            delete(fWait)
        else
            T.P=[];
            T.D=[];
            T.A=[];
            T.epsilon=[];
        end
    end

    function [ C ] = F6(trajet,type)
        % C=condition(trajet,type)
        if iscell(trajet) && iscell(type)
            C=true;
        else
            C=false;
        end
    end
 end
```

Appendix 3: Program « car » *Calculation of the required power for each edge*

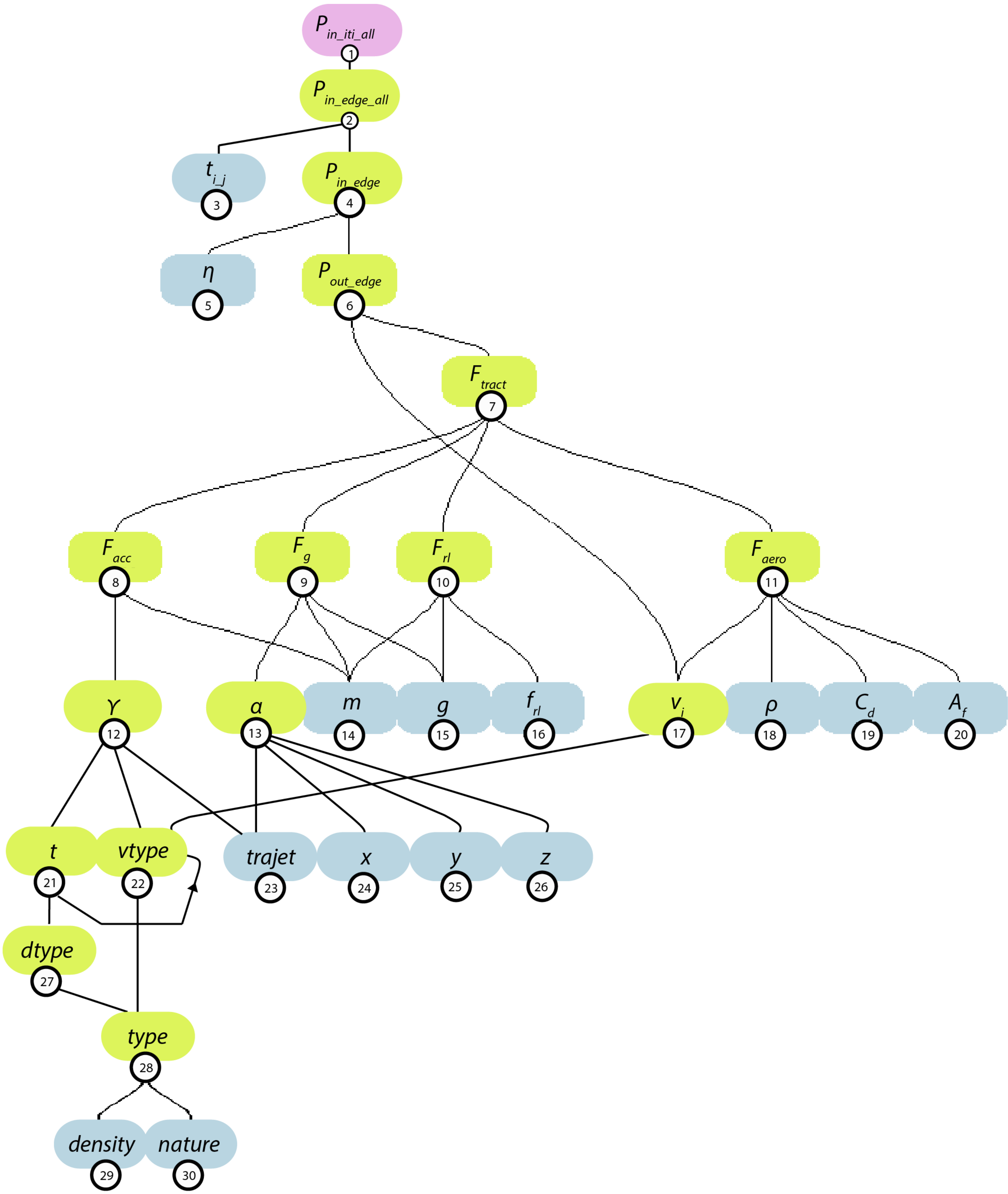
```
function [ P_i_n_a_r_e_t_e ] = car ( eta , gamma , alpha , m , g , f_r_l , v ,
rho , C_d , A_f )

 [ F_a_e_r_o ] = F1(rho,C_d,A_f,v)                    ;
 [ F_g ] = F6(m,g,alpha)                              ;
 [ F_r_l ] = F11(m,g,f_r_l)                           ;
 [ F_a_c_c ] = F17(m,gamma)                           ;
 [ F_t_r_a_c ] = F10(F_a_e_r_o,F_g,F_r_l,F_a_c_c);
 [ P_o_u_t_a_r_e_t_e ] = F14(v,F_t_r_a_c)             ;

P_i_n_a_r_e_t_e = P_o_u_t_a_r_e_t_e/eta;

function [ F_a_e_r_o ] = F1(rho,C_d,A_f,v)
% F_a_e_r_o=0.5*rho*C_d*A_f*v^2
F_a_e_r_o=0.5*rho*C_d*A_f*v.^2;
end

function [ F_g ] = F6(m,g,alpha)
% F_g= m*g*alpha
F_g= m*g*alpha;
end

function [ F_t_r_a_c ] = F10(F_a_e_r_o,F_g,F_r_l,F_a_c_c)
% F_t_r_a_c=abs(F_a_c_c-F_g-F_a_e_r_o-F_r_l)
F_t_r_a_c=F_a_c_c+F_g+F_a_e_r_o+F_r_l;
end

function [ F_r_l ] = F11(m,g,f_r_l)
% F_r_l = f_r_l*m*g
F_r_l = f_r_l*m*g;
end

function [ P_o_u_t_a_r_e_t_e ] = F14(v,F_t_r_a_c)
% P_o_u_t_a_r_e_t_e=v*F_t_r_a_c
P_o_u_t_a_r_e_t_e=v.*F_t_r_a_c;
end

function [ F_a_c_c ] = F17(m,gamma)
% F_a_c_c=m*gamma
F_a_c_c=m*gamma           ;
end

end
```

Appendix 4: Program « speed »: *Calculation of the time, grade and travelled distance of the different phases (acceleration and constant speed) for each edge*

```
function [ t , v , gamma , d , alpha ] = speed ( type , vtype , dtype , trajet ,
x , y , z )


[ la ] = F10(type,dtype)      ;
[ lt ] = F11(trajet,x,y,z)    ;
[ l ] = F8(la,lt)             ;
[ delta_d ] = F7(l,la)        ;
[ v_i ] = F9(type,vtype)      ;
[ delta_t ] = F6(delta_d,v_i);

t=[0;cumsum(delta_t)];
v=[0;v_i];
```

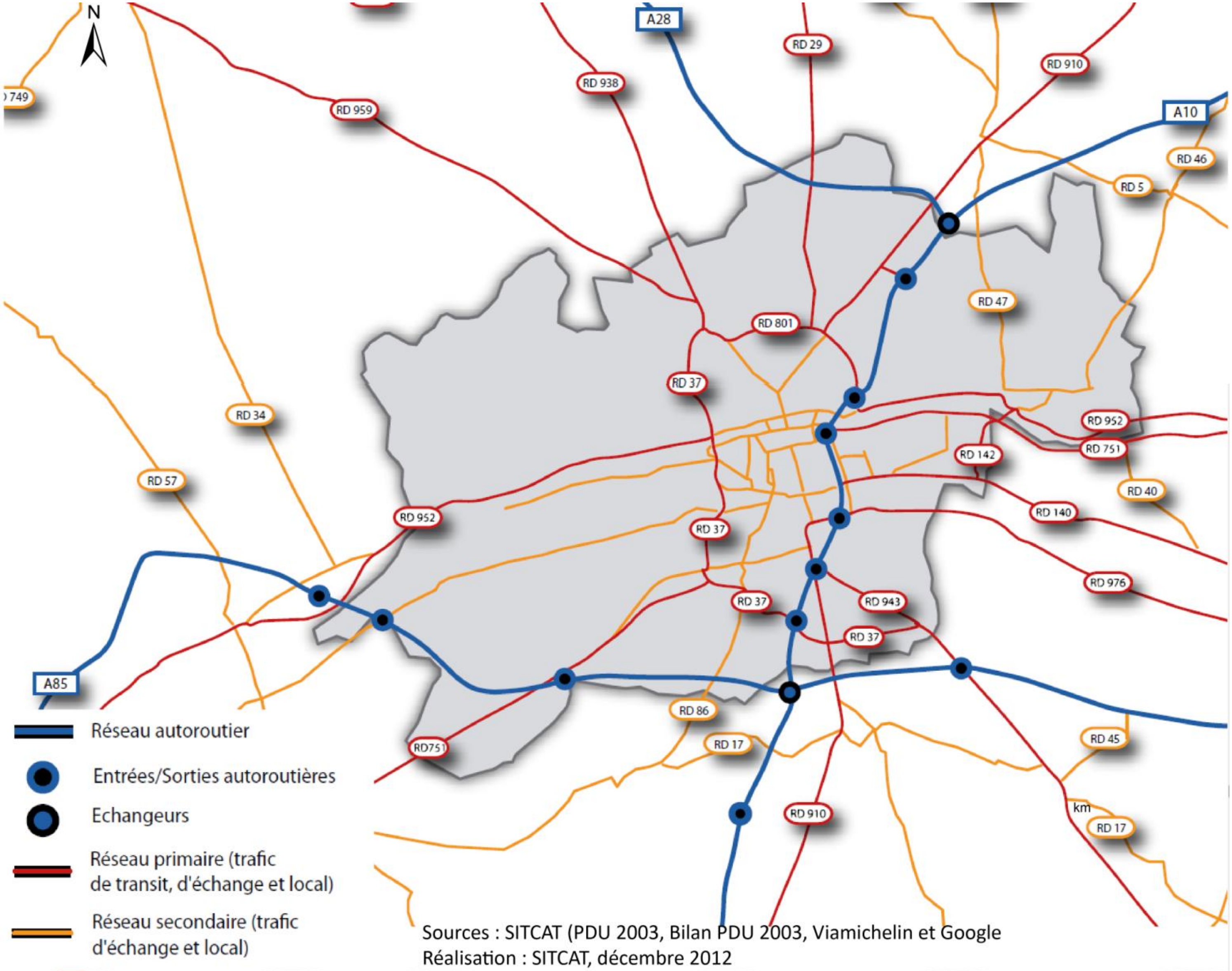
```
%dt=[0;cumsum(delta_t)];
vf=[0;v_i];
gamma=[0;diff(vf)./delta_t];
d=[0;cumsum(delta_d)];
alpha=(diff(z(trajet))./lt);
alpha(lt==0)=0;
alpha=[alpha;alpha];
alpha=[0;alpha(:)];

function [ delta_t ] = F6(delta_d,v_i)
% delta_t=(delta_d)/(60*v_i)
delta_t=delta_d./v_i/60;
end

function [ delta_d ] = F7(l,la)
% delta_d=[la;l]
delta_d=[la;l];
delta_d=delta_d(:);
end

function [ l ] = F8(la,lt)
% l=lt-la
l=lt-la;
l(l<0)=lt(l<0);
end

function [ v_i ] = F9(type,vtype)
% v_i=(vtype\{type\})/(3.6)
v_i=[vtype(type);vtype(type)];
v_i=v_i(:)*1000/3600; % en mètre seconde
end

function [ la ] = F10(type,dtype)
% la=dtype\{type\}
la=dtype(type);
end

function [ lt ] = F11(trajet,x,y,z)
% lt=(diff(x\{trajet\})^2+diff(y\{trajet\})^2+diff(z\{trajet\})^2)^{0.5}
lt=(diff(x(trajet)).^2+diff(y(trajet)).^2+diff(z(trajet)).^2).^0.5;
end

end
```

Appendix 5: Chart for calculate the whole required power in a agglomeration

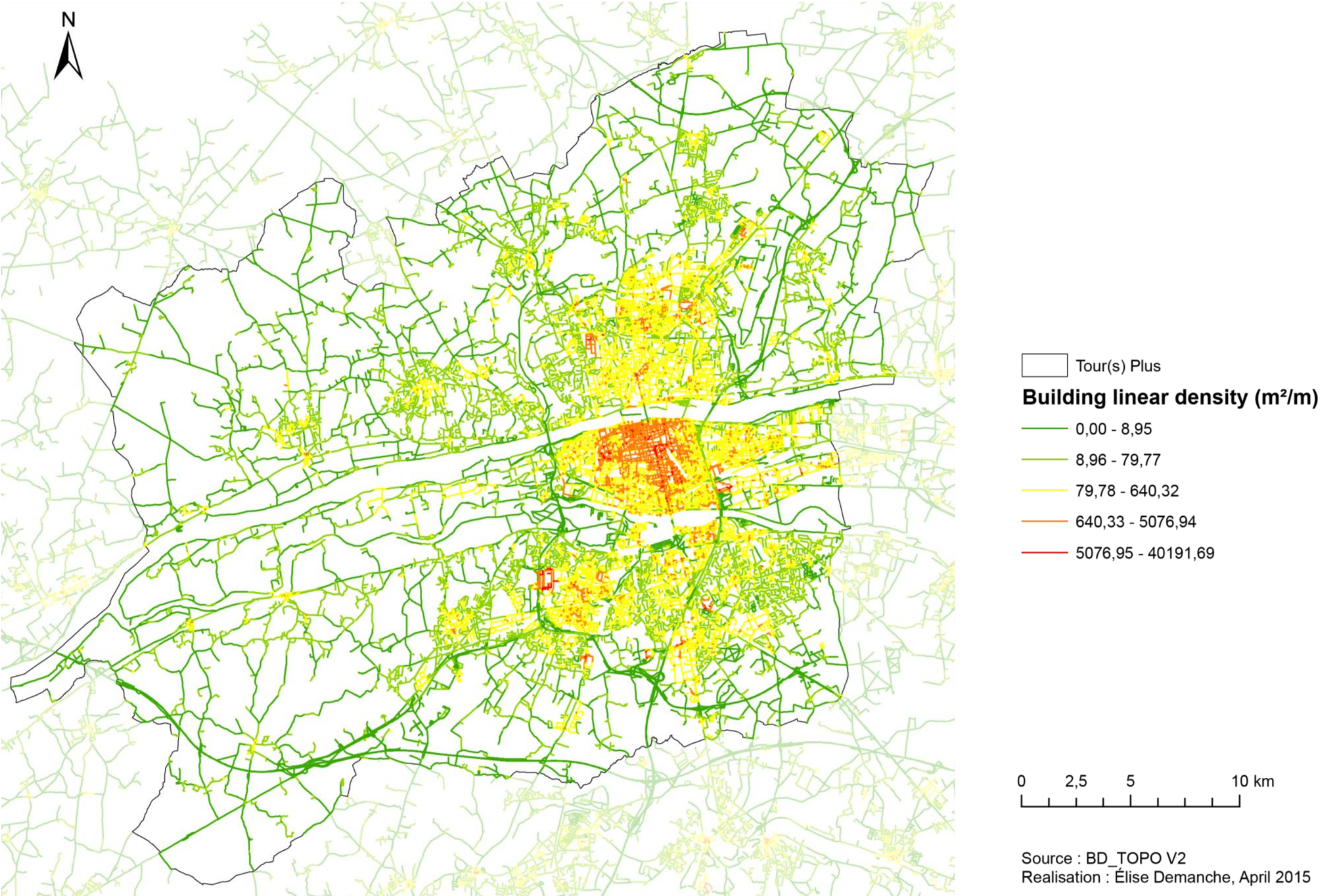


		Definition	Unit	Min - Max	Formula
1	$P_{in\_iti\_all}$	Input power required for all the vehicles of the agglomeration	Watt		$Pin\_iti\_all = \sum_{k=0}^{n} Pin\_edge\_all$
2	$P_{in\_edge\_all}$	Input power required for all the vehicles of each edge of itineraries	Watt		$P_{in\_edge\_all} = P_{in\_edge} \cdot t_{i\_j}$
3	t_{i_j}	Matrix of flows between each city of the agglomeration	Number of vehicles	0 – 15 273	--
4	P_{in_edge}	Input power for an edge: *electrical power supplied to an electric motor*	Watt		$P_{in\_edge} = P_{out} / \eta$
5	η	Electric motor efficiency	--	0 – 1	--
6	P_{out_edge}	Output power for an edge: *mechanical power given out by an electrical motor*	Watt		$P_{out\_edge} = F_{tract} \cdot v(t)$
7	F_{tract}	Tractive force	Newton		$F_{tract} = F_{acc} + F_{aero} + F_g + F_{rl}$
8	F_{acc}	Acceleration force	Newton		$F_{acc} = m.\Upsilon(t)$
9	F_g	Hill climbing force	Newton		$F_g = m \cdot g \cdot \sin(\alpha(t))$
10	F_{rl}	Rolling resistance force	Newton		$F_{rl} = f_{rl} \cdot m \cdot g$
11	F_{aero}	Aerodynamic drag	Newton		$F_{aero} = ½ \cdot \rho \cdot C_d \cdot A_f \cdot v(t)^2$
12	Υ	Vehicle acceleration	m/s^2		$\Upsilon = (\Delta vtype)/ t$
13	α	Grade	°		$\alpha = \sin\left(\frac{\Delta z(trajet)}{\sqrt{(\Delta x(trajet))^2 + (\Delta y(trajet))^2 + (\Delta z(trajet))^2}}\right)$
14	m	Vehicle mass	kg	750 – 2 100	--
15	g	Gravity acceleration	m/s^2	9.81	--
16	f_{rl}	Rolling resistance constant	--	0.005 – 0.015	--
17	v_i	Speed of the vehicle	m/s		$v_i = vtype \cdot (1000/3600)$
18	ρ	Air density	kg/m^3	1.255	--
19	C_d	Drag coefficient	--	0.19 – 0.5	--
20	A_f	Frontal surface	m^2	1.5 -	--
21	*t*	Time during the acceleration phase			t = dtype / vtype
22	vtype	Speed according to the type	Km/h	20 - 130	vtype (type)
23	trajet	Succession of the number of nodes	--	1 – 5910	--
24	x	Coordinate x of a node	--	507 191 - 530 835	--
25	y	Coordinate y of a node	--	6 691 221 - 6 710 819	--
26	z	Coordinate z of a node	--	42 – 116	--
27	dtype	Acceleration distance according to the type	meter	1.4 - 183	dtype (type)
28	type	Type of the edge	--	1 - 7	type (density, nature)
29	densit	Building linear density	m/m^2	0 -	--
30	nature	Nature of the edge	--		--

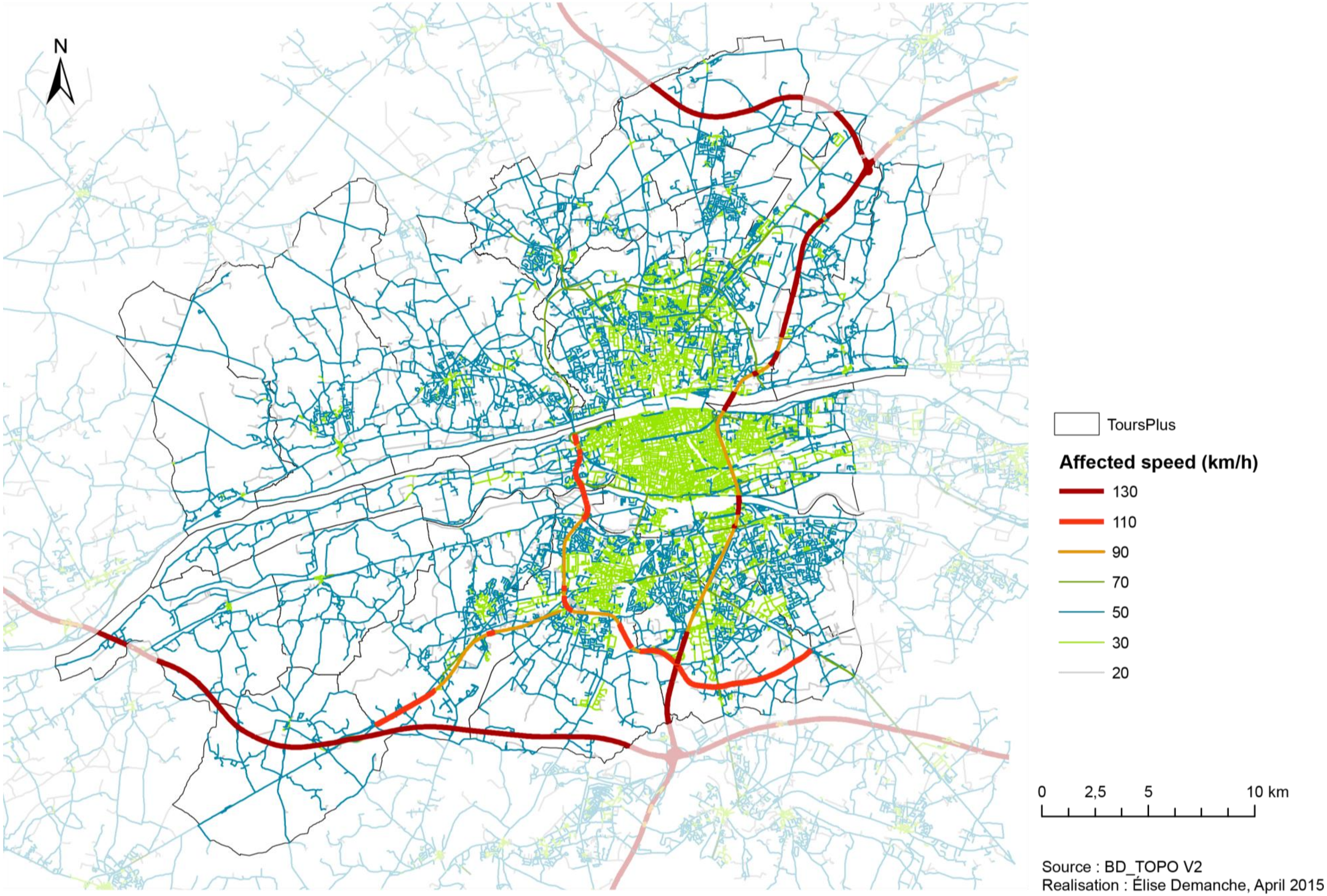
Appendix 6: Organization of the roadway network in Tour(s) Plus



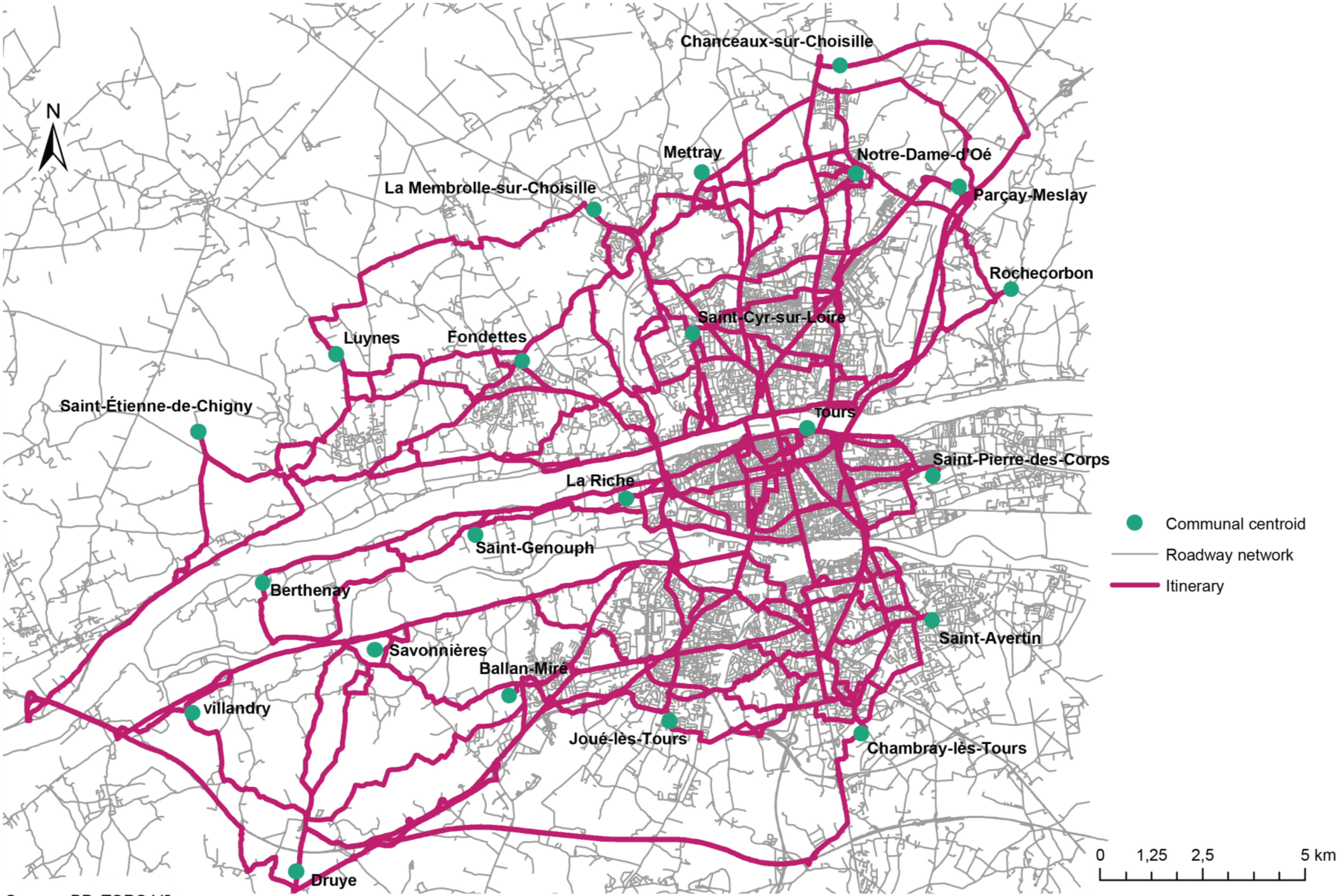
Appendix 7: Building linear density in Tour(s) Plus



Appendix 8: Affected speed on the edge of Tour(s) Plus

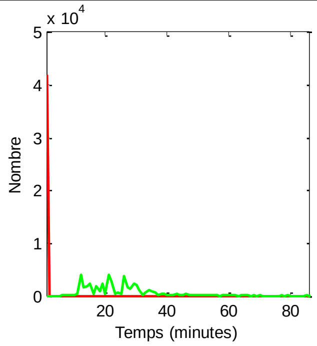


Appendix 9: Itineraries between each city in Tour(s) Plus

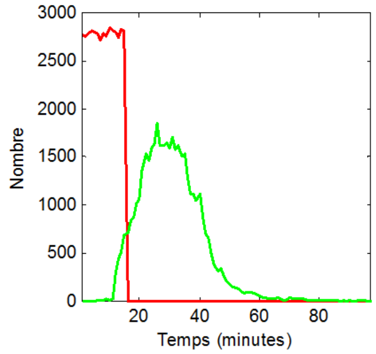


Source : BD_TOPO V2
Realisation : Élise Demanche, april 2015

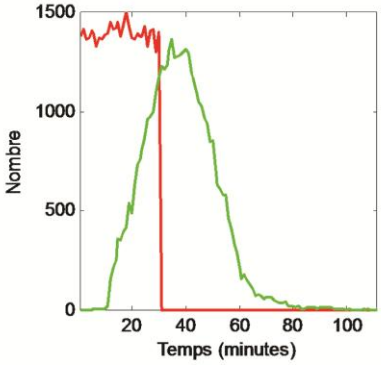
Appendix 10: Number of departures (in red) and number of arrivals (in green) according to departures-interval



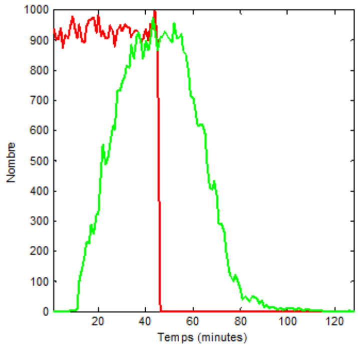
0 minutes



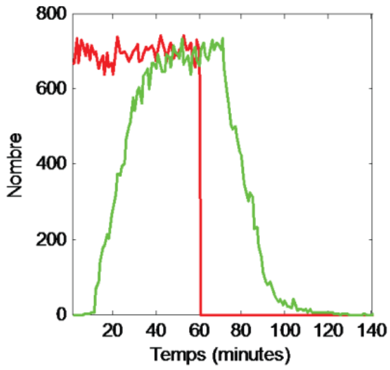
15 minutes



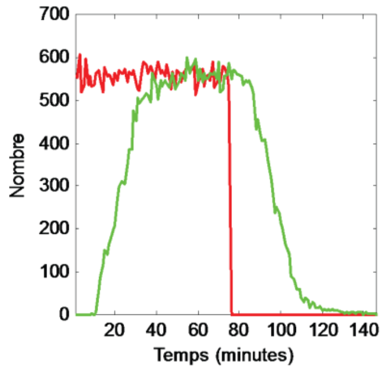
30 minutes



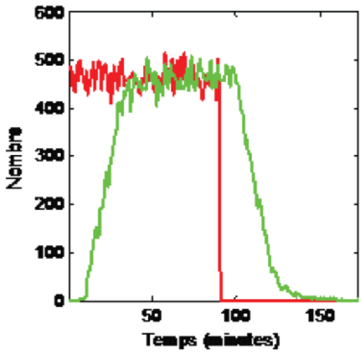
45 minutes



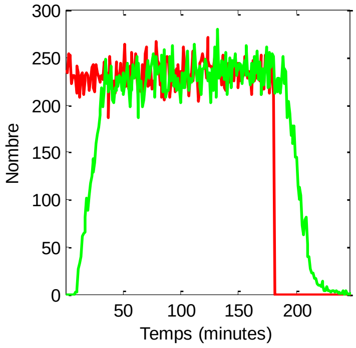
60 minutes



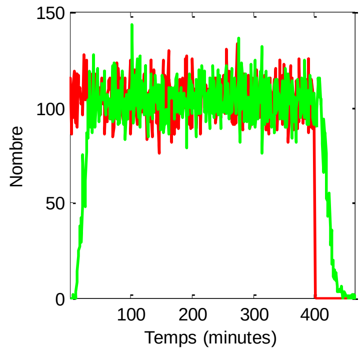
75 minutes



90 minutes



180 minutes



400 minutes

Appendix 11: Proportion of edges according to their type

Type	Speed (km/h)	Number of edges	Percentage
1	130	635	1
2	90	1 093	2
3	110	834	1
4	70	2 708	4
5	50	35 428	49
6	30	30 743	43
7	20	661	1

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DA 5
2014-2015

Establishment of the electric demand load curve required for the individual vehicles in an agglomeration, supposing all-electric vehicles

First electric vehicles date from the middle of the 19^{th} century but lost quickly all interest with the apparition of the thermal vehicles. In the middle of the 20^{th} century, thermal vehicles were at their zenith. Nowadays knowledge, technologies and political commitment for a sustainable development increasing, the use of electric vehicles is on the rise.

On one hand, scientific researches from decades have allowed to improve the efficiency of batteries even if it stays quite limited. This is why many researches focus on it. On the other hand, researches treating the electric consumption are rarer. Some studies establish link between vehicles parameters and consumption and succeed to obtain an average consumption based on data from test travels. However, knowing the accurate consumption of electric vehicles in an agglomeration intends to set up a pertinent network of charging points.

This paper proposes a method to acquire the load curve (instantaneous electric power required as a function of time) and the total consumption required by electric vehicles according to the roadway network of the agglomeration. In a long run, each agglomeration could use it to know its own electric consumption due to electric vehicles and realize an optimize network of charging points. This method is put into practice for the whole pendular travels of the Tour(s) Plus, simulating that all the individual vehicles are electric.

Keywords: Electric vehicles – Electric power – Electric consumption - Load curve -