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**Projet de Fin d'Etudes**

## **Modelling traffic congestion:**

*Relationships between urban density and traffic congestion  
Case-study of Tours' agglomeration*



**COUVRET Maxime**

**2013-2014**

**Directeur de recherche**  
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**Auteur: COUVRET Maxime**

**Directeur de recherche: MAIZIA Mindjid**

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## **Avertissement:**

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## Formation par la recherche et projet de fin d'étude en génie de l'aménagement:

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.**

## Remerciements:

Ce Projet de Fin d'Etudes, bien que réalisé seul, n'aurait pu aboutir sans l'aide de différents intervenants. Je tiens à remercier :

- Monsieur Mindjid Maïzia, Professeur des Universités en 'Aménagement de l'espace et Urbanisme', directeur de ce projet de recherche, pour son soutien, sa disponibilité et ses conseils pendant tout le long de l'exercice.
- Monsieur Pascal Riffonneau, Responsable du Service 'Infrastructures et Grands Projets' à la Communauté d'Agglomération Tour(s)plus, pour m'avoir fourni les données de comptage de mon cas d'étude.
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# Introduction to the phenomenon of traffic congestion:

## *Automobile cities and the notion of auto-dependence:*

Nowadays, automobile dependence is a crucial issue of urban transport in urban areas. All over the world, the auto-dependent cities manifest problems such as loss of walkability, viable public transit, job access, etc. [Kenworthy<sup>1</sup>, Laube<sup>2</sup>, 1996]. This idea of *auto-dependence* could be defined as better accessibility for motorists than the accessibility for non-motorists (pedestrians, riders, transit-users, etc...) [Dupuy<sup>3</sup>, 2002]. Applied to a city, it means that the car is the most practical way to travel.

Traffic congestion, a consequence of auto-dependence, is today a broad field of transportation research [Downs<sup>4</sup>, 2004]. There are many different ways to define the principle of traffic congestion. It involves many different factors such as queuing, slower speeds, increased travel times which impose costs on the economy and impact the commuters as well as the non-vehicular road-space users [European Conference of Ministers of Transport, 2007]. In this paper traffic congestion is considered as *the moment when the density of traffic exceeds the capacity of the road, so when the speeds of the vehicles are reduced compared to the speed limits.*

## *Management of traffic congestion through the years:*

Transportation planners and engineers have been attempting for more than 80 years to forecast traffic flow in order to avoid traffic congestion as far as possible. Since the early 1980s and the development of the ITS (Intelligent Transportation Systems), advanced traffic management systems play an important role in managing congested traffic [E. Vlahogianni<sup>5</sup> and al.]. They use traffic-surveillance-related information from a variety of sensors deployed across roadway networks. The data is then used in algorithms, frequently updated and more accurate, to estimate some fundamental parameters of congestion such as vehicle speed, vehicle length, time headway, number of kilometres per capita [Singh and Li<sup>6</sup>, 2012].

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<sup>1</sup> **Jeff Kenworthy** is an Associate Professor in Sustainable Settlements at Murdoch University, Western Australia.

<sup>2</sup> **Felix Laube** is an Associate Professor in Sustainable Settlements at Murdoch University, Western Australia.

<sup>3</sup> **Gabriel Dupuy** is a French Professor known for his works on transport networks related to urban planning.

<sup>4</sup> **Anthony Downs** is an American economist specializing in public policy and public administration.

<sup>5</sup> **Eleni Vlahogianni** is a researcher from the N.T. University of Athens specializing in traffic operations.

<sup>6</sup> **Karandeep Singha, Baibing Li** are members of the School of Business&Economics in Loughborough University.

## Aims of this report:

### *Project research in the field of traffic congestion:*

This project is a piece of student work realised to find out how research projects are led today. The choice of the transportation field is personal and the research is guided by a specialist of the field.

Congestion is today a sensitive subject and appears as a good subject to complete the training program. Indeed, the subject involves several sciences such as urban planning, transportation, mathematics and informatics.

### *Zoom on the interaction between congestion and urban density:*

The work carried out in this article deals with the study of traffic congestion through one of its main parameters, vehicle speed, and its relation to urban density. To achieve this goal, the next section introduces a state of the art illustrated by specific literature and a resulting assumption made from the current statements and debates.

In order to check this assumption, a traffic model is extracted from the literature and implemented for a case-study: the Tours' agglomeration, Tour(s)Plus<sup>7</sup>, France.

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<sup>7</sup> [www.agglo-tours.fr/](http://www.agglo-tours.fr/)

# State of the art:

## Recent researches of a relationship between traffic and urban density:

In the 90s, a strong interaction between *urban density* and congestion is hypothesized by the scientific level. *Urban density* is defined in a spatial sense as: “a number of units in a given area” [Boyko<sup>8</sup> and Cooper<sup>9</sup>, 2011]. Indeed, in the 90s, two Australian researchers Kenworthy and Newman<sup>10</sup> advocated the theory that a higher urban density (in terms of capita/surface) leads to a lower fuel consumption and car-use. Due to tables and graphs showing the values of densities in several cities, the authors ensure that high-density towns substantially reduce traffic and travel distances and consequently prevent the speed reductions of the motorised vehicles on the roads. This theory remains strong today and is still observed all around the world.

Kenworthy and Newman determine the relationship between the urban density and the annual car kilometres per capita or the annual transit trips per capita (considering that the values of  $R^2$  are acceptable). The following schemes allow them to advocate that a higher urban density decreases traffic congestion; here is the case of the biggest cities in the world.

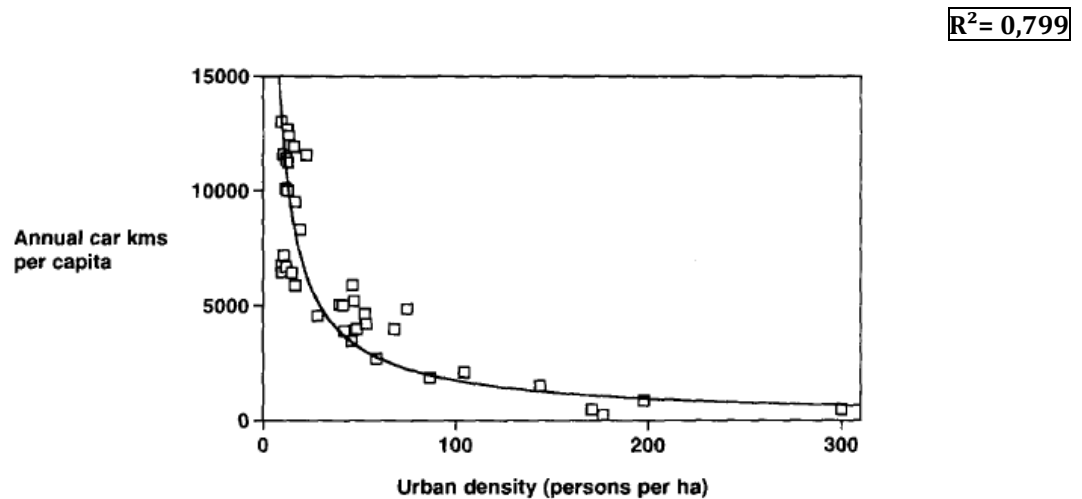


Figure 1: Car kilometres per capita correlated to urban density

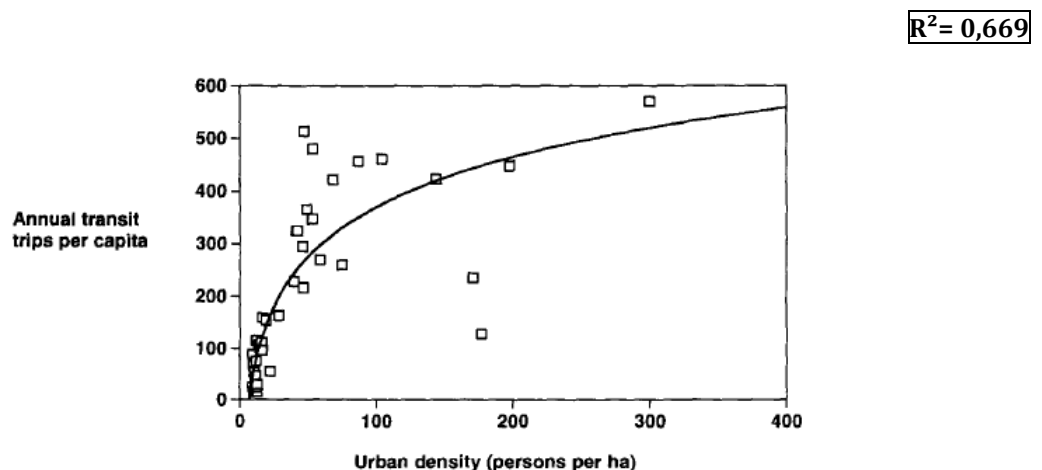


Figure 2: Annual transit trips per capita correlated to urban density

<sup>8</sup> Christopher Bokyo is Doctor of Design Management at the University of Lancaster.

<sup>9</sup> Rachel Cooper is Doctor of Design Management at the University of Lancaster.

<sup>10</sup> Peter Newman is an environmental scientist, author and educator.

## *Integration of the notion of density in planning projects:*

Very quickly after the publishing of Kenworthy's work, the principle of *density* has become associated with the idea of modern development. Particularly in Europe, cities integrate urban density in planning documents as a way to tackle and reduce energy consumption of transport but also of the dwellings and several other ideas related to the economy or social aspects.

In the case of traffic congestion, the notion of urban density is immediately seen by the politicians as way to reduce it. However, even though Kenworthy et al showed that in dense cities, annual transit trips increase, no work clearly proves it.

Today, with the concept of sustainable cities, urban density is still considered as promoting environmental and social advantages and it appears difficult to be opposed [Nessi<sup>11</sup>, 2010]. However, at the scientific level, the debate still exists to define whether urban density is really a solution to tackle congestion.

## *How are congestion and density related today? What are the criticisms?*

There are plenty of criticisms on the interaction between urban density and transportation. Some call into question the principle of density itself and by this fact the relationship between density and congestion whereas others question the way to carry out transportation studies.

Density is mostly criticised by authors as a necessary condition in urban planning. Williams<sup>12</sup> (2000) asks if sustainable development is really linked to the densification of cities. Fouchier<sup>13</sup> (2010) advocates that urban density is not the right notion and describes the principle of *urban intensity* which is a better use of the urban areas through a greater number of activities and people to use it. These two researchers show that the question of density is more complex than it seems. Another question is often raised: if the relationship is admitted, which is the most relevant scale to think the densification? The neighbourhood? The city? The metropolitan area? Kenworthy did not precise this point in his work.

Some people such as Bouteille<sup>14</sup> (2001), a property developer, also say that 30 years of suburban development did not create the obstacles denounced earlier. Concerning transportation, time spent in vehicles (white line on the following graph) is not changing even if the distances do (black line on the following graph). Congestion is, to Bouteille, not correlated at all with density.

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<sup>11</sup> **Helene Nessi** is a French professor specialized in the interactions between networks, mobility and planning.

<sup>12</sup> **Katie Williams** is an English professor interested in urban design and sustainable behaviours.

<sup>13</sup> **Vincent Fouchier** is a French professor of the IAU who works on the notions of urban density and intensity.

<sup>14</sup> **Arnaud Bouteille** is member of the editorial board of *Etudes Foncières*.

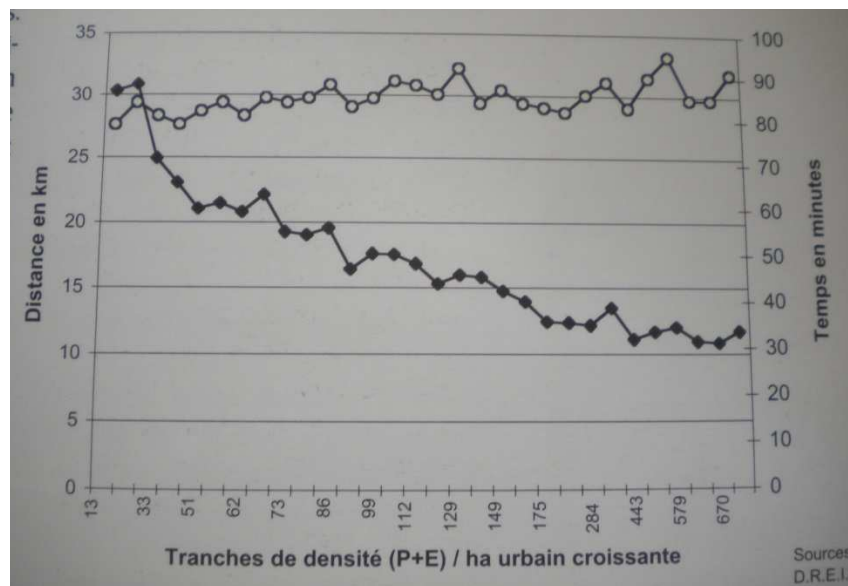


Figure 3: Transportation in time and distance related to urban density

Furthermore, densifying urban areas is also seen as “only worsening traffic congestion and air pollution” [Cox<sup>15</sup>, 2000]. Moreover, standing for density is something difficult also on a political level, this quotation from an article summarised the political debate well:

*“The anti-sprawl movement wants to replace a substantial share of automobile use with transit use. But despite expensive attempts in the United States and internationally, no urban area has accomplished this. Materially reducing car use would require more than Portland, Ore.-style urban-growth boundaries. It would require dismantling suburbs and forcing residents into a small, dense core. This is a platform no politician is likely to propose.”<sup>16</sup>*

Other authors also point out that current transportation studies are not accurate enough to determine if density and congestion are really correlated. Nessi advocates that only a few socio-economic variables are taken in account, for example transportation studies never have a look at social categories. Furthermore, studies are always based on week trips but never during the week end [Orfeuill<sup>17</sup>, 1999]. The same author also shows that, during the week ends, people living in the centres drive their car more than the people living in the suburbs.

Current debates at the political or scientific level are still very conflictual today on this subject of congestion and urban density. It is maybe the degree of importance in this relationship which is the most contested. To Cervero<sup>18</sup> and Kockelman<sup>19</sup> (1997), urban density does not impact mobility much. It is more a set of factors that follow the density such as the presence of transit systems, pedestrian areas and places of convergence. This statement illustrates the range of visions well.

<sup>15</sup> **Wendell Cox** is a leading proponent of the use of the private car over rail projects. He is the principal and sole owner of Wendell Cox Consultancy, an international public policy firm and specializes in urban policy, transport and demographics.

<sup>16</sup> [http://articles.philly.com/2005-09-07/news/25428950\\_1\\_urban-sprawl-urban-growth-job-growth](http://articles.philly.com/2005-09-07/news/25428950_1_urban-sprawl-urban-growth-job-growth)

<sup>17</sup> **Jean-Pierre Orfeuill** is a French professor specializing in urban mobility.

<sup>18</sup> **Robert Cervero** is an American professor of city & regional planning.

<sup>19</sup> **Kara Kockelman** is a professor of Transportation Engineering in the University of Texas.

## Checking the assumption of urban compactness proponents:

To check the findings of Kenworthy and Newman, it is necessary to find a connection between the two key components which are the urban density, in terms of capita/surface, and the traffic congestion. The graphs of the previous section showed that higher density increases the number of transit trips and reduces the annual car kilometres per capita. It can be advocated that urban density decreases traffic congestion but how important is it if it is true?

Following this process, the aim of this section is now to make a personal idea on the debate by determining the relationship between urban density in capita/surface and a chosen parameter of congestion: the time spent by the commuters in their cars. According to Kenworthy, people should spend less time in their cars for equivalent trips in high density cities compared to the people in low density cities.

To achieve this goal, two cases are studied: first, the European Capitals and then the French Major Cities. The urban density can be, in this case, quantified by *the number of people living in a given city in capita/km<sup>2</sup>*.

### ▪ Case of the European capitals :

This graph highlights the relationship between the urban density of the European capitals and the average hours lost in traffic per capita per year and per country.

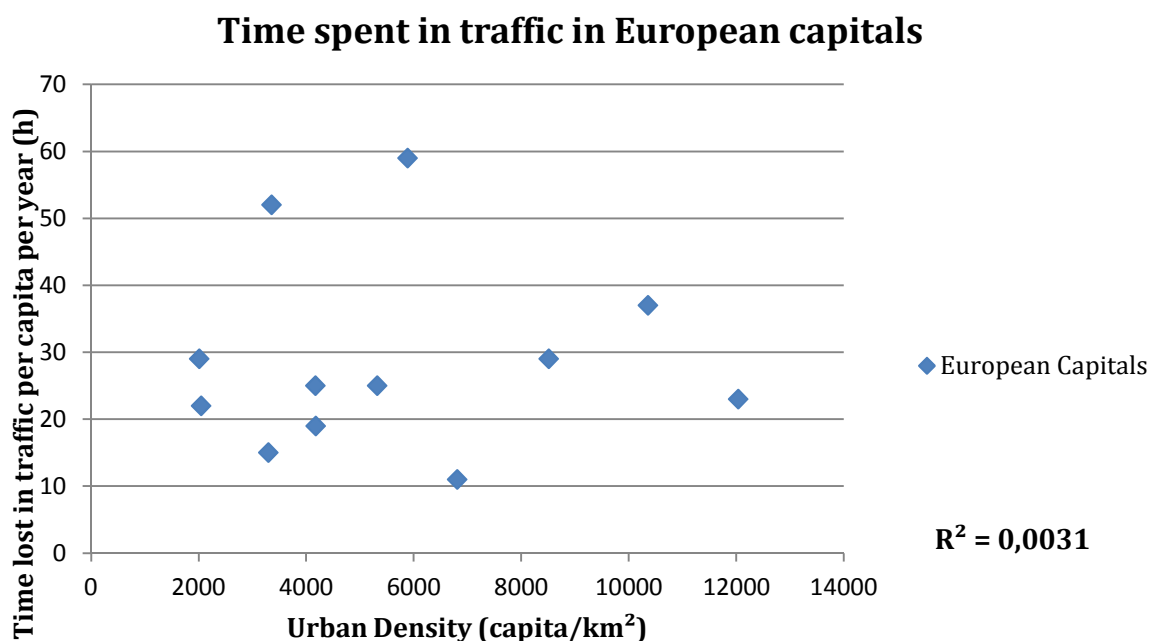


Figure 4: Time spent in traffic in the European cities

Carried out by M. Couvret

The value of  $R^2$  is close to 0. The time spent in the traffic does not seem to be related to the urban density, so the hypothesis is not true at the scale of European capitals. The next example shows the case of French cities.

- **Case of the French cities :**

This second graph highlights the relationship between the urban density of French cities and the average time minutes to go to work per capita.

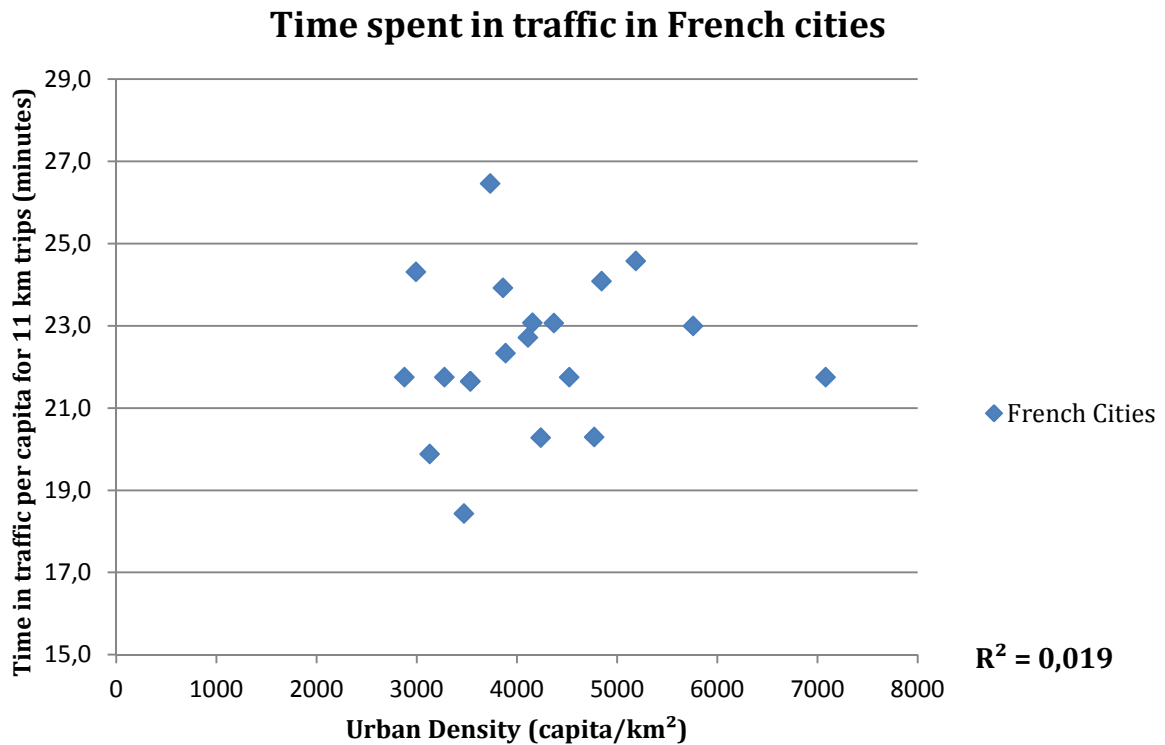


Figure 5: Time spent in traffic in French Cities

Carried out by M. Couvret

The value of  $R^2$  is close to 0 as well. The time spent in traffic is again not linked to the urban density. The hypothesis is not true at the scale of the main French cities.

The two case studies show that a higher urban density in terms of capita/surface in urbanised European areas contributing to the decreasing of the traffic congestion is not always true. Indeed, the link between the two factors does not exist in these cases. This work allows proving that Newman and Kenworthy's idea that a higher urban density (in capita/surface) decreases the traffic congestion is questionable and may be not always relevant.

### *Formulation of a resulting assumption:*

After showing the debates around congestion and density and thanks to the results of the previous section, the idea is to start from a new assumption. This resulting assumption will be the guideline for this paper and will join the current debate around density and congestion. The choice is made from Newman and Kenworthy's reversible hypothesis: ***"In the general case urban density, in terms of workspace/surf, is not contributing to the reduction of the traffic congestion"***. The idea is to check a new path, because there are a few studies currently that take the same approach. The first step is to validate or not the assumption and then see if the assertion of Kenworthy is still relevant on specific scales for densification. Here, density is considered as a factor that enhances congestion by reducing the speed of the vehicles. Furthermore, a new definition of urban density is proposed. This definition is made according to Bokyo's definition: *'The densities are stated due to parcels, side-to-side distances between buildings, and floor area ratios and plot ratios'*. The notion is defined as floor areas, or workspaces, per surface.

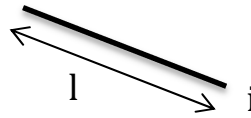
# Construction of a model from road engineering:

## Definitions and variables:

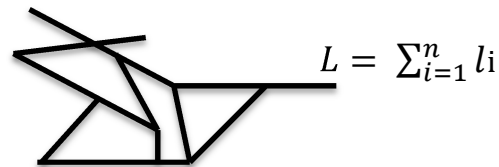
An answer to the assumption is through an accurate definition of the different variables.

- **Road entities:**

Link: a link  $i$  is the part of a road of a length  $l$  included between two crossroad intersections.



Network: a network is constituted by the whole links.



[Cohen<sup>20</sup>, 1993]

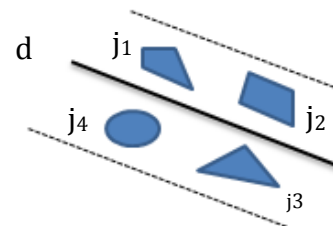
- **Linear density:**

Density can be calculated in different ways. In a first step, the idea is to calculate densities of each link which is significant in terms of urban density (in workspace per surface). Maybe a determination between these linear densities and traffic congestion is possible and could validate the assumption.

*How to explain the choice of a linear density that only takes into account the buildings along the links?*

The GART<sup>21</sup> (Groupement des Autorités Responsables de Transport – Group of Authorities Responsible for Transportation) introduces the notion of “contrat d’axes” that aims to build the road corridors denser in order to reduce the land consumption for housing and activities and improve the use of transit. Here, the choice is made to calculate the linear densities along the links in this sense. Linear density only takes into account the buildings that surround the road. This does not seem representative because the density around a link is not obviously related to its traffic flow. However, it is interesting to check if there is a relationship between congestion and linear density.

Every link can now be described due to its *linear density*  $d_i$  and this density is calculated with the heights of the buildings  $j_n$ , their number of floors and the work space.



<sup>20</sup> **Simon Cohen** is director of research in the field of traffic engineering.

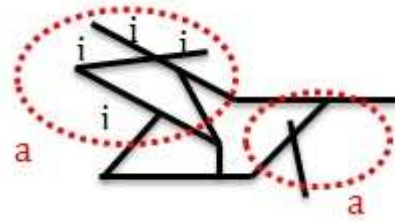
<sup>21</sup> [www.gart.org/](http://www.gart.org/)

- **Areal density:**

After working on linear densities, the idea is to calculate the general case with the areal densities, the main work of this paper. In this case, urban areas are created.

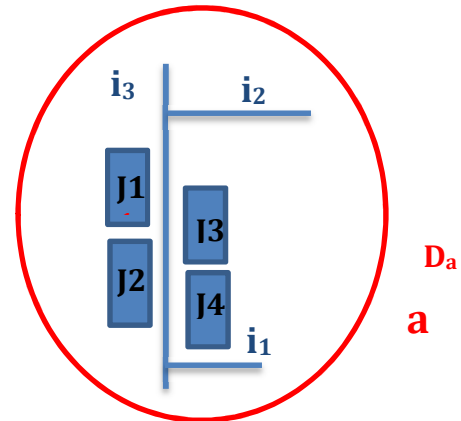
**Urban Area:** an urban area is a space of the city characterised by its urban density, its number of links and the speeds of the vehicles on the links. All the urban areas **a** compose the study area **A**.

$$A = \sum_{j=1}^n a(j)$$



The Urban Density **D** of an urban area **a** is:

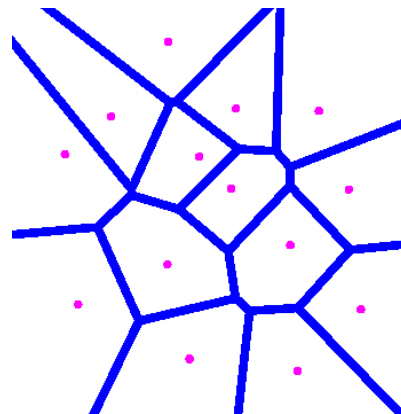
$$D(a) = \frac{Surf(Workspace)}{Surf(Urban Area)}$$



*Cutting the study area with administrative boundaries?*

Cities are usually cut-out according to an administrative system such as the districts, “arrondissements” in Paris, quarters, etc... In transportation, this cutting is not adapted because there is no relationship between administrative boundaries and the road network.

The solution proposed here is to cut-out the studied area, using the Voronoi diagrams that could be defined by the following definition: “There is a space on whom some objects, called sites, exert a certain influence. Each point of the space belongs to the region of that site whose influence is strongest» [Klein<sup>22</sup> and al., 2009].



The advantage of this diagram is the possibility of changing the scale and finding the one which is the most adapted to get the best coefficient of determination **R<sup>2</sup>** between congestion and urban density (in terms of workspace/surface).

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<sup>22</sup> **Rolf Klein** is a Professor of Computer Science of the University of Bonn, Germany.

## Speed indicator and Congestion indicator:

At a macroscopic scale, the traffic flow is assimilated to a fluid and allows us to use expressions from the hydrodynamic models [Lighthill and Witham<sup>23</sup>, 1955]. Here the model comes from the US Department of Transportation<sup>24</sup> and was created in the 1930s by Greenshield. This version of the model is focused on the speed. Indeed, comparing the different speeds on different links is a way to analyse where the congestion appears in a city at a given time.

The speed is described by the following expression:

$$v(i) = f(t, i, a)$$

With  $t$ : time,  $i$ : number of the link,  $a$ : number of the urban area.

$v(i)$  is called the **Speed indicator**.

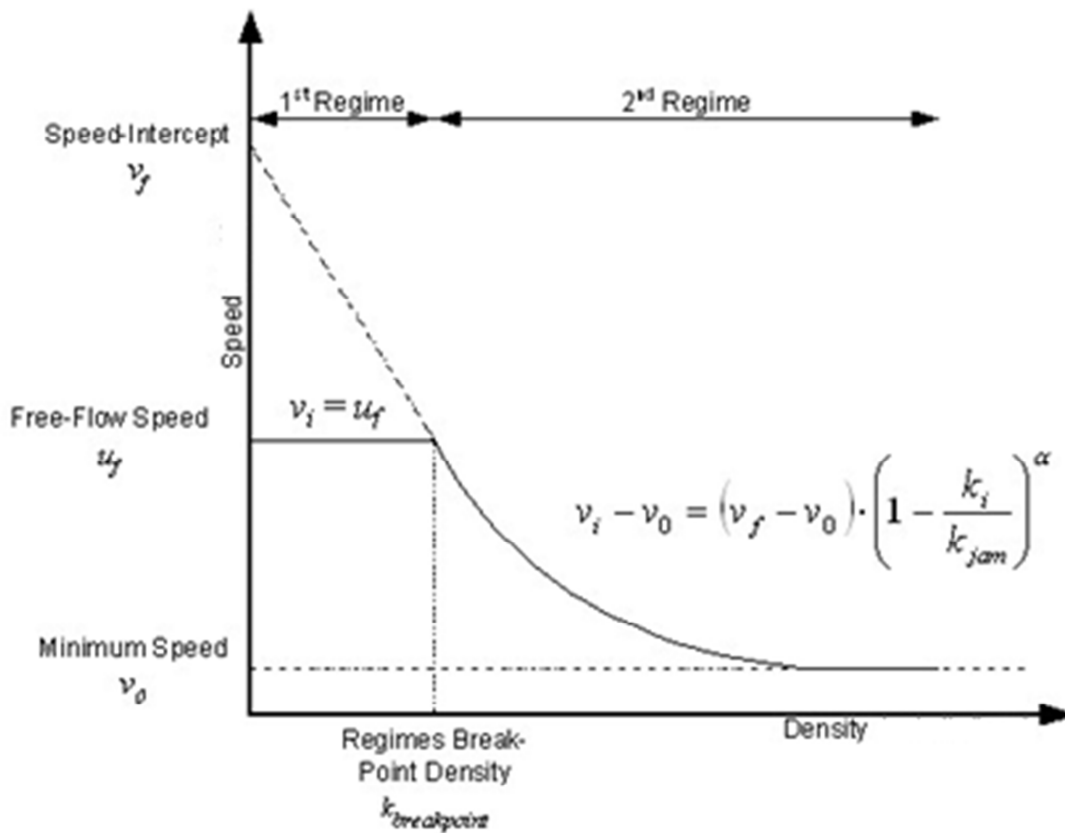


Figure 6: Model for traffic propagation

US Department of Transportation

In this work,  $\alpha = 1$  and  $v_0 = 0$  for a simplification of the formula.

The relation implements several variables described below. Each lane on a link is considered independently of the other. This postulate allows us to obtain standard values of a one-lane link and multiply the values for multi-lanes links.

<sup>23</sup> Researchers who suggested a relation assuming that traffic flow is always in equilibrium with density.

<sup>24</sup> [www.dot.gov/](http://www.dot.gov/)

**Density k:** number of vehicles **n** on a particular link **i** at a particular time **t**. In veh/km.

$$k = f(t, n, i)$$

The maximum value for a lane at capacity is **65 veh/km**. This value is extracted from the Alliance for International Conflict Prevention and Resolution (AICPR)<sup>25</sup> and is equivalent to a situation of congestion. For example, a 3-lane link has a density of  $3*65=195$  veh/km.

**Flow q:** number of vehicles **n** crossing a point of a road **i** during a given  $\Delta t$ . In veh/h.

$$q = f(t, n, i)$$

The considered value is **2200 veh/h**. This theoretical value is from the AICPR data and the following formula allows us to calculate the practical values of traffic flow:

$$q = 2200 * C(c) * C(hgv) * C(w)$$

$C(c)$ , coefficient of correlation, equals 0.75 because the drivers are used to the roads and the data collected during a working day.

$C(hgv)$ , coefficient of heavy goods vehicles, equals to 0.98 or 1.

- 1 is attributed to the links considered without heavy good transit.
- 0.98 for the links considered with heavy good transit at a low percentage and for a flat network.

$C(w)$ , coefficient linked to the width of the roads, from 0,78 to 1 following the type of the road.

For a given area **a** (see section 'Areal densities'), the expected outcomes are different values of the speed **v** for the different links **i** that compose the area. The different **v<sub>i</sub>** create a statistical distribution. To analyse the tendency, several parameters exist such as the mean, the mode, the median, the range, the standard deviation, etc...

In the case of this project, the parameter carried is the weighted mean described by the equation below:

$$\bar{x} = \frac{w_1x_1 + w_2x_2 + \dots + w_nx_n}{w_1 + w_2 + \dots + w_n} \quad \text{where the } \mathbf{x} \text{ are the data and } \mathbf{w} \text{ the non-negative weights.}$$

$$\text{In terms of speed: } v(t, a) = \frac{v_1 * l_1 + v_2 * l_2 + \dots + v_n * l_n}{L}$$

$$\text{with } L = \Sigma(l_1 \dots l_n)$$

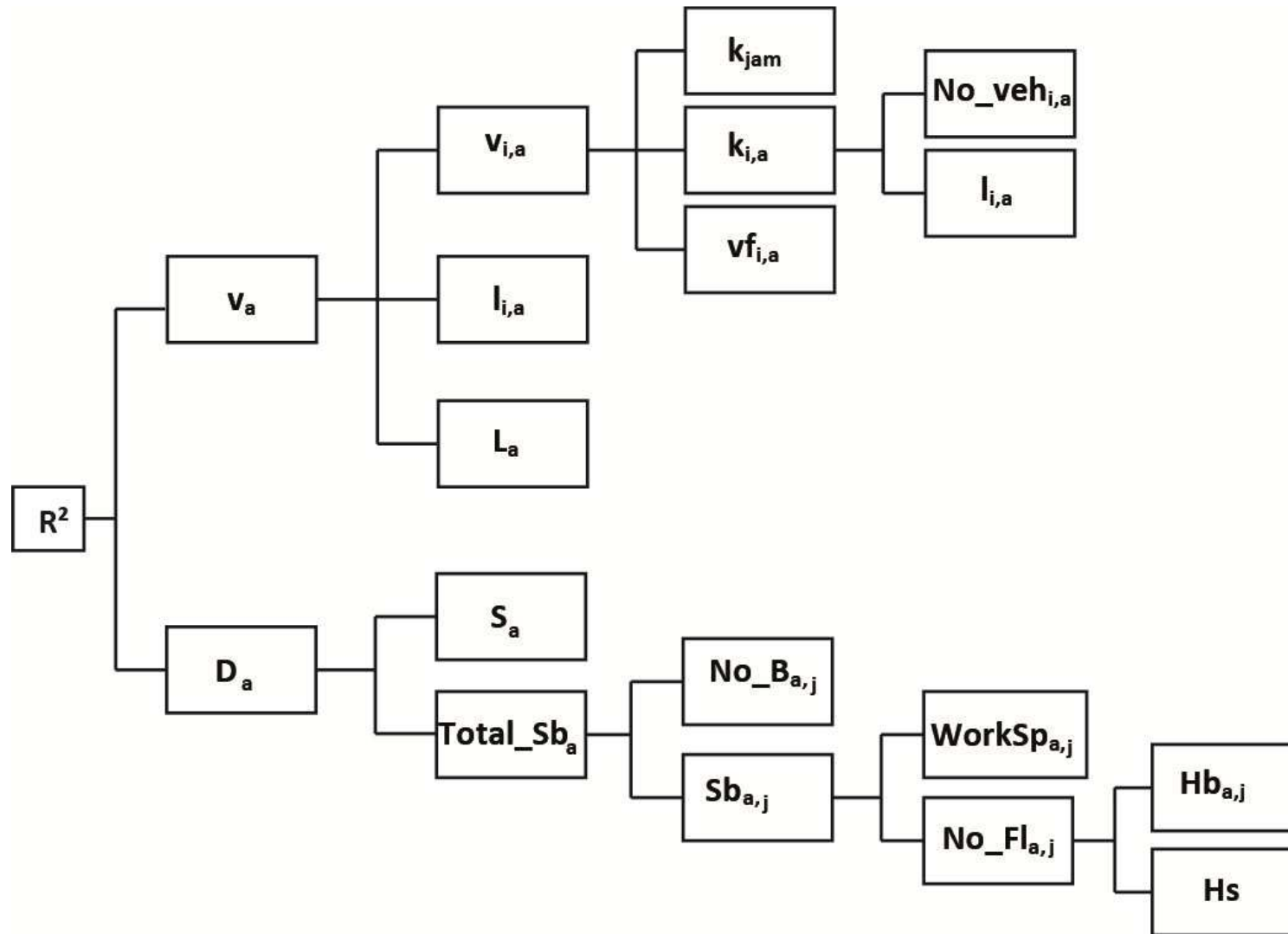
$v(t, a)$  is called the **Congestion indicator**.

These definitions of the different variables allowed us to create a mathematical model represented by a chart, for the case of the areal densities, with the accurate definitions of each variable.

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<sup>25</sup> [www.aicpr.org/](http://www.aicpr.org/)

*Implementation of a system:*



	<b>Definition</b>	<b>Unit</b>	<b>Values (min/max)</b>	<b>Formula</b>
$D_a$	Density of an urban area <b>a</b> .		0 / 2	$D(a) = \frac{Total\_Sb\ a}{S\ a}$
$S_a$	Surface of an urban area <b>a</b> .	km <sup>2</sup>	1 / 115	----
$Total\_Sb_a$	Total surface of buildings in an area <b>a</b> .	km <sup>2</sup>	0 / 15	$\sum S_{a,j}$
$No\_B_{a,i,j}$	Number of buildings <b>j</b> in an urban area <b>a</b> .		0 / 51968	----
$S_{a,j}$	Surface of a building <b>j</b> in an area <b>a</b> .	m <sup>2</sup>	0 / 363178	$No\_Fl_{a,j} * WorkSp_{a,j}$
$WorkSp_{a,j}$	Floor surface of a building <b>j</b> .	m <sup>2</sup>	0 / 23027	----
$No\_Fl_{a,j}$	Number of floors in a building <b>j</b> in an urban area <b>a</b> .		0 / 29	$\frac{Hb_{a,j}}{Hs}$
$Hb_{a,j}$	Height of a building <b>j</b> in an urban area <b>a</b> .	m	0 / 87	----
$Hs$	Standard height of a floor.	m	3	----

	<b>Definition</b>	<b>Unit</b>	<b>Values (min/max)</b>	<b>Formula</b>
$V_a$	Congestion indicator. Weighted mean speed of each urban area <b>a</b> .	Km/h	0 / 130	$\frac{\sum(v_{i,a} * l_{i,a})}{L_a}$
$V_{i,a}$	Speed indicator Effective speed of each link <b>i</b> in an urban area <b>a</b> .	Km/h	0 / 130	$v_{f_{i,a}} * \left(1 - \frac{k_{i,a}}{k_{jam}}\right)^\alpha$
$L_a$	Total length of all the links <b>i</b> in an urban area <b>a</b> .	Km	0 / 200	$\sum l_{i,a}$
$l_{i,a}$	Length of a link <b>i</b> in an urban area <b>a</b> .	m	2 / 2253	----
$k_{jam}$	Maximum density in free-flow speed conditions. Related to the nature of a road.	Veh/km	0 / 195	----
$k_{i,a}$	Density of vehicles on a particular link <b>i</b> in an urban area <b>a</b> .	Veh/km	0 / 390	----
$v_{f_{i,a}}$	Maximum speed on a link <b>i</b> in an urban area <b>a</b> .	Km/h	0 / 130	----
$No\_veh_{i,a}$	Number of vehicles on a link <b>i</b> in an urban area <b>a</b> .	----	----	----

## *Type of roads selected and examples of speed determination:*

Roads are defined following two criteria: the number of lanes and the speed limit. These data allow us to create several categories:

<b>Name</b>	<b>Number of lanes</b>	<b>Speed Limit (km/h)</b>
<b>1_lane_30</b>	1	30
<b>1_lane_50</b>	1	50
<b>1_lane_70</b>	1	70
<b>1_lane_90</b>	1	90
<b>2_lanes_50</b>	2	50
<b>2_lanes_70</b>	2	70
<b>2_lanes_90</b>	2	90
<b>2_lanes_110</b>	2	110
<b>2_lanes_130</b>	2	130
<b>3_lanes_50</b>	3	50
<b>3_lanes_70</b>	3	70
<b>3_lanes_90</b>	3	90
<b>3_lanes_110</b>	3	110
<b>3_lanes_130</b>	3	130

For each category, the speed is then calculated. Examples of speed determination are available in [Appendix 1](#).

## Case-study of Tours:

### *Tours in the national and local network:*

Tours (Indre-et-Loire) is a town of 135,000 inhabitants at the centre of an urban area of around 350,000 people<sup>26</sup>.

The city is well integrated in the motorway network and is crossed by the A10 (North to South) and the A85 (East to West). Furthermore, the city is connected to the other cities of Indre-et-Loire (eg: Chinon, Loches) by national roads.

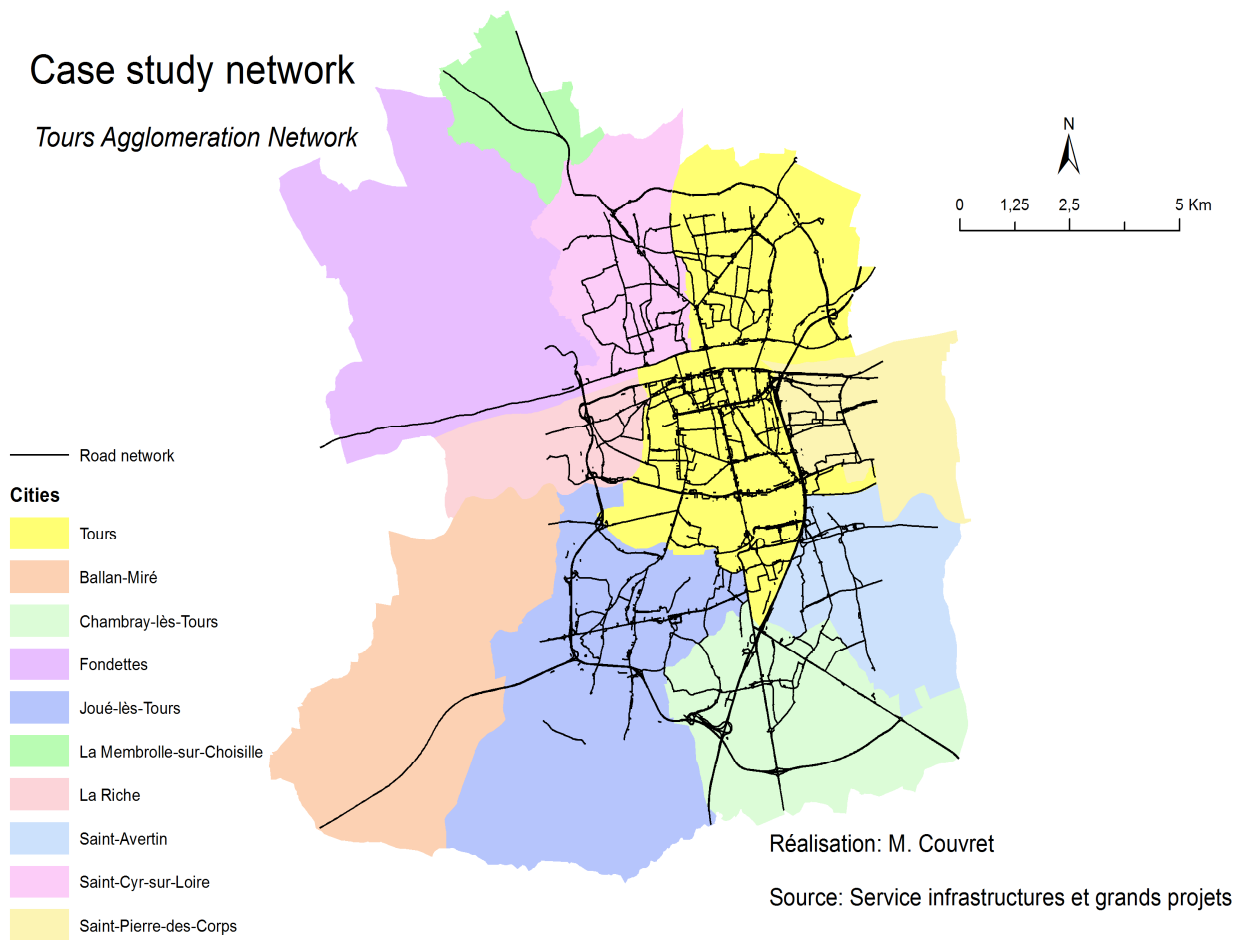


Figure 7: Indre-et-Loire's main road network

<sup>26</sup> Figures from the Insee website ([www.insee.fr](http://www.insee.fr))

## Selected Network:

This work is based on a particular network extracted from public data and implemented on a GIS (Geographic Information System). The following map shows the case study network. This network is mostly on the territory of Tours but some roads are also situated in other cities which are part of Tours' urban area. This choice was made following the data collected ([Appendix 2](#)) from the agglomeration and the stake to extend this case study to a wider area. These data represent the number of vehicles on the network during the evening rush hour (5pm to 6pm). Another map showing the different types of road, according to the previous part is available in [Appendix 3](#).



**Figure 8: Studied network and cities concerned**

## Results and interpretation:

### *Congestion and linear densities:*

Densities in terms of floor surfaces are calculated within a buffer zone of 30 metres around the links. This value is chosen following several tests, 30 metres appears to be the best value to select a maximum of building immediately surrounding the road network.

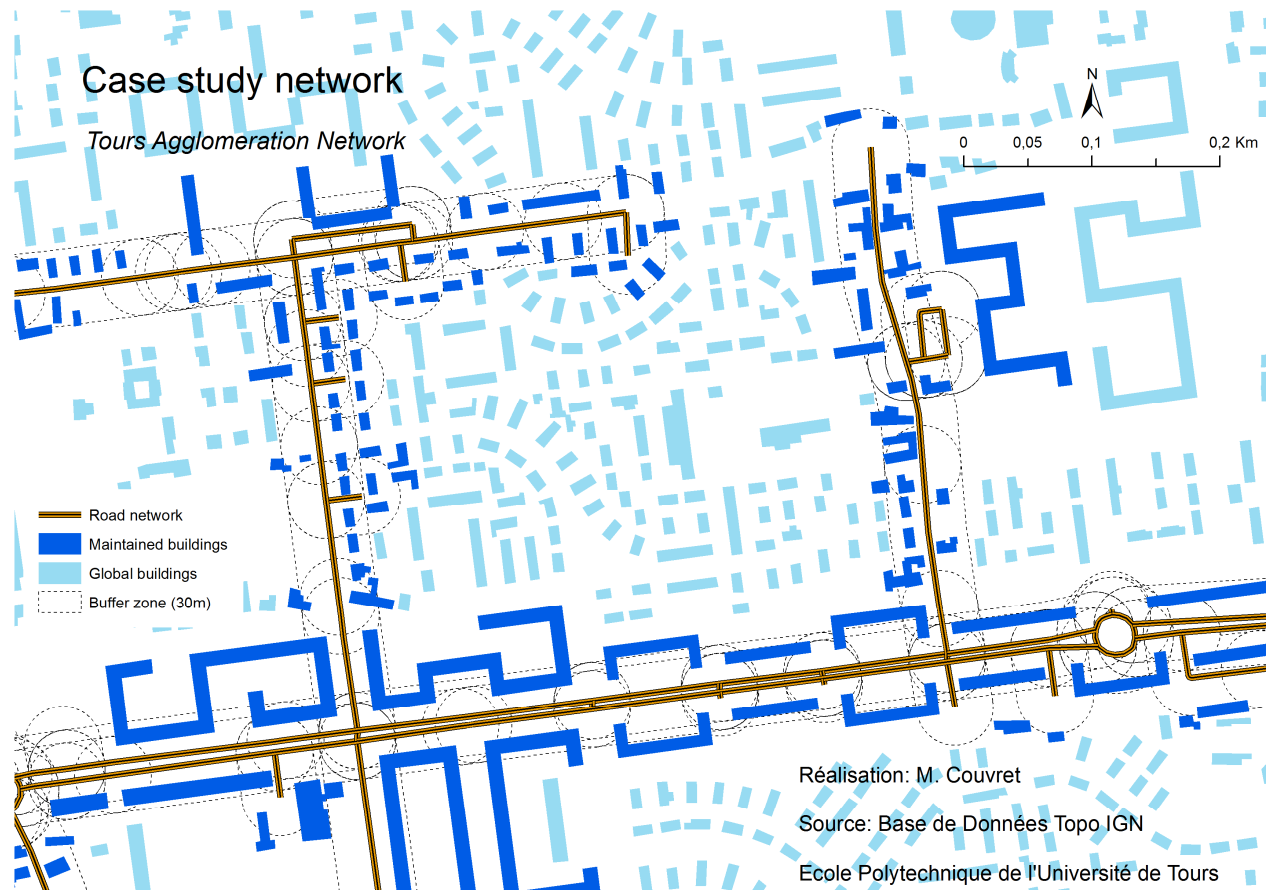


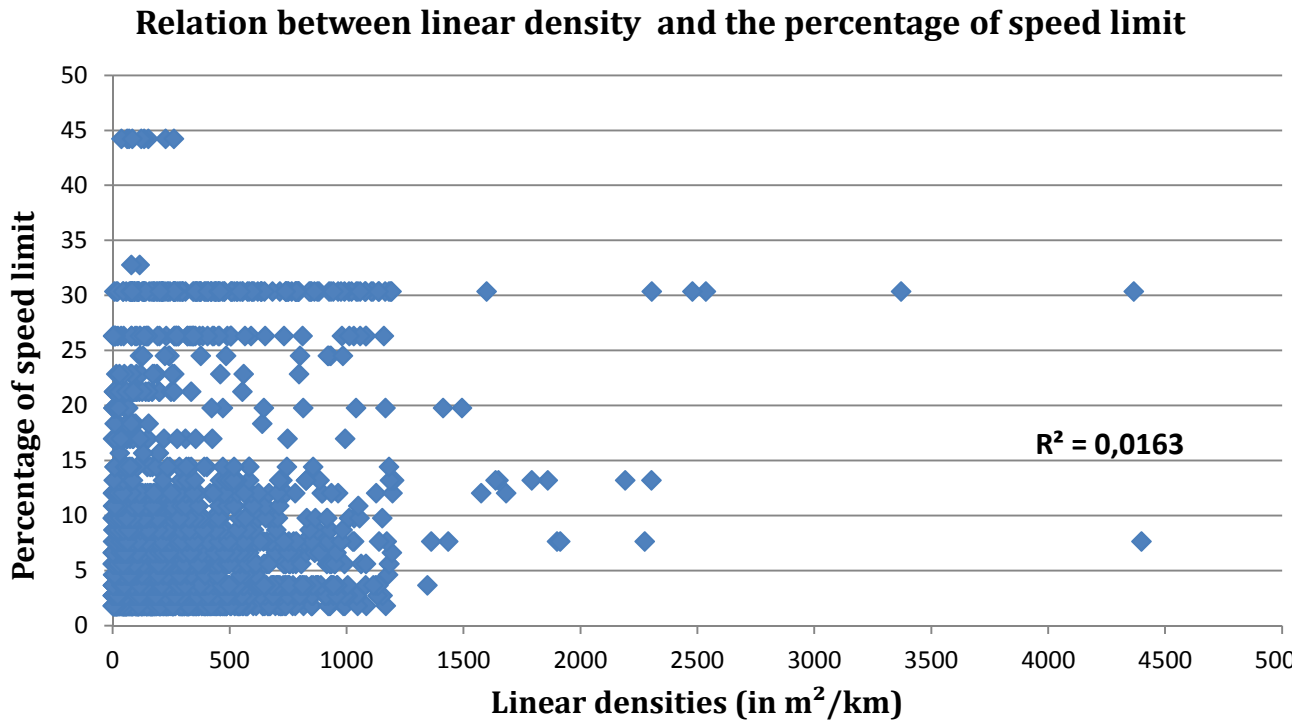
Figure 9: Zoom on the buffer and the maintained buildings

Following the chosen model, densities are calculated for each link of the network in  $m^2/km$ . The resulting map of the linear densities is presented in [Appendix 4](#) in order to show that the network is affected by a higher density in the centre of Tours (in red on the map) than its suburbs (in blue on the map).

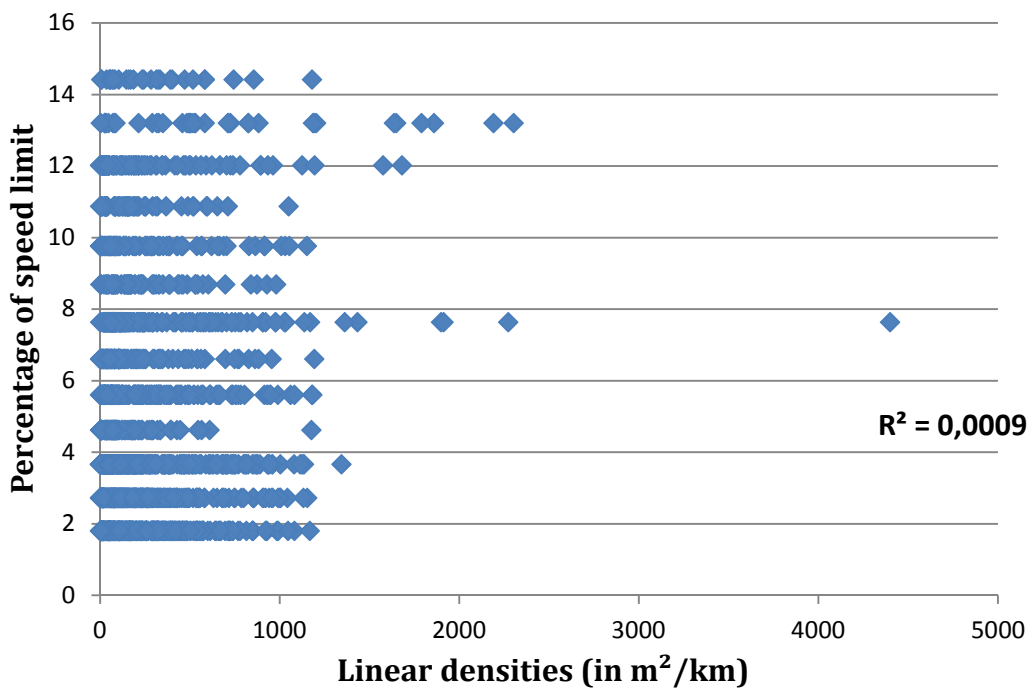
Several tests were conducted to complete this part. In order to give back the most understandable work, an example is presented for a specific type of link, the '1\_lane\_50' which represents the most common link in the whole network.

Due to the selected model introduced in the previous parts, it is now possible to determine a speed indicator according to the traffic flow during the evening rush hour. From this speed a percentage is expressed. It represents the ratio between the speed indicator and the speed limit. The lower this percentage is, the higher the difference between calculated speed indicator and the speed limit is, so the more the street is congested.

The following graph shows the result for a scatter graph of more than 2300 values.



The graph indicates no relationships between the two variables. If a zoom is made on the low part of the scatter graph, we can see this phenomenon:



All the results are situated on one among thirteen values of y (on this graphic). The indicator speed is not continuous. This fact comes from the data of traffic flow provided by Tours' agglomeration. Indeed, the traffic flow figures resulted from a mathematical model which is not accurate enough to provide a wide range of values. When the speed is calculated, the same traffic flows are often used so the same values are obtained.

For the other types of roads, the same kinds of results appear. It is possible to conclude that there is no relationship between linear density and traffic congestion.

## *Congestion and areal densities:*

The speed indicator used in the previous section is then implemented on a numerical computing environment in order to configure the Voronoi diagram, as described in the definitions, and to see the impact of the size of the area on the relationship congestion/urban density. The aim of this section is to determine the congestion indicator of each area thanks to the calculation of a weighted mean (see 'Speed indicator and Congestion indicator'). The point is also to optimize the coefficient of determination  $R^2$  according to the size of the areas (so the number of polygons implemented by the Voronoi diagram).

- **Example of a Voronoi diagram:**

Here is an example of a Voronoi diagram of 20 cells (in blue) on the study-case network.



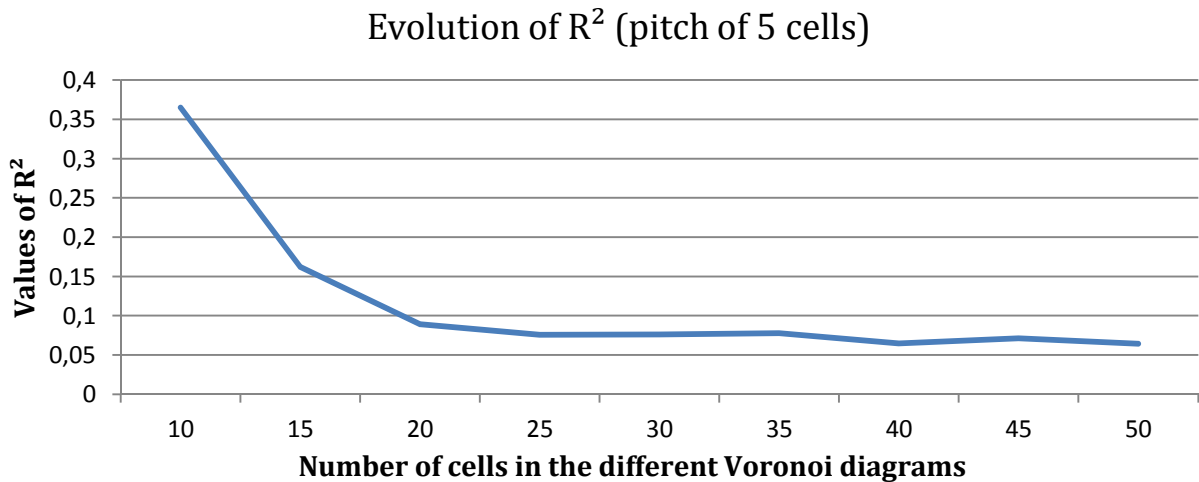
Figure 10: Example of a Voronoi diagrams (20 cells)

- **Code of the implemented program :**

The program created to generate the different Voronoi diagrams and the related coefficients of determination is available in [Appendix 5](#).

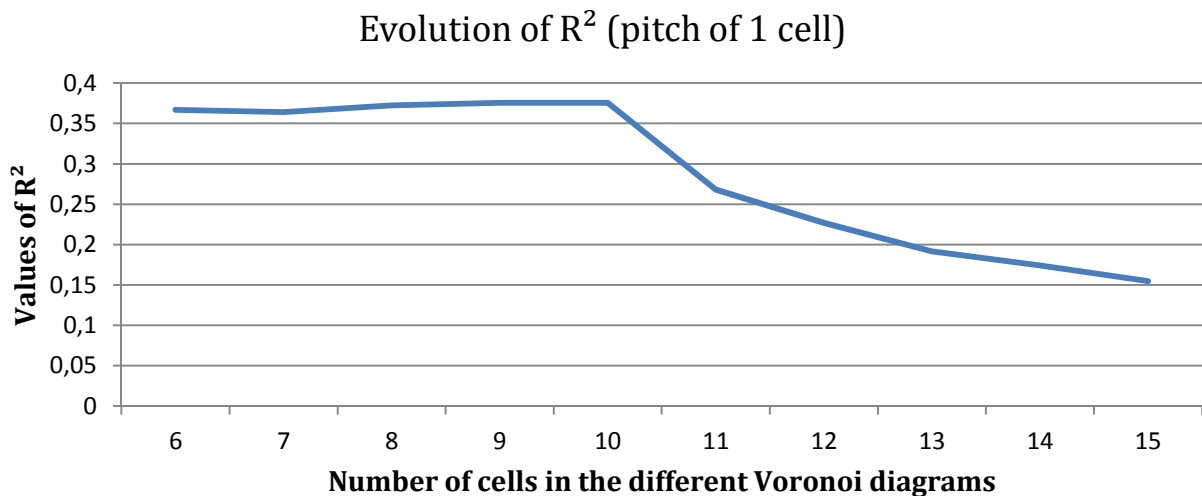
▪ **Results following the size of Voronoi cells :**

The first results are generated for a very different number of cells in the diagram, from 10 cells to 50 cells with a pitch of 5. These conditions allow having an interesting range of  $R^2$  which is significant.



*The values of  $R^2$  are mean values of several tests of the program with the same conditions and inputs.*

The resulting curve shows that the determination tends towards 0 when the number of cells is higher than 15 cells. However, when the number of cells is lower than 15, the  $R^2$  increases. If a correlation exists, it is situated under this value. In order to be more precise, other data are given in input : the following graph shows values of  $R^2$  from 6 cells to 15 with a pitch of 1.



*The values of  $R^2$  are mean values of several tests of the program with the same conditions and inputs.*

The resulting curve reaches a maximum when the number of cells is less than or equal to 10 cells.

The results allow analysing a trend is the relationship between congestion (through the chosen congestion indicator) and urban density. The next section intends to make an interpretation of these outcomes and a correlation with the chosen assumption and then the political and scientific debates presented in the state of art.

## *Interpretations related to the chosen assumption:*

The value of  $R^2$  reaches a maximum of 0,37 when the Voronoi diagram used contains less than or equal to 10 cells. This value is considered acceptable for the work. As a reminder, the assumption of this piece of work is:

***In the general case urban density, in terms of workspace/surf, is not contributing to the reduction of the traffic congestion”.***

The assumption can be checked in this part into 2 sections:

Is there any relation between congestion and urban density in the general case?

Is urban density reducing traffic congestion in specific cases?

- ***Is there any relationship between congestion and urban density in the general case?***

The results from the previous section clearly show that the relationship between congestion (with the chosen congestion indicator) and urban density is very limited. Indeed the  $R^2$  is different from 0 only for specific numbers of cells, under 10. This low number of cells reflects urban areas with very important surfaces, from 30 km<sup>2</sup> with 10 cells to much bigger areas with fewer cells. As a comparison Tours, the main city of the studied area has a surface of about 35 km<sup>2</sup>.

Building on the outputs of this case-study, this point allows interpreting that, at a neighbourhood scale or a district scale, congestion and urban density are not connected. It is only when a look is given at a metropolitan scale that a determination is possible. In other words, a densification of a street, a quarter does not impact the congestion of this same street or quarter. The impact will be significant on the whole network of the metropolitan area.

To meet the political debate, this piece of work allows showing that the principle of density has to be used smartly in the planning documents and not be seen as an automatism (at least to tackle congestion). There is no sense to act on the density of a small area as a neighbourhood thinking that it could impact its congestion.

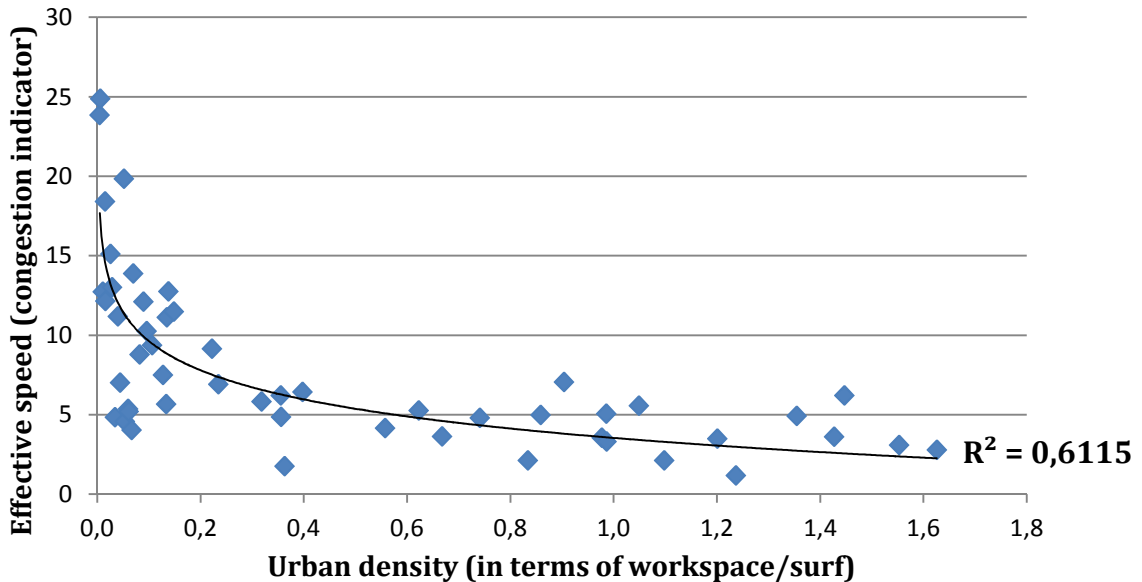
Considering the assumption of Kenworthy who advocates for a relationship between density and traffic, a warning can be set: the link exists only in very specific congestion. Indeed, the researcher showed that, at a city scale, the relationship exists (see '*Recent researches of a relationship between traffic and urban density*'), but this present work shows that it is not the case at a lower scale.

After showing that the determination is only made for specific cases, the next section interprets the moment where the two factors are in relationship and whether a higher density decreases congestion, as advocated by Kenworthy, or if at the contrary the congestion increases.

- ***Is urban density reducing traffic congestion in specific cases?***

In order to answer to this question, other series of tests are led for Voronoi diagrams with less than 10 cells. Data are then collected and implemented on the spreadsheet application. The next graphics gives a representative idea of the results obtained, in this case for a scatter graph of 50 points where each point represents a cell with a particular urban density and a weighted mean speed extracted from the congestion indicator.

## Effective speed of vehicles regarding urban density



The coefficient of determination is considered acceptable because close enough of Kenworthy's main findings (see '*Recent researches of a relationship between traffic and urban density*'). For the case of the Tours' agglomeration, the results shows that the denser an area is in terms of workspace, the more the vehicles are encountering queuing problems, slower speeds or increased travel times. Here, density is not contributing to reduce the congestion problems but conversely to increase them. The results validate the assumption and shows that doubts can be raised about the conclusions of the 'pro-density' researchers, on the field of congestion.

### *Limits of this work and sources of improvement:*

This piece of student work gives significant trends to answer to the assumption and to join the debate around the notions of congestion and urban density. However the results can be further refined, especially to enhance the value of  $R^2$  which determines the interaction between density and congestion.

The case-study is set from GIS data and data collected from the agglomeration, several corrections were made on the network's and the buildings' features (geo-referencing, corrections of natures, number of ways, number of floors). Furthermore, the flows' data extracted from the agglomeration work were sometimes not very readable and interpretable.

The chosen speed indicator can also be enhanced or changed in order to be closer to reality. Indeed the output values of effective are surely lower than in practice. This can be advocate by practical tests on the network at the rush hour.

$$v_i - v_0 = (v_f - v_0) \cdot \left(1 - \frac{k_f}{k_{jam}}\right)^\alpha$$

$v_f$  could also be the effective speed in free-flow conditions
the other root  $k$  could be implemented

minimum speed can be a non-zero value
according to literature could be 1 to 4.

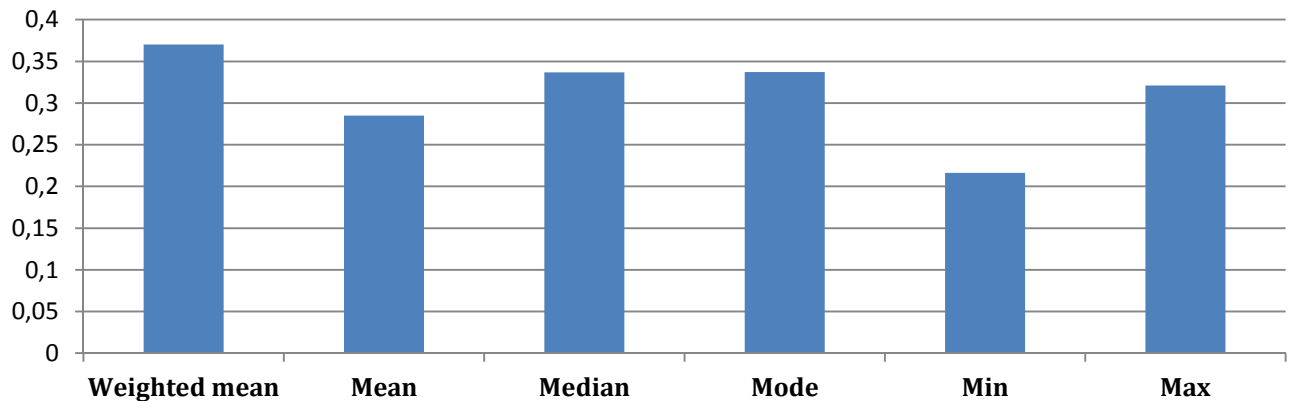
$k_{jam}$  could take other values than the AICPR's ones.

In logistic and transport planning, the use of Voronoi diagrams is common for example to calculate the shortest trips. However, cutting the network due to a Voronoi diagram is questionable as well. Maybe there are more significant ways to determine areas: urban entities, areas of attractions, etc...

Concerning the program implemented, some details could be improved: the way to close the outer cells, the way to cut the links which cross several cells, etc...

At last, it could be interesting to try another parameter as the weighted mean speed to obtain a better congestion indicator. Several tests were conducted for this point and are presented in the following table (case of an 8 cells' diagram).

$R^2$  following the selected parameter



*The values of  $R^2$  are mean values of several tests of the program with the same conditions and inputs.*

## Conclusion:

With an increasing number of people on Earth and an always bigger auto fleet, congestion problems become a real threat for the accessibility, the development and the economy of big cities and metropolitan areas. Furthermore, the stakes are also related to environmental concerns, especially the air quality and the global warming. For more than 20 years, the concept of densification is seen as way to address these issues. However, the debate around the notions of urban density and congestion is still very controversial. If today, densification is always advocated to all scales of a city or a metropolitan area, its impact in the process of tackling congestion remains questionable.

The aim of this piece of student work was to understand the main concepts of this debate both at a scientific and a political level and then to propose a personal research related to the key findings. In this paper, the demonstration was made that urban density and traffic congestion are not always in interaction. The question of scale is central and it appears clearly that a denser district or neighbourhood will only affect the congestion at the scale of the city and not the district itself. The study of Kenworthy concerning big cities from different continents is made in the same context. However, concerning the impact itself, the case-study shows the opposite situation as what Kenworthy advocates. Indeed, in this work, the denser an area is the more the streets are congested. The work of the Australian researcher suggests that with denser cities, the number of transit trips per capita increase and so congestion decrease. This work shows that this assertion is not always true.

The question addressed here is huge but necessary in order to both improve our ways to analyse the current problems of cities all around the world and to define better patterns for their future. This debate also joins the broader concept of sustainable development in the transportation sector. It could be interested to extend this case-study by another approach related for example to the impact of transit systems on congestion or make deeper analyses of the impact of the urban forms.

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## Appendixes:

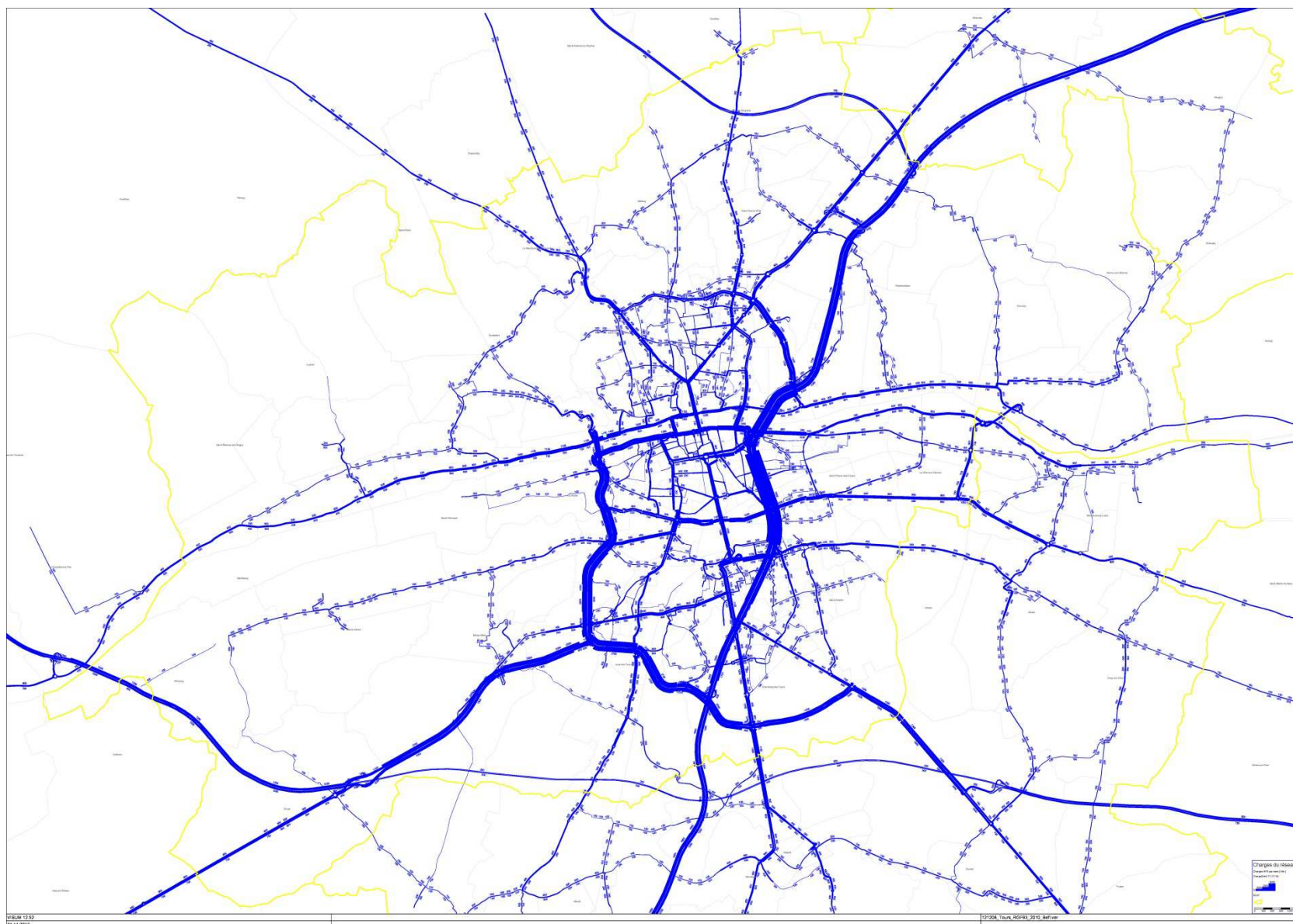
### Appendix 1:

Type of road	C(w)	C(hgv)	C(c)	Flow (max)	Density (capacity)	Speed limit	A	B	Flow (collected data)	$\Delta$	k	Speed
1lane_30	0,78	1	0,75	1287	65	30	-0,3	39,6	800,0	593,4	105,0	5,77287368
1lane_50	0,86	1	0,75	1419	65	50	-0,3	43,7	600,0	1100,3	114,4	6,00712273
1lane_70	0,88	1	0,75	1452	65	70	-0,3	44,7	900,0	758,8	105,1	13,4198591
1lane_90	0,9	1	0,75	1485	65	90	-0,4	45,7	1200,0	400,7	93,5	25,2861378
2lanes_50	0,88	1	0,75	2904	130	50	-0,2	44,7	750,0	1480,5	242,0	3,46898259
2lanes_70	0,92	0,98	0,75	2975	130	70	-0,2	45,8	1000,0	1391,0	235,9	6,48203996
2lanes_90	0,94	0,98	0,75	3040	130	90	-0,2	46,8	2600,0	316,6	179,5	27,8807326
2lanes_130	1	0,98	0,75	3234	130	130	-0,2	49,8	1600,0	1250,7	222,4	18,7970852
3lanes_50	0,88	1	0,75	4356	195	50	-0,1	44,7	1100,0	1450,0	333,4	7,25440302
3lanes_90	1	0,98	0,75	4851	195	90	-0,1	49,8	3800,0	374,7	250,0	32,3000487
3lanes_130	1	0,98	0,75	4851	195	130	-0,1	49,8	1750,0	1508,0	320,5	23,1697364

This graph shows the calculation of the speed in case of congested traffic. These values are examples and give an idea of the method.

- Calculation of the Flow (max) due to the three coefficients: C(w), C(hgv), C(c).
- Determination of the Density for the maximum Flow following the type of road.
- Calculation of the constants A and B with a linear system.
- Calculation of  $\Delta$ .
- Determination of the Speed (Here only one value is displayed because the second value doesn't reflect a situation of congestion).

Appendix 2:

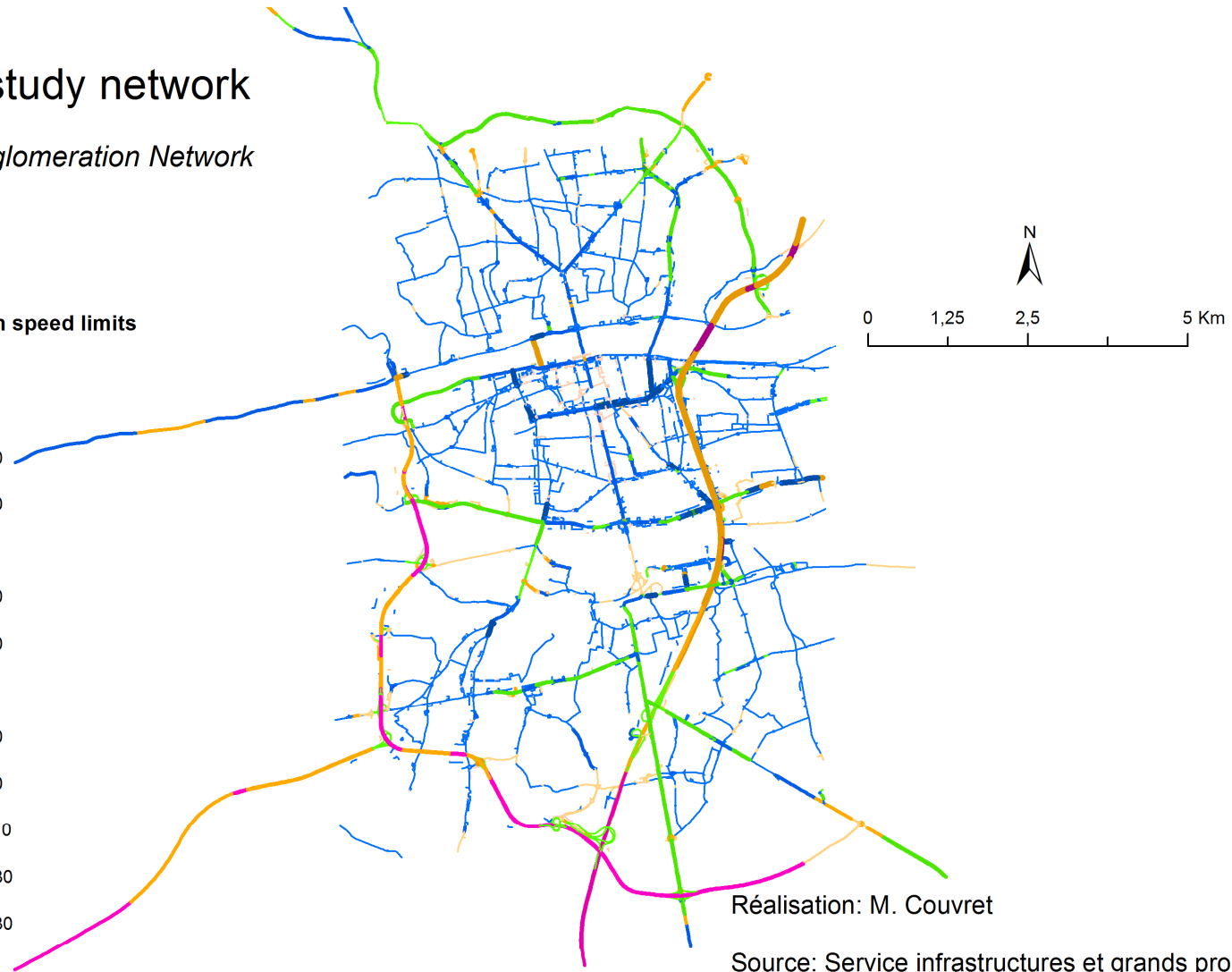


# Case study network

*Tours Agglomeration Network*

## Type of road with speed limits

- 1\_lane\_30
- 1\_lane\_50
- 2\_lanes\_50
- 3\_lanes\_50
- 1\_lane\_70
- 2\_lanes\_70
- 3\_lanes\_70
- 1\_lane\_90
- 2\_lanes\_90
- 3\_lanes\_90
- 2\_lanes\_110
- 2\_lanes\_130
- 3\_lanes\_130



Réalisation: M. Couvret

Source: Service infrastructures et grands projets

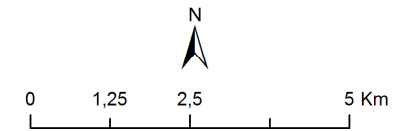
Communauté d'Agglomération Tour(s)plus



## Case study network

*Tours Agglomeration Network*

*Linear densities along the roads*



Réalisation: M. Couvret

Source: Base de Données Topo IGN

Ecole Polytechnique de l'Université de Tours

## Appendix 5:

```
clear
load('Test_1.mat','Matrice_initiale')
load('Test_2.mat','xb','yb','SurfBati')

xi=Matrice_initiale(:,8);
xj=Matrice_initiale(:,9);
yi=Matrice_initiale(:,10);
yj=Matrice_initiale(:,11);
vitesse=Matrice_initiale(:,6);

k=5;
ITERATION=10;
R2=ones(1,ITERATION)*inf;

for iteration=1:ITERATION
    prisi=zeros(1,length(xi));
    prisi=prisi(:);
    prisj=zeros(1,length(xj));
    prisj=prisj(:);
    k=k+1;
    xc=min(xi)+(max(xi)-min(xi))*rand(1,k);
    yc=min(yi)+(max(yi)-min(yi))*rand(1,k);
    [v,c]=voronoin([xc(:),yc(:)]);
    xv=v(:,1);
    yv=v(:,2);
    SurfBatiPoly=ones(1,length(c))*inf;
    DENSITEB=ones(1,length(c))*inf;
    VITESSEM=ones(1,length(c))*inf;
    sv=zeros(length(c),1);
    inp=ones(1,length(c))*inf;

    for i=1:length(c);
```

```

cf=c{i};
cf(cf==1)=[ ];
ini=inpolygon(xi,yi,xv(cf),yv(cf));
inj=inpolygon(xj,yj,xv(cf),yv(cf));
index=ini==1 | inj==1;
index=index==1 & prisi==0 & prisj==0;
xini=xi(index);
xinj=xj(index);
yini=yi(index);
yinj=yj(index);
prisi(index)=1;
prisj(index)=1;
distij=((xini-xinj).^2+(yini-yinj).^2).^0.5;
distTotal=sum(distij);
vitesseM=(sum(vitesse(index).*(distij)))/distTotal;
VITESSEM(i)=vitesseM;
inp=find(inpolygon(xb,yb,xv(cf),yv(cf)));
SurfBatiPoly(i)=sum(SurfBati(inp));
sv=polyarea(xv(cf),yv(cf));
densB=SurfBatiPoly(i)/sv;
DENSITEB(i)=densB;

```

end

```

index=isnan(DENSITEB) | isinf(DENSITEB) | isnan(VITESSEM) | isinf(VITESSEM);
DENSITEB(index)=[ ];
VITESSEM(index)=[ ];
R12 = corrcoef([DENSITEB(:) VITESSEM(:)]);
r12 = R12(1,2) ;
R2(iteration)=r12^2;

```

end

```

[R2max,idR2max]=max(R2);

```

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## **Modelling traffic congestion: Relationships between urban density and congestion**

For more than 80 years, scientists are creating mathematical models to understand and tackle congestion. Indeed today in automobile-dependent cities, congested streets can lead to problems of walkability, viable public transit, job access, etc... Within the context of sustainable development the question of congestion is at the centre of the debate at a political and a scientific level. It's today common to admit that making cities denser is a way to reduce time loss in vehicles, costs and CO2 emissions. But is it always the case? Some scientists and politics are contesting this statement for different reasons: opposite situation, lack of studies, wrong definitions of density, unrealistic opposition against suburban development, etc...

This project intends to introduce the current progress made on the thematic and then figure out the doubts that still exist in the relationship between urban density and congestion. In order to illustrate this research in a more practical way, a case-study is presented. Due to a chosen mathematical model, this relationship is checked according to a proposed assumption.

**Keywords:** Traffic congestion, urban density, automobile dependence, sustainable development.