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# Modélisation de scénarios de mobilité prospectifs sur Île-de-France à l'aide du modèle ANTONIN 3

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## Table of contents

Table of contents .....	3
List of figures .....	5
Introduction .....	8
Part 1: Identification of public transit gaps in 2035.....	9
The big lines of the developed methodology .....	9
Definition of the study area .....	10
Definition of what is a transport deficiency .....	11
Other Working Hypotheses .....	12
The main principles of the ANTONIN 3 model .....	14
Calculation of the Transport Offer .....	15
Global accessibility to employment: .....	15
Local accessibility to employment .....	17
The socio-economic perspective – Calculation of the transport demand.....	23
The Principal Component Analysis.....	24
Total score .....	29
Identified zones : .....	30
Vigneux-sur-Seine.....	31
Champigny & Chennevières-sur-Marne .....	32
Argenteuil (nord).....	33
Clichy-sous-Bois .....	34
Trappes .....	35
Second priority deficient areas & false alarms.....	36
Chanteloup-les-Vignes .....	36
Évry .....	37
Valenton .....	38
Quartiers Europe – Grand Ensemble (Sevran).....	39
Short Discussion.....	40
Part 2: Sensitivity tests in Antonin 3 .....	42

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Sensitivity tests acting on the P + E. structure. ....	43
Sensitivity to revenue .....	46
Sensitivity to the unemployment rate. ....	50
Sensitivity to the population aging .....	51
Sensitivity to the employment positions. ....	55
Tests acting on the mode and destination choice. ....	57
Sensitivity to the Navigo price .....	59
The fuel cost variable in Antonin 3 .....	61
Part 3: Forecasting Scenarios in Antonin 3 .....	64
Boulevard Peipherique: Modeling of a decrease in the maximum allowed speed.....	64
Modeling Results.....	66
Balancing the Est-West employment unbalance .....	70
Tightening the availability of parking spaces inside Paris .....	83
Modeling results .....	85
Conclusion.....	98
Bibliography.....	100
Electronic books & Reports .....	101
Printed books & Reports .....	101
Doctoral Dissertations .....	101
Annexes.....	106
Annex 1 Summary of the identified zones potentially facing PT gaps (Part 1).....	107
Annex 2 PCA Factor Loadings .....	108

## List of figures

Figure 1 - J.M. Schomburg - Statistical demographics plan of Paris and the Île-de-France region. Paris Urban Area can be seen in deep red.....	12
Figure 2 – An overview of the zoning and the public transit network used by Antonin 3. ....	13
Figure 3 - Schematic functioning of Antonin 3. Source: Île-de-France Mobilités -Antonin 3 Manual.....	14
Figure 4 - Employment positions in Île-de-France. Note the impact of airports and the unbalanced distribution of employment between the east and the west of Paris region. .	15
Figure 5 – Number of Accessible employment position by Public Transport. Note the effect of heavy rail corridors in the accessibility of employment of regions in Île-de-France periphery.....	16
Figure 6 – Accessible employment by private vehicles. Note the decreased accessibility of Paris city center in relation to the Petite Couronne (which is due to the lack of parking space, decreased speeds etc.), and the East-West unbalance that reflects the larger availability of employment in the West. ....	17
Figure 7 – Percentage of accessible employment by car in relation to the employment positions that are available in an 8 km buffer zone. The homogeneity of the map reflects the efficient mesh of the road network. Note that the east-west employment disequilibrium disappears: the local indicator is largely unbiased to the absolute value of employment and it largely comments on the quality of the transport network.....	19
Figure 8 – Local TC Accessibility. The low percentages of the accessible employment positions in relation to the total employment positions in an 8 km radius can be attributed to the impedance function in the nominator. On the other hand, the denominator does not have such constraints, something that evidently leads to globally feeble ratios. It should be noted though that the color coding is done by quantiles of equal number of features, leading to a correct global picture. ....	21
Figure 9 – Morangis to Orly by public transport (HERE Maps) .....	23
Figure 10 - Total amount of explained variance by each principal component.....	26
Figure 11 - The factor plan for the first two principal components .....	28

Figure 12 – The 30% of the zones with the lowest total score.....	29
Figure 13 – Overview of the identified zones .....	30
Figure 14 – Identified zones in Vigneux-sur-Seine .....	31
Figure 15 - Identified zones in Champigny & Chennevières-sur-Marne.....	32
Figure 16 - Identified zones in Argenteuil (nord) .....	33
Figure 17 – Identified zones in Clichy-sous-Bois.....	34
Figure 18 – Altitude differences in Clichy-sous-Bois. Source : topographic-map.com .....	35
Figure 19 - Identified zones in Trappes .....	35
Figure 20 - Identified zones in Chanteloup-les-Vignes .....	36
Figure 21 – Identified zones in Évry.....	37
Figure 22 – Identified zones in Valenton.....	38
Figure 23 –Valenton to Orly by car .....	39
Figure 24 – Identified zones in Europe-Grand Ensemble.....	40
Figure 25 - Schematic functioning of Antonin 3. This range of scenarios changes the “Population et emplois” input variables of the model. Source: Île-de-France Mobilités - Antonin 3 Manual.....	44
Figure 26 – Calculated elasticities with respect to the income, unemployment rate and the percentage of the population over 60 y.o. ....	46
Figure 27 – Change of the economically active population with respect to changes in the unemployment rate. ....	50
Figure 28 – Variation of the population pyramid.....	52
Figure 29 – Ratio of received home-work trips by zone in relation to the available employment.....	57
Figure 30 - Schematic functioning of Antonin 3. This range of scenarios changes the “Offre de Transport” input variables of the model. Source: Île-de-France Mobilités - Antonin 3 Manual.....	58
Figure 31 – Elasticities with respect to the Navigo card & fuel prices. ....	59
Figure 32 - Car Cost per Km. Source: ADETEC .....	61
Figure 33 - The Boulevard Périphérique. Source: Jean-Baptiste Gurliat - Ville de Paris.....	65
Figure 34 –Home-Work car trips received by zone. ....	67
Figure 35 – Evolution of the modal share of public transit for the home-work trips received per zone. ....	68

Figure 36 – Total Home-Work trips received by zone.....	69
Figure 37 – Change in the average distance for the home-work car trips received by zone....	70
Figure 38 - Individual & collective housing in Île-de-France: note the East-West housing unbalance (2017 MOS data).....	72
Figure 39 – Identified zones for the Est-West employment unbalance scenario .....	73
Figure 40 – Evolution of the home-work public transit trips received per zone.....	75
Figure 41 - Evolution of the average distance for public transport trips emitted by each zone during the morning rush hour.....	76
Figure 42 - Evolution of the average distance for public transport trips received by each zone during the morning rush hour.....	76
Figure 43 – Change in passenger-km for the public transit network .....	77
Figure 44 – Evolution of the public transit home-work trips received by the selected zones in Val de Fontenay. ....	79
Figure 45 – Evolution of the total number of the Home-Work trips by public transit destined towards Val de Fontenay, in relation to the total Home-Work trips by public transit that are emitted by every zone.....	81
Figure 46 – Absolute number of extra trips attracted by Val de Fontenay under this scenario	82
Figure 47 – Different parking cost categories coded in Antonin. Source: Antonin 3 Manual.	83
Figure 48 – Change in the modal split .....	85
Figure 49 – Change in the daily passenger-km per mode. ....	85
Figure 50 – The modal split of Paris – note the large share of walking and public transit who collectively account for 85% of the total trips .....	86
Figure 51 – Evolution of the number of the received, public transit home-work trips.....	87
Figure 52 – Evolution of car’s modal share. ....	89
Figure 53 – Evolution of the average distance of car home-work trips .....	90
Figure 54 – Daily trips per mode .....	93
Figure 55 – Change in the modal split in Paris, Petite Couronne & Grande Couronne.....	94
Figure 56 – Change in passenger-km per mode.....	95
Figure 57 –Evolution of the number of car home-work trips .....	96
Figure 58 – Evolution of the car modal split for home-work trips .....	97

## Introduction

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Public transit modeling is probably one of the most efficient ways of evaluating “in vitro” the effects of the proposed investments in transportation projects, which are capital intensive, slow in their execution and involve a vast range of stakeholders with often conflicting needs. During my internship within Île-de-France Mobilités, the Paris’ public transport authority, I had the opportunity to work with Antonin 3, one of the most advanced modeling solutions. The document follows the chronological order of my three main missions. It starts with a diagnostic of public transit gaps: using a rigorous mathematical approach which combines an accessibility analysis from an employment point of view, and a Principal Component Analysis which succeeds in providing an objective socioeconomic assessment of the different sectors inside Île-de-France, the methodology proposes an intuitive list of zones facing isolation issues in 2035. This first mission is followed by a sensitivity analysis of Antonin 3: a series of elasticities is calculated and commented on, with the aim of discovering which inputs weight heavier on the results of the model and thus need to be thoroughly refined. Finally, the insights of the sensitivity analysis are used in order to model four forecasting scenarios: a possible reduction of the speed limit of the Boulevard Périphérique, the effects of a fare-free public transit inside Île-de-France, a tightening of the parking space availability inside Paris and the effects of a “rebalance” of the employment positions between the east and the west of Île-de-France. For all parts, there has been an effort of aligning our findings with the relative literature, alongside with an analysis of the results which aims at shedding light to the inner workings of Antonin 3. I hope that the reader finds this document interesting and informative.



## Part 2: Sensitivity tests in Antonin 3

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The second mission of the PFE encompasses a series of sensitivity tests that aim at revealing the behavior of the model to changes (radical or not) of its inputs. The objectives of this mission are once again dual:

- The insights and the output data of the sensitivity analysis could be used to complete the existing documentation of Antonin 3, which, as an ad-hoc modeling solution, created specifically for Île-de-France and Île-de-France Mobilités, often lacks the extensive documentation of proprietary. On that matter, the team was also interested in verifying numerically some of the previously observed behaviors of the model.
- The second objective was to observe the behavior of the model in extreme, “rupture” scenarios and evaluate whether the results are meaningful and can be used, not only to gain insights about extreme events, but also to guide the eventual contingency plans for a different number of situations, in the case of an extreme rise of fuel prices for instance.

The key indicator that has been retained in order to evaluate the sensitivity of the model at this stage of the project is the elasticity, defined as the percentage change in a good’s consumption caused by each one-percent change in its price or other quantity acting on the offer or the demand of transit services. For example, a -0.5 elasticity of metro trips with respect to its price means that each 1% price increase causes public transit travel to decline by 0.5%. Elasticities of less than 1.0 absolute value are called inelastic, meaning that prices cause less than proportional consumption changes. Consistently, elasticity values greater than 1.0 absolute value are called elastic, meaning that price changes cause more than proportional consumption changes.

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While there are many methods of calculating elasticities, due to the large relative changes of the underlining quantities, the retained calculation method has been that of the arc elasticity<sup>22</sup>, defined as :  $\varepsilon = \frac{\Delta \log Q}{\Delta \log P}$ , for a start and end point.

### **Sensitivity tests acting on the P + E. structure.**

The first range of sensitivity tests will act of the Population and Employment structure of the model. Four key variables have been tested, namely the:

- Sensitivity to revenue
- Sensitivity to the unemployment rate.
- Sensitivity to the percentage of the population over 60 years old.
- Sensitivity to prices :
  - Sensitivity to fuel prices
  - Sensitivity to the cost of a monthly Navigo card<sup>23</sup>.

At this stage, the scenarios follow a “ceteris paribus” logic: In order to test the sensitivity of the model to the different inputs, only one variable is modified at a time. This allows for much more intuitive results, where the changes can be directly linked to an identifiable differentiation on the socioeconomic input data. This obligation can be restrictive: the beforementioned aging scenario for instance, is not a true prospective scenario since the eventual changes refer only to changes to the population pyramid. A true prospective scenario would also need to make assumptions on the new employment rate of the >60 years old population segment by the year 2035, assume different mobility behaviors for the seniors than those included in the EGT 2010 etc. Consequently, tracing back the origin of the scenario results would include a substantial level of difficulty in this case.

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<sup>22</sup> Litman T. (2004) “Transit Price Elasticities and Cross-Elasticities,” Journal of Public Transportation, Vol. 7, No. 2, ([www.nctr.usf.edu/jpt/pdf/JPT\\_7-2\\_Litman.pdf](http://www.nctr.usf.edu/jpt/pdf/JPT_7-2_Litman.pdf)), 2004, pp. 37-58

<sup>23</sup> A monthly Navigo card allows for unlimited public transit trips within Île-de-France.

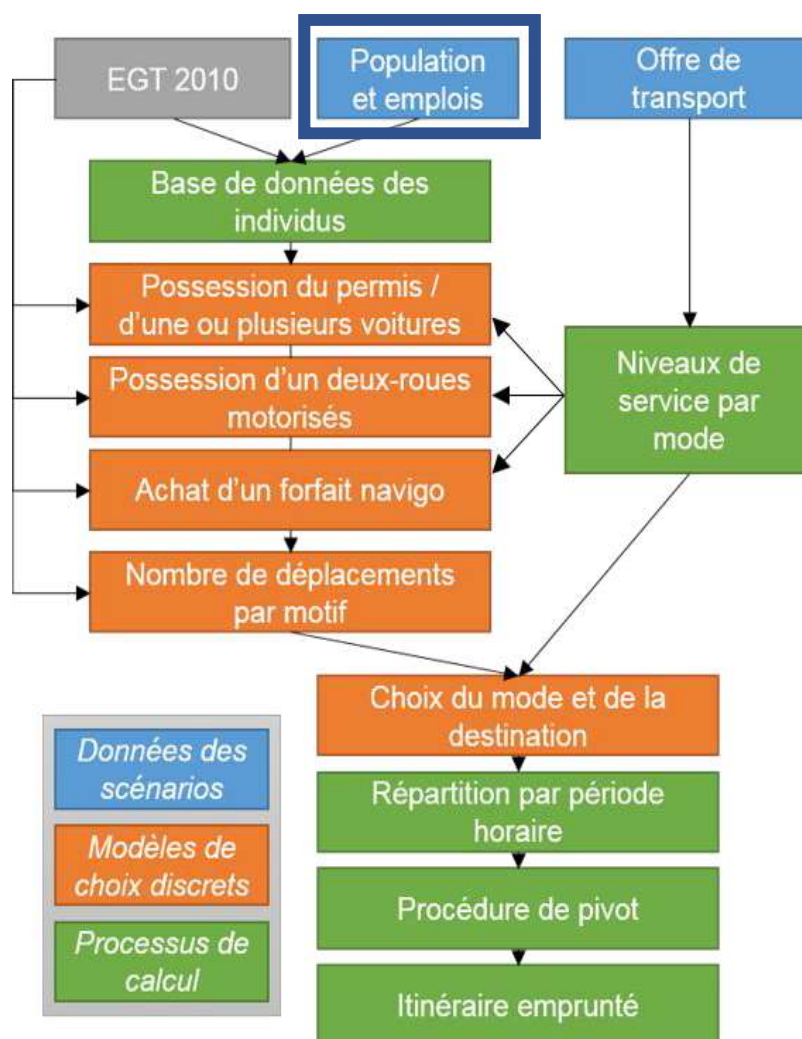


Figure 25 - Schematic functioning of Antonin 3. This range of scenarios changes the “Population et emplois” input variables of the model. Source: Île-de-France Mobilités -Antonin 3 Manual

Several different elasticities have been calculated in order to test the sensitivity of the various outputs of the model. The indicators include:

- PTWALK (Day/Peak): The number of trips by public transport before the pivot procedure during a complete day / the rush hour. As the name suggests, this indicator refers exclusively to the trips where the access is done on foot<sup>24</sup> and which comprise the overwhelming majority of public transport trips in Île-de-France. In order to see clearly through any distortions that the pivot procedure could impose on the implicit

<sup>24</sup> Accordingly, this indicator does not include the trips where a commuter leaves his vehicle and transfer to the public transit system for the remainder of the journey.

model elasticities, the indicators in this section always refer to the situation before pivot. It should be noted though that further analysis has shown that the effect of the pivot is minimal, with only minimal variations on the final quantities and without any changing of signs of the elasticities.

- CAR\_DR: The number of trips by car before the pivot during the rush hour
- WALK: The number of trips on foot before the pivot during the rush hour.
- D-T (Cadres/Autres): The number of home-work trips for “cadres” (a generic term characterizing white-collar commuters belonging to upper socioeconomic classes) and “others” (Autres), defined automatically by Antonin 3 based on range of socioeconomic indicators such as the revenue.
- Education: A composite indicator including the number of home-school trips and any other trip with an educational purpose.
- VOYKM (RER/Metro/Optile): The total vehicle-km for the Metro/RER/Optile networks respectively.

#### The pivot procedure

A frequent approach to modeling, which can substantially enhance the accuracy of the model, is to formulate the model as predicting changes relative to a base-year situation. Often, base-year traffic flows can be observed rather accurately and the restriction of the model to predicting differences reduces the scope for errors in the modeling –caused by errors in the model itself or in the inputs to the model – to influence the outputs. Mathematically, in normal growth cases, the usual approach is to apply the ratio of model outputs for base and forecast situations as a growth factor to the base matrix.

A collective figure of the elasticities of inputs affecting the P+E structure of the model is shown below:

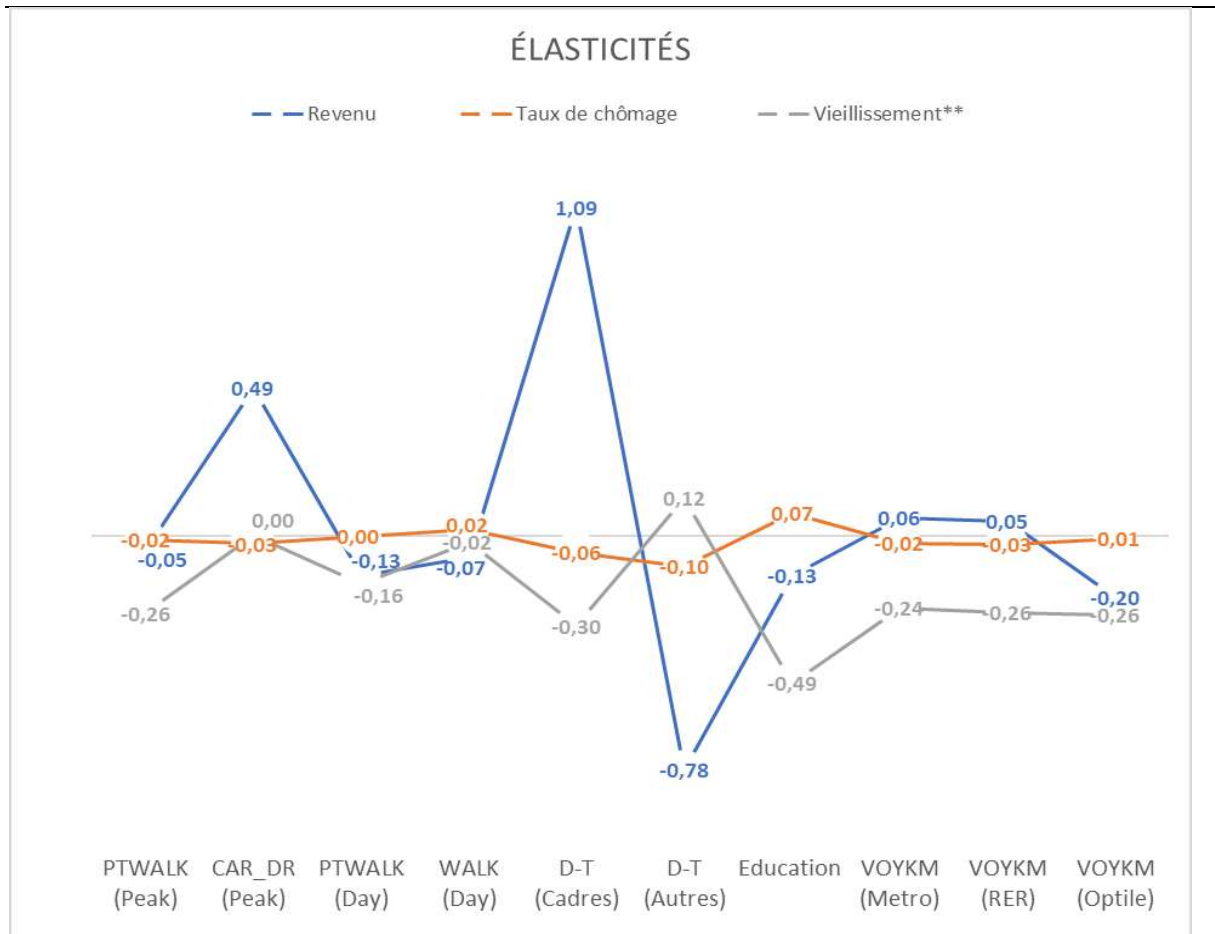


Figure 26 – Calculated elasticities with respect to the income, unemployment rate and the percentage of the population over 60 y.o.

### Sensitivity to revenue

The elasticity of the model with respect to changes in the revenue is of particular interest since it allows for interesting parallel insights in respect to the more general behavior of the model. The most vocal feature of graph 19 is the spike in the middle, accounting for the elasticities of the Home-Work trips for both the “Cadres” and the “Autres” ( $\epsilon = 1.09$  and  $\epsilon = -0.79$  respectively). These two elasticities seem to have a certain relation with each other - analysis has shown that increases on the value of one of them usually lead to decreases on the value of the other. The reason for that seems to be closely related to the functioning of the model. While the employment positions at the entry of Antonin 3 are characterized based on their typology as jobs for “Cadres” or jobs for “Autres”, there is no such a priori characterization of the individuals/households. Instead, Antonin 3 uses the various

socioeconomic variables at its input to recreate a synthetic population and then calculate its mobility behavior based on the results of the EGT. As a part of this process, the individuals/households are attributed a “Cadres” / “Autres” characterization and they are matched to the equivalent the employment positions. Changing the revenue interferes with this characterization process: a reduction in revenue (while the activity rate stays the same) leads to less “cadres” and thus to less “cadre” home-work trips. The opposite is true as well: a poorer population is a population with more “Autres”, who commute towards the equivalent employment positions. This result shows well the importance of the revenue variable to correctly predict the generated D-T trips when it is important to distinguish between the various socioeconomic categories.

At the same time, the elasticity of trips by car with respect to the revenue during the rush hour is important, though inelastic in the strict sense ( $\epsilon=0.49$ ). The latter means that a 10% increase in the revenue will lead to a ~5% increase in the daily trips by car during the rush hour. This result is higher than the calculated elasticity from a study from Collet, who, has econometrically estimated that the long term elasticity of car trips with respect to the revenue is at the order of 0.22, 0.27 and 0.30 for the Grande Couronne, Petite Couronne and Paris respectively<sup>25</sup>. Johansson and Schipper (1997), summarizing elasticities from various studies also find similar results: elasticity with respect to income vary between -0.1 and 0.35, with the researchers' ‘best guess’ being at 0.2<sup>26</sup>. Mayeres et al. (2000)<sup>27</sup>, summarizing elasticities from European studies with a slightly different methodology, which separates essential and optional trips elasticities, have calculated that the elasticity of essential and optional car trips with respect to revenue are 0.70 and 1.53 respectively.

Increased of personal vehicles (via an income increase) can also work competitively to the transportation system: the elasticity of the usage of the Optile bus network<sup>28</sup> (expressed in passenger-km) with respect to the revenue, is negative ( $\epsilon = -0.2$ ). Intuitively, in the areas

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<sup>25</sup> Collet, R. (2008). Addiction à l'usage de l'automobile en France et mesures d'élasticités.

<sup>26</sup> Johansson, O., & Schipper, L. (1997). Measuring the long-run fuel demand of cars: separate estimations of vehicle stock, mean fuel intensity, and mean annual driving distance. *Journal of Transport Economics and Policy*, 277-292.

<sup>27</sup> Mayeres, I. (2000). The efficiency effects of transport policies in the presence of externalities and distortionary taxes. *Journal of Transport Economics and Policy*, 233-259.

<sup>28</sup> Optile (Organisation Professionnelle des Transports d'Île-de-France) is a public transport organisation, created from a merger between several private bus companies serving suburban Paris with more 1,289 regular bus lines.

served by the Optile network (principally in the Grande Couronne<sup>29</sup>), a rise in revenue will lead to a modal shift from the public transportation system (where the low housing density and population often lead to lower PT offer in comparison to the city center), to the private car, which has become more affordable. Of course, this phenomenon presupposes the lack of credible alternatives. As it can be seen from the positive elasticities in the same indicator for the Metro and RER systems ( $\varepsilon_{\text{Voykm(Metro)}} = 0.06$  and  $\varepsilon_{\text{Voykm(RER)}} = -0.05$ ), a rise in revenue will not diminish the load (via a switch to private motorization) in those systems since their attractiveness is not a matter of lack of other options but a consistent choice that valorizes the superiority of those networks in comparison to the existing alternatives. The slight rise in their loads can also be attributed to an induced demand that originates from trips to activities that are now affordable due to the increased revenue. Be that as it may, due to the increased car use in the Grande Couronne and the fact that in this scenario the total activity rate stays stable, the overall use of public transportation slightly diminishes ( $\varepsilon_{\text{PTWALK, Peak}} = -0.05$ ,  $\varepsilon_{\text{PTWALK, Day}} = -0.13$ ).

These results also show a certain coherence with the existing literature: Mayeres et al.<sup>30</sup>, reported results for the Bus and Metro passenger-kms is of a slightly different order with an elasticity with respect to revenue of 0.59. This result is far from the marginal 0.06 and -0.20 that has been calculated for Antonin 3. Some reasons for this non-negligible difference can be traced back to various socioeconomic and perceptual differences between Île-de-France and other European cities. For instance, the Parisian metro serves almost exclusively inner Paris, an already rather privileged sector. In comparison to other cities where the metro system could traverse neighborhoods representing various socioeconomic backgrounds, the Paris metro passenger-km might be less elastic to revenue because the Parisians are overall better-off, with any relative revenue change having a more limited effect on their living standards. In short, the revenue of the Parisians might already be beyond the income threshold where any change would be reflected in their mobility choices.

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<sup>29</sup> Four departments on the outskirts of Île-de-France: Seine-et-Marne, Yvelines (78), Essonne (91) and Val-d'Oise (95), with 5,309,035 inhabitants in 2015

<sup>30</sup> Mayeres, I. (2000). The efficiency effects of transport policies in the presence of externalities and distortionary taxes. *Journal of Transport Economics and Policy*, 233-259.

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The sign for the educational trips elasticity ( $\varepsilon_{\text{Education}} = -0.13$ ) can appear as slightly counterintuitive: an increased income is often related to a higher level of educational attainment<sup>31</sup>. While it is probably true that the someone with a university-level education will gain more in average than the typical high-school graduate, the same is not true for the someone that is *currently attending educational activities*: the income of the actual student is often much lower than the income of other socioeconomic categories. The negative sign of the elasticity implicitly transcribes the fact that *the more one gains, the less probable it is that he is a student*. An increase in the revenue will econometrically be correlated to a decrease in educational activities, and thus a decrease in the trips that leads to them.

Interestingly, the single most important factor for the dimensioning of new transportation projects, namely the elasticity of public transport trips during the morning rush hour with respect to revenue, is very low ( $\varepsilon_{\text{PTWALK, Peak}} = -0.05$ ). This means that even crude estimations of the revenue variable will not alter substantially the results of the model. The equally low elasticities for the RER and Metro networks, reinforce this notion. It is probably having this behavior in mind that the current revenue estimations at the input of Antonin are indeed very crude: for example, the revenue is supposed to stay the same between 2025 and 2035. This analysis shows though that such an approach might be problematic in many ways: not only the trips can be attributed to the wrong motive (cadres / others / students etc), but it can also lead to a straight underestimation of the importance of the Optile network and an important modal shift towards private means. A proposition for Île-de-France Mobilités would thus be to link the revenue to the price index in order to correctly reflect the purchasing power of the households. In the technical notes I have reviewed for the IDFM team, provided by Significance, the firm behind the development of Antonin 3, and it is validated by the sensitivity analysis, the income is a significant predictor for almost all of the econometric components of Antonin 3. Thus, the need of a correct estimation of the revenue is evident. A final note in this section is that it is not clear from the technical notes whether the income variable has been adjusted to inflation. If it is unadjusted, it could possibly give important margins of errors in future forecasting scenarios: a 2% inflation rate could lead to a 25% decrease of the purchasing power of 1 euro in just 15 years.

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<sup>31</sup> Bound, J., & Turner, S. (2007). Cohort crowding: How resources affect collegiate attainment. *Journal of public Economics*, 91(5-6), 877-899.



### Sensitivity to the unemployment rate.

The unemployment rate variable is indirectly affecting Antonin through changes in the activity rate. Starting from the activity rate of the Institut Paris Region for 2035, and the unemployment rate according to the latest projections of the Insee, the new number of working-age adults having an employment has been calculated. The latter has been re-introduced to Antonin and the outputs have been used to calculate the elasticity with respect to change in the unemployment rate.

As it quickly becomes clear from figure 19, Antonin is largely insensitive to changes in the unemployment rate. The largest elasticity is the elasticity of Home-Work trips for the “Autres” socioeconomic category, is standing at  $\epsilon_{D-T, \text{Autres}} = -0.10$ , meaning that a 10% increase in the unemployment rate will lead to a 1% decrease in the number of Home-Work trips. The low sensibility can be partially explained by the fact that the unemployment rate is “hidden” inside the total inactivity rate (since the only related inputs in Antonin for each zone are the number of people in each zone and the number of working age population actually having a job), which also includes the part of the population in retirement, students and young children, the people that voluntarily do not work etc. Figure 20 puts this into perspective: a 50% percent increase of the unemployment rate leads to a mere 4.7% decrease in the total number of the active population having a job, an almost tenfold decrease. Interestingly, this also means that in order to calculate the elasticities of the selected indicators with respect to changes of the activity rate, one simply has to multiply the calculated elasticities by  $\sim 10$ .

$\Delta\%$ Unemployment Rate	$\Delta\%$ Economically active population
-50%	4.8%
-25%	2.4%
-10%	1.0%
+10%	-0.9%
+25%	-2.3%
+50%	-4.7%

Figure 27 – Change of the economically active population with respect to changes in the unemployment rate.

Given that Antonin’s inputs structure is difficult to change, being insensitive to the unemployment rate is not necessarily problematic since the contrary would mean that the

model is overly sensitive to the activity rate. For example, an indicator with an elasticity of  $\varepsilon=1$  with respect to the unemployment rate would lead to an elasticity of  $\varepsilon=10$  with respect to the activity rate, meaning that a 10% change would give a 100% change in the value of the indicator. Such changes in values are almost non-existent in the bibliography, where elasticities even for the most elastic goods rarely go beyond  $\varepsilon=4$  or  $\varepsilon=5$ <sup>32</sup>. The agents of Île-de-France Mobilités have also confirmed that the unemployment rate does little to affect the mobility patterns of the Region.

Be that as it may, all the signs of the calculated elasticities remain intuitive. At the exception of Walking mode and the Education purpose, all other elasticities are negative and reflect the reduction of transportation needs that goes with the reduction of the active workforce. Interestingly, trip generation for “Autres” is more elastic to changes in the unemployment rate than trip generation for the “Cadres”, reflecting the unfortunate fact that a rise in the unemployment rate affects disproportionately the more fragile socioeconomic classes ( $\varepsilon_{D-T, \text{Autres}} = -0.10$  vs.  $\varepsilon_{D-T, \text{Cadres}} = -0.06$ ). The positive sign for the education motif can be explained once again by the notion that the lesser the activity rate, the more the “students”, in this context meaning the part of the population that is commuting to and from educational activities<sup>33</sup>.

### **Sensitivity to the population aging**

The sensitivity of the model to an aging population is of much interest to Île-de-France Mobilités since it is overwhelmingly predicted that the percentage of people more than 60 years old will continue to increase. According to a recent study<sup>34</sup> by the Insee, forecasting population evolutions until 2050, the proportion of Île-de-France residents aged 65 or over will represent 21.9% of the population in 2050, or 2,884,000 Île-de-France residents, against 13.4% in 2013 (1.6 million Île-de-France residents).

Thus, the aim of this scenario is to evaluate the capacity of Antonin to model scenarios that include important changes to the population structure of Île-de-France. On that end, the population pyramid for 2035 (as it has been modeled by the Institut Paris Region) has been

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<sup>32</sup> Litman, T. (2004). Transit price elasticities and cross-elasticities. *Journal of Public Transportation*, 7(2), 3.

modified in the following manner: the percentage of people over the age of 60 years old (comprising of the categories 61-75 and >76 years old) has been increased by steps of 10%, while the other population categories have been proportionally decreased so that the total population stays the same. An overview of the result of the process can be seen in figure 28. The calculated elasticities in this section can be interpreted as the elasticity of each indicator with respect to the percentage of the population that is over 60 years old.

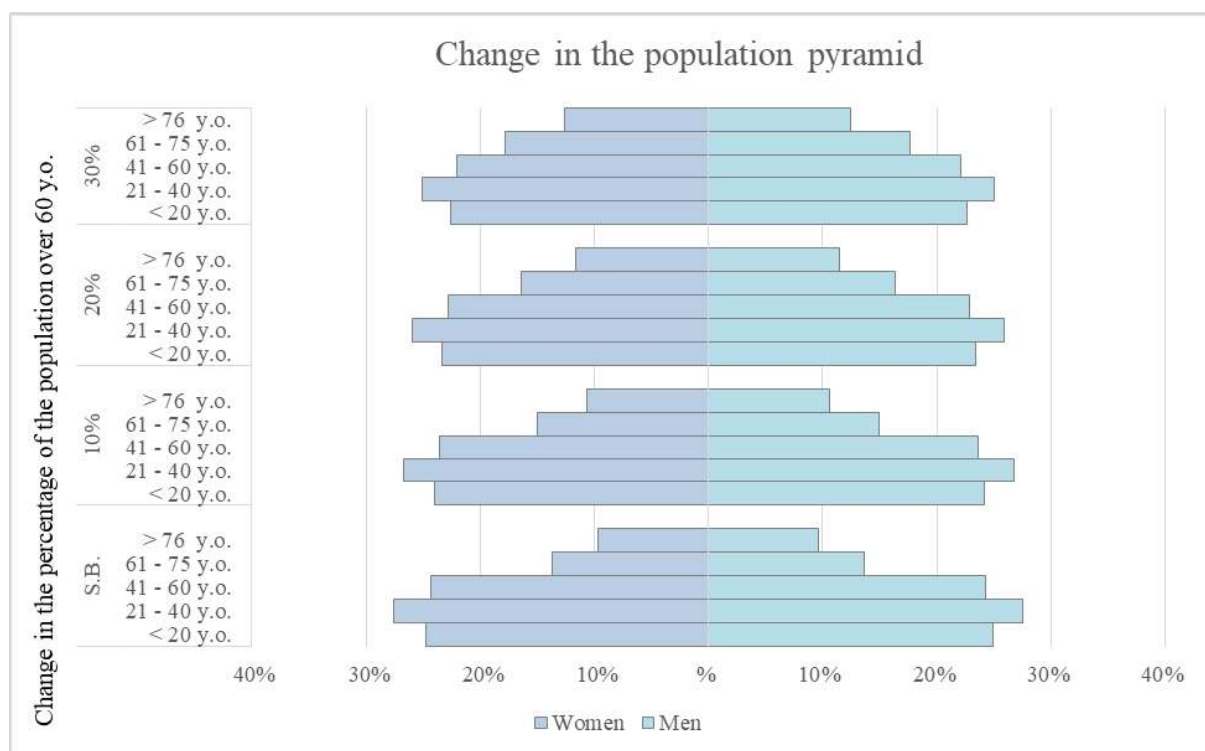


Figure 28 – Variation of the population pyramid

The results are once again the habitual: the most elastic indicator of the range of this test’s calculated elasticities are the trips with an education motive, whose elasticity was calculated at  $\varepsilon_{\text{Education}} = -0.49$ . Most of the other indicators are also negative, reflecting the reduced mobility needs of an aging population. As with the revenue scenario, the Home-Work trips have an opposite sign which can be attributed to the fact that the older an individual is, the more probable it is he belongs to the “Cadres” socioeconomic class. The trips by car during the rush hour also appear completely unaffected to changes in the age structure, with an equivalent elasticity of  $\varepsilon_{\text{CAR\_DR,Peak}} = 0$ . Since the activity rate remains stable, older population privileges private means to access their workplace (econometrically, the car drive is positively

<sup>34</sup> Poncelet, T., & Trigano, L. (2017). Mêmes vieillissante, l’Île-de-France resterait la région la plus jeune de France métropolitaine en 2050.», Insee Analyses Île-de-France à la page n° 62, juin 2017.

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correlated with a rise in the average age). Of course, this does not relate well to the observed reality where car usage diminishes not only between the >60 y.o. and 40 to 60 y.o age groups but also at the interior of the > 60 y.o. age group. While 48% of trips for 61-65 year olds are made by car, the figure drops to 26% for those over 81. For 61 - 65 year olds, 15% of car trips are made as a passenger, against 32% for those over 81<sup>35</sup>.

On the contrary, all public transit elasticities are negative ( $\varepsilon_{\text{Voykm(Metro)}} = -0.24$ ,  $\varepsilon_{\text{Voykm(RER)}} = -0.26$  and  $\varepsilon_{\text{Voykm(Optile)}} = -0.26$ , reflecting the increasing uneasiness of the elderly with respect to the public transport network. Finally, the elasticity of the total daily trips has been calculated at  $\varepsilon_{\text{Total Trips}} = -0.05$ , meaning that a 10% increase of the part of the population over the age of 60 will induce a 0.5% reduction in the number of total trips in Île-de-France. Although the absolute value of the decrease is not very substantial, it is certainly transcribes the fact that the constraints inherent in the different modes can lead to an outright renunciation of mobility for the elderly, a result that has already been discussed by Tillous (2014)<sup>36</sup>.

Of course, an important point of consideration is that the calibration of the model was done using the data of the EGT 2010, implicitly assuming a certain mobility behavior older people that might be completely different from that of the future. This discussion is integrated to a more broad research framework, with much of the literature on the topic where mobility needs and capacities are not constant in the life of an elderly person, but are likely to change with age and between different generations.

While seniors travel less than other age groups of the population, today's seniors travel more than seniors in the 1990s. Thus, in 2008, those over 65 made 25% of daily trips more than in 1994 (CEREMA, 2014)<sup>37</sup>. This phenomenon is unsurprisingly transnational: findings of U.S survey targeting the baby-boomers (defined as people born from 1946 to 1964, during the post-World War II baby boom) demonstrated that, after retirement, 90% of them expect to continue to learn, travel, and study, while 80% plan to be engaged in volunteering activities<sup>38</sup>.

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<sup>35</sup> STIF, IAU, OMNIL. (2013). Enquête globale transport – la mobilité des seniors.

<sup>36</sup> Tillous, M. (2017). Les voitures de métro réservées aux femmes comme instrument d'action publique: une réponse à quel problème?. Géocarrefour, 91(91/1).

<sup>37</sup> Cerema. (2014). Les seniors : un enjeu pour les politiques de déplacements

<sup>38</sup> Harper, S. (2014). Ageing societies. Routledge.

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New generations of retirees are also increasingly motorized, in a context of an overall increase in living standards over the past decade (INSEE, 2010)<sup>39</sup>. Many people still drive well beyond their 80s, and most older Americans depend on the car as their primary means of transportation until they can drive. Srinivasan et al. (2006)<sup>40</sup> people drive vehicles at an older age; 45% of 85-95 year olds were still driving in 2001, compared to only 36% in 1990. This tendency is only expected to grow stronger in the future. Accounting for the sex factor in car drive potency, in 2007 in France, 91% of men had a driving license compared to 76% of women, while in 1974 they were 32% compared to 70% of men (Demoli, 2014)<sup>41</sup>. This implies that for women of the older generations, the possession of a license and therefore the possibility of using the car alone is rarer, a tendency well inverted for the generations to come.

The structure of the job market is also subject to shifts affecting mobility characteristics: Recent studies have underlined the growing role of workers over the age of 60 in the labor market: new older workers, already more educated than the previous generations, healthy and productive for a longer time and have higher relative earnings<sup>42</sup>. Parallel societal changes such as having children later in life and the ever increasing cost of healthcare are contributing to the tendencies of working past the retirement age, which, on its part, is pushed further in order to reflect the rising life expectancy and to account for the pressure of the pension system.

In the light of the above, we could confidently posit that it is very difficult to model true perspective scenarios incorporating radical changes in the population behavior, as these have been bibliographically documented above. Doing this would entail a recalibration of the econometric parameters of the model with data derived from sources other than the EGT, something radically different from the current practice. For the time being, the model stays well within the limits of the potency of the EGT 2010 and its future versions, which, on the one hand assures its excellent predictive ability for non-disruptive scenarios, and on the other

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<sup>39</sup> Blanpain, N., & Chardon, O. (2010). Projections de population à l'horizon 2060 Un tiers de la population âgé de plus de 60 ans.

<sup>40</sup> Srinivasan, N., McGuckin, N., & Murakami, E. (2006). Working retirement: Travel trends of the aging workforce. *Transportation research record*, 1985(1), 61-70.

<sup>41</sup> Demoli, Y. (2014). Women take the wheel. *Travail, genre et sociétés*, (2), 119-140.

<sup>42</sup> Harper, S. (2014). *Ageing societies*. Routledge.

hands leaves a vast range of possible future phenomena out of its scope. For these reasons, Antonin seems more adapted to short-term “tactical” predictions, where the behavior of people can be assumed as stable and in conformity with the preferences revealed in the latest EGT, than long-term “strategic” ones, who in any case imply variations of the implicit commute patterns of Antonin 3 is based on.

### **Sensitivity to the employment positions.**

One of the particularities of Antonin is the way it incorporates the number of employment positions in the destination choice. In Antonin, choosing of the destination and the mode in Antonin happens simultaneously by the application of an econometric model that tries to recreate the decision making of each individual. In this process, the number of employment positions per zone functions as an attractiveness factor for each zone: the more the employment positions within the zone, the more attractive the zone becomes (especially for the Home-Work trips). In the case of Antonin, this attractiveness is proportional only to the ratio of the employment positions of one zone to the total number of employment positions in Île-de-France. Thus, adding new employment positions proportionally to the existing in all of Île-de-France will not change the final trip distribution and the modal choice, since the attractiveness of all zones rises uniformly.

While perhaps counterintuitive, this approach is defensible in the case of a disaggregated econometric model, where every zone generates trips towards every other zone based on the latter's attractiveness characteristics (obviously, for the most distant zones, the trips that are generated are practically zero). This however makes the elaboration of a global sensitivity test with respect to the total number of employment positions impossible. More insights on the behavior of the model in relation to the number of employment positions will be discussed later in the report through a prospective scenario concerning the employment position distribution between the East and the West of the Paris urban area.

A second particularity of the disaggregated nature of destination choice in Antonin 3 is that one individual is not necessarily attributed to one employment position. In the trip distribution phase of the classic 4-steps model, origins with destinations, are matched - often

using a gravity model-, by a calculation that takes into account the relative activity at the origin and destination as well as the travel cost to go between them. In the case of Antonin, there is no destination vector that will “anchor” the total number of e.g. Home-Work trips to no more than the employment positions in the destination zone. Instead, the econometric nature of the model treats the number of employment positions as one, indistinguishable (although with important weight to the final result), input among the other socioeconomic indicators of each zone. Figure 23 renders the latter visible by depicting the ratio of the Home-Work trips received by each zone to the employment positions of each zone. While inside Paris the ratio is about ~0.6 H-W trips by employment position, a figure that is comprehensible and expected given that not all employment positions generate trips on a given working day (mainly due to days off, maternity leaves, sick days etc.), there are other zones (in red) that receive (much) more H-W trips than the available employment positions. A more second look reveals that the concerned zones are mainly “difficult” ones, characterized by elevated poverty and unemployment rates. Interestingly, *the red zones of figure 23 are the zones that could potentially attract much more commuters if insecurity issues are dealt with.* The results of Antonin 3 show the potential attractiveness of these zones (who are mainly located close to major transportation corridors or in proximity to important employment poles), that is currently hampered by the lack of investments in office spaces due to the unappealing nature of these neighborhoods.

Symmetrically, the zones in deep blue are attracting less Home-Work trips than the available employment positions, and, in any case, less than those that are observed in reality. The most notable example is the zones around the “La Défense” business district. The reason sheds light on one of the limits of the models (and most probably, every equivalent model): in the case of “La Défense “ the lower amount of trips stems from the inability of Antonin 3 to account for the “additional attractiveness” of the pole due to its symbolic status in the Parisian agglomeration and in the mind of the Parisians, that allows it to attract commuters from much further away than it would normally do. This problem has been already identified by Île-de-France Mobilités, and in the case of “La Défense”, in order to achieve realistic public transport charges, an ad hoc correction is applied by manually doubling the trips destined to the sector.

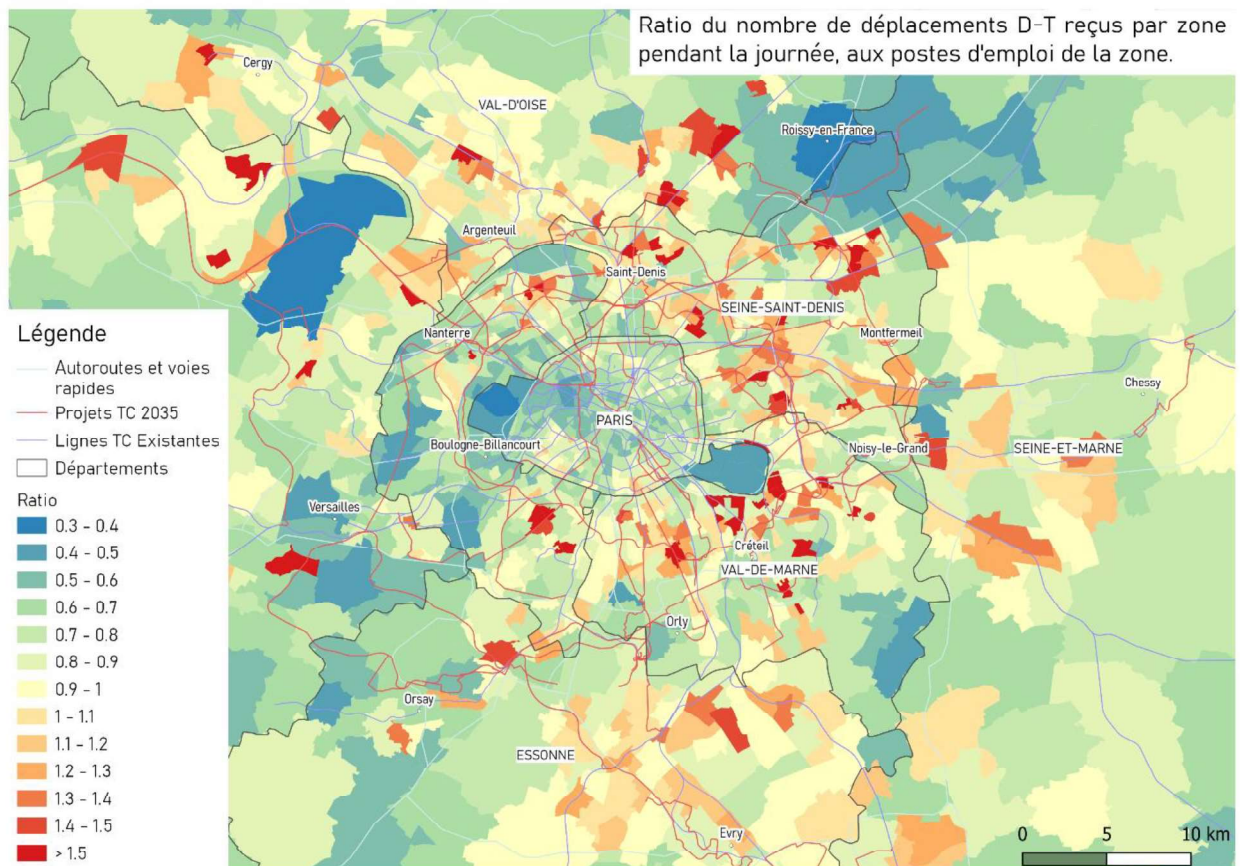


Figure 29 – Ratio of received home-work trips by zone in relation to the available employment

### Tests acting on the mode and destination choice.



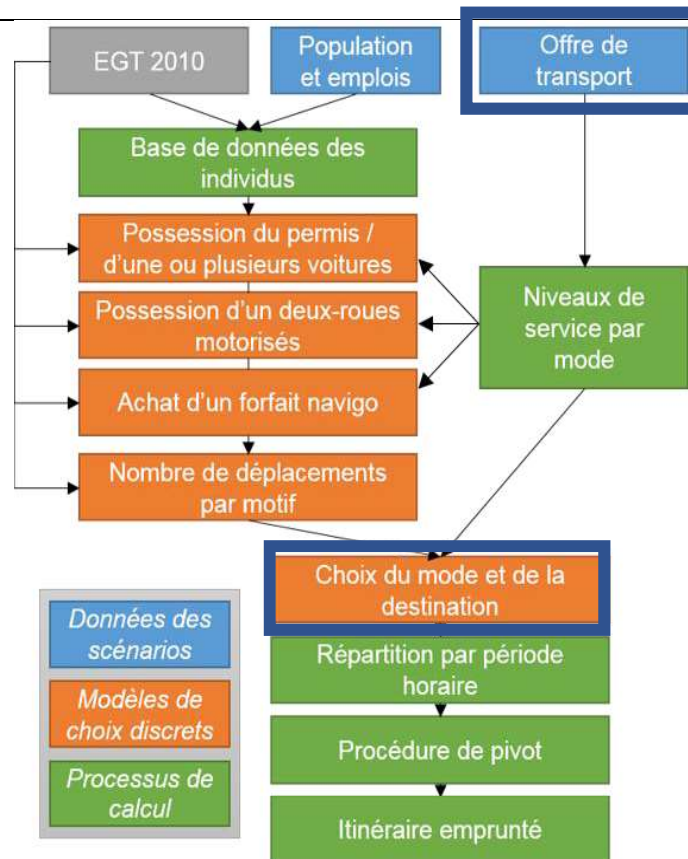


Figure 30 - Schematic functioning of Antonin 3. This range of scenarios changes the “Offre de Transport” input variables of the model. Source: Île-de-France Mobilités - Antonin 3 Manual

The second series of tests goal has been to determine the sensitivity of Antonin with respect to the costs of fuel and public transport. These costs are included in different stages of Antonin:

- The cost of public transport is taken into account along with the population characteristics and it affects the probability of purchasing a Navigo monthly pass. The marginal public transit costs are then included in the composite cost (including time and a component that refers to opportunity cost – the cost of not having chosen a different mode), which will define the probability of choosing a certain mode through a logit model.
- The cost of fuel is only in the modal choice and the logit model and it is a component of the total car cost.

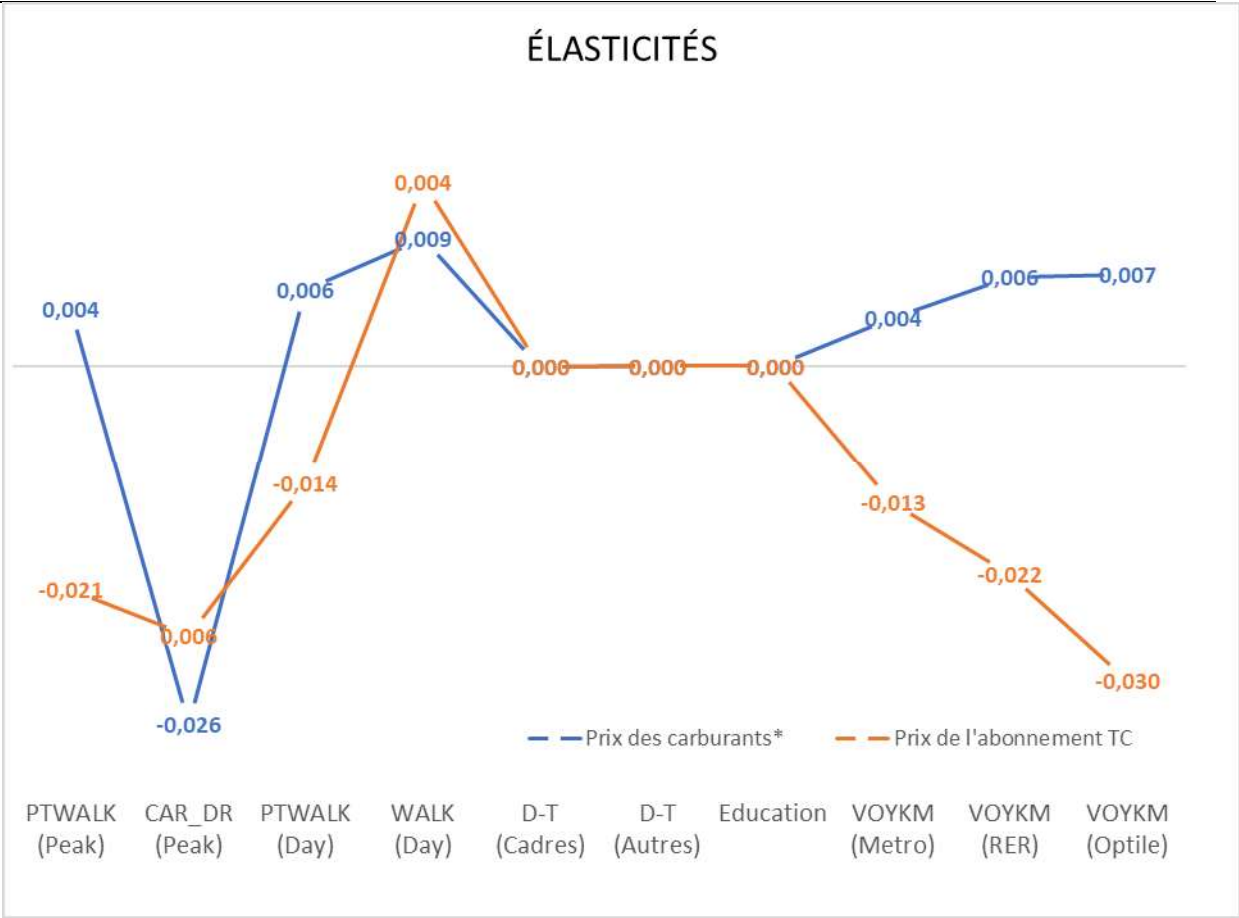


Figure 31 – Elasticities with respect to the Navigo card & fuel prices.

**Sensitivity to the Navigo price**

As it can quickly be seen from the calculated elasticities in figure 31, the model remains largely unaffected from changes in price for changes for both scenarios: all elasticities are zero for all practical purposes. Be that as it may, the elasticities’ signs remain coherent to what one would expect. It is interesting to note that, in conformity to most transportation modeling approaches, the choice of whether one will commute or not is dependent only on his socioeconomic characteristics (more precisely, the characteristics of his zone of origin), as those are captured by the EGT 2010. Changes in different transportation costs are taken into account only later, in the combined choice of the mode and the destination. Numerically, this can be seen in the elasticities of the Home-Work trips (D-T) and the trips with an educational motive, that are exactly equal to zero.

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This result is in contradiction to much of the existing literature. The classic Simpson-Curtin rule<sup>43</sup> proposes an elasticity with respect to price at -0.33, meaning that a 10% increase in the price of public transport reduces their attendance by 3.3%. While certainly simplistic, this value is generally accepted and corresponds to a reasonable estimation compared to all the estimates made in the literature<sup>44</sup>. In a meta-analysis of 81 studies, Holmgren (2007)<sup>45</sup> shows that elasticities with respect to price take values ranging from -0.009 to -1.32, with an average value of -0.38. Small and Verhoef (2007)<sup>46</sup>, for their part, believe that a simple rule is to consider that this elasticity is around -0.4. Finally, Chen et al. (2011)<sup>47</sup> show that in New York, use of public transport decreases significantly when its price increases, but increases little when its price decreases.

Once again, the reason for the difference between the literature and the actual results of Antonin 3 is the hegemonic position of the public transport system within the region: the general consensus among the agents of Île-de-France Mobilités is that even a significant change in price would not change radically the demand. The high car costs, the difficulty of finding a parking space inside Paris and the unaffordability of private parking spaces and the reliable public transport offer in the densely urbanized poles of Île-de-France make the best part of the population insensitive to changes in the price of a Navigo Pass, basically due to the lack of viable alternatives.

In the meanwhile though, an increase in the Navigo price is a recurrent and highly politicized theme in the news: the latest implications of an impending increase have been expressed by Valérie Pécresse (president of Île-de-France Mobilités), in the midst of the coronavirus lockdown that drained the financial resources of Île-de-France Mobilités. Thus, taking also into consideration the interest of the Public Transit Authority to this question, a more detailed analysis of evolutions in the Navigo Price will be included in a following section.

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<sup>43</sup> Litman, T. (2019). Transit price elasticities and cross-elasticities. Victoria, Canada: Victoria Transport Policy Institute.

<sup>44</sup> Deguitre, L. & Courel, J. (2020). Les déterminants du choix modal - Synthèse des connaissances scientifiques. Institut Paris Region

<sup>45</sup> Holmgren, J. (2007). Meta-analysis of public transport demand. *Transportation Research Part A: Policy and Practice*, 41(10), 1021-1035.

<sup>46</sup> Small, Kenneth & Verhoef, Erik. (2007). The Economics of Urban Transportation. *The Economics of Urban Transportation*. 1-276. 10.4324/9780203642306.

<sup>47</sup> Chen, C., Gong, H., & Paaswell, R. (2008). Role of the built environment on mode choice decisions: additional evidence on the impact of density. *Transportation*, 35(3), 285-299.

### The fuel cost variable in Antonin 3

Fuel price is taken into account as a trip cost factor in Antonin 3, affecting the cost of the different transport alternatives and thus, their probability to be chosen by the user. More precisely, fuel price is modeled as a component of the total cost of car ownership, which is applied only on the car driver mode. The actual total car cost is 0.325 €/km, and it is based on a study done by ADETEC in 2012<sup>48</sup>. This figure is calculated as a linear approximation between the values 0.31 €/km and 0,34 €/km that have been estimated for 2008 and 2012 by ADETEC respectively. The total car cost is supposed to stay the same up to year 2029, while from year 2030, a flat 20% increase is applied. Apart from fuel, the total cost also includes lubricant, toll, insurance, maintenance and depreciation costs, and it is broken down as it follows:

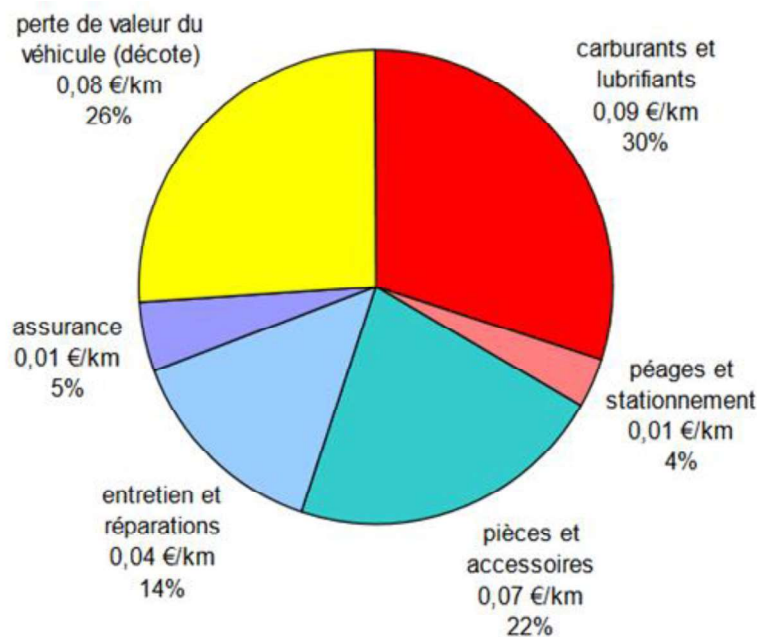


Figure 32 - Car Cost per Km. Source: ADETEC

The coded car prices have a certain crudeness that is inconsistent to the very detailed data used at other parts of Antonin 3. ADETEC data could be considered as outdated, while it is certainly counterintuitive to consider that the car cost will stay the same between 2008 and 2029. The 20% cost increase after 2030 is not supported by bibliographical references. The

<sup>48</sup> ADETEC. (2012). Le coût réel de la voiture.

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practice of using the total cost of ownership as the determinant in the modal choice is an almost textbook example of the classic economic concept of total costs versus marginal costs through the critical question of *what does a car user really perceives as the cost determinants of his modal choice?*

There is a limited, yet enlightening bibliography related to the relationship between actual and perceived value of the car costs. Henley et al. (1981)<sup>49</sup>, have estimated that most auto users were unable to articulate driving costs for the work trip. Even after the dramatic changes in fuel prices at the beginning of the 80's, individuals in the study area still underestimated driving costs although there were able to provide more accurate cost estimates. Shiftan and Bekhor (2002)<sup>50</sup> have suggested that it is the private variable costs that affect the travel choice in the short run, while the private fixed costs for a car as interest, insurance, taxes, vehicle inspection, parking place at home and time-dependent car depreciation should affect the decision of owning (another) car, and thereby affect the possible travel choices in the long run. Indeed, the researchers have showed that while 96% of their drivers' sample takes at least fuel cost into account when using the car, it is only 38% that also consider at least a second cost source such as insurance, maintenance or depreciation costs. Only a mere 5% of the respondents that considered all of the study's costs (fuel, insurance, maintenance and depreciation), while a 3% considered no costs at all. Similarly, Glazebrook (2009)<sup>51</sup>, working in the perceived cost of transport modes in Sydney, points out that the "out-of-pocket" cost is the cost most likely to be perceived by the traveller and which will affect travel choices.

At the same time, car costs in general and fuel costs in particular are usually used not only to calculate the trip cost of different transport alternatives but can also define to the access of the individuals to a private vehicle, limiting their actual transportation choices upstream. Thus, it must be included in the car possession module of Antonin 3. Detailed analysis has shown however that, during the re-estimation of the parameter of the car possession module of

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<sup>49</sup> Henley, D., Levin, I., Louviere, J., Meyer, R. (1981). 'Changes in Perceived Travel Cost and Time for the Work Trip During A Period of Increasing Gasoline Costs.' *Transportation* 10 (1981) 23-34

<sup>50</sup> Shiftan Y. & Beckhor S. (2002), 'Investigating Individual's Perception of Auto Travel Cost'. *International Journal of Transport Economics* Vol. 29, No. 2, pp. 151-16.

<sup>51</sup> Glazebrook G. (2009), 'Taking the Con Out of Convenience: The True Cost of Transport Modes in Sydney'. *Urban Policy and Research* Volume 27 - Issue 1

Antonin 3 the car cost variable has not been included in the final econometric formula to the absence of fuel consumption data for years 1976 and 1983 that impeded the accuracy of the and a recent study by Cornut in 2016 (referenced in the Antonin 3 manual) which did not find significant results for fuel data cost on car ownership based on the same data. The direct implication of the latter is that in Antonin 3, changes in fuel price do not lead to changes in car possession, meaning that it is impossible to model reliable rupture scenarios, where high variations of fuel prices would lead to equally important car use changes and shifts to the public transport.

Recourse to the existing literature enlightening: Calvet and Marical (2011)<sup>52</sup> have studied the relationship between the price of fuel and household fuel expenditure based on the Insee Family Budget survey. They have showed that the short-term price elasticity of fuel is quite low (between -0.25 and -0.35), resulting to low adjustment of household consumption according to short-term price changes. On the other hand, in the long term and provided that the changes in consumption resulting from the changes in prices observed in the past are reproducible, the adaptation capacities are strong: households might choose to buy a car with lower fuel consumption or abandon the car altogether. The calculated elasticities are between - 0.6 and - 0.7 and are higher for modest and urban households who are more prone to change their behavior in the light of price changes.

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<sup>52</sup> Calvet, L., & Marical, F. (2011). Consommation de carburant: effets des prix à court et à long terme par type de population. *Economie et statistique*, 446(1), 25-44.

## Part 3: Forecasting Scenarios in Antonin 3

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In the final part of this paper, the insights of the sensibility tests are used in order to model four forecasting scenarios, whose goal is mainly to evaluate the mobility implications of political choices that are probable (or less probable for that matter) to happen in the future. Of these scenarios, it is highly probable that three will be the object of a future detailed study by Île-de-France Mobilités. Thus, the aim is to give a concise first “reading” of the situation, which will steer the future efforts of the team, than perform a complete mobility analysis. The “Est-West” unbalance scenario, a purely theoretical exercise, is mostly intended to complete the discussion that started in the elasticity with respect to employment chapter, and provide a deepened look in Antonin 3’s mechanisms.

### **Boulevard Peipherique: Modeling of a decrease in the maximum allowed speed.**

The Paris ring road, locally called Boulevard Périphérique, is a circular lane, 35.04 km long, which circles the city of Paris. A strong link in the structuring network of the Île-de-France region, the ring road is the only motorway ring road so close to the heart of a major urban area. While the car's modal share is declining in the center of the agglomeration, traffic on the ring road is still heavily congested and represents 1.1 million daily trips, or 35 to 40% of Parisian traffic, and more than 250,000 vehicles per day and per direction on its most frequented sectors<sup>53</sup>. The Boulevard Périphérique is also notoriously congested: In 2018-2019, the section of the inner ring road between Porte de Charenton and Porte de Bercy is saturated or blocked 36% of the daytime (7 am-9pm)<sup>54</sup>. Due to its large frequentation and recurring traffic jams, the ring road generates significant pollution, in particular high atmospheric pollution: the Boulevard Périphérique is single-handedly the source of the 1/6 of azote dioxide pollution inside Paris, where one in two inhabitants is exposed to emission levels that can be twice the maximum tolerated level<sup>55</sup>. Notice pollution is equally notable: more than 100,000 inhabitants live in a 150m buffer area around the Boulevard Périphérique,

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<sup>53</sup> Lévêque, F. (2019). Le Périphérique parisien, des nuisances mais aussi des bénéfices (No. hal-02152850).

<sup>54</sup> Cosnard, D. (2019), « Grand Paris : mais que faire du périphérique ? », sur lemonde.fr.

<sup>55</sup> Azière, E. (2019). Le périphérique, quelles perspectives de changements?

out of which 40,000 are exposed to noise levels that are beyond the maximum allowed levels<sup>56</sup>.

With that in mind, the current mayor of Paris, Anne Hidalgo, the called for a vast consultation on the future of the Paris ring road, concretized in the report of the Information and Evaluation Mission (MIE) of the Paris Council of May 2019<sup>57</sup>. The report included 40 propositions which aim at alleviating the atmospheric and noise problems, and at the same better integrating the ring road to the urban tissue of Paris, minimizing the urban discontinuities. The cornerstone of the plan is to transform the currently elevated highway into an urban boulevard, with vertical signalization which will allow pedestrians to easily cross it.

The latter will be also included by a speed limit of 50 km / h from the outset, the next step to a long tradition of ad-hock speed regulations in the boulevard. The last lowering of the maximum speed from 80 km / h to 70 km / h, carried out in 2014, made it possible to reduce polluting emissions and to make traffic more fluid, since the average speed of traffic which amounts to only 35 km / h on the ring road<sup>58</sup>.

The objective of the following modeling exercise will thus be to model the effects of the



beforementioned speed reduction, always positioning ourselves from an employment point of view.

Figure 33 - The Boulevard Périphérique. Source: Jean-Baptiste Gurliat - Ville de Paris

<sup>56</sup> Idem

<sup>57</sup> Idem

<sup>58</sup> Idem



## Modeling Results

The effects of the proposed decrease of the maximum allowed speed do not weight a lot on the mobility in Île-de-France and, in any case, they are largely localized around the trace of the Boulevard Périphérique. The reason for the latter can be traced back to the fact that the maximum allowed speed cannot be realistically achieved for the most part of the working day and especially for the morning rush hour, where the increased demand imposes much more moderate maximum speeds. Thus, a change of the maximum allowed speeds only affects the off-peak flow, which represents a small part of the total daily traffic flow. This can explain why, while certainly intuitive, the changes in the mobility characteristics after a decrease in the maximum allowed speed are of a mostly limited scope.

Unsurprisingly, the reduction in maximum speed affects the car trips that are received by the zones adjacent to the Boulevard Périphérique. Figure 34 depicts the number of received home-work trips by car in 2035, after the implementation of the 50 km/h speed limit. The effects of the changes, although marginal for the reasons explained above and not exceeding a reduction of 1.5% in the number of daily trips in the worst of cases, are mostly presented around the zones encircling the Boulevard Périphérique. One can note a certain imbalance: the reduction in car trips is mostly looking outwards and towards the Petite Couronne than towards Paris, confirming that the relatively limited use of private vehicles in Paris city center makes it largely indifferent to changes affecting private mobility. On the contrary, there are zones situated for example far inside the department of Yvelines, whose proximity to the feeder highways of the Boulevard Périphérique (in this case the A13), makes them prone to get affected by changes in it. The same phenomenon also exists in the north towards Saint-Denis and in the south towards Orly, along the traces of A1 and A6 respectively.

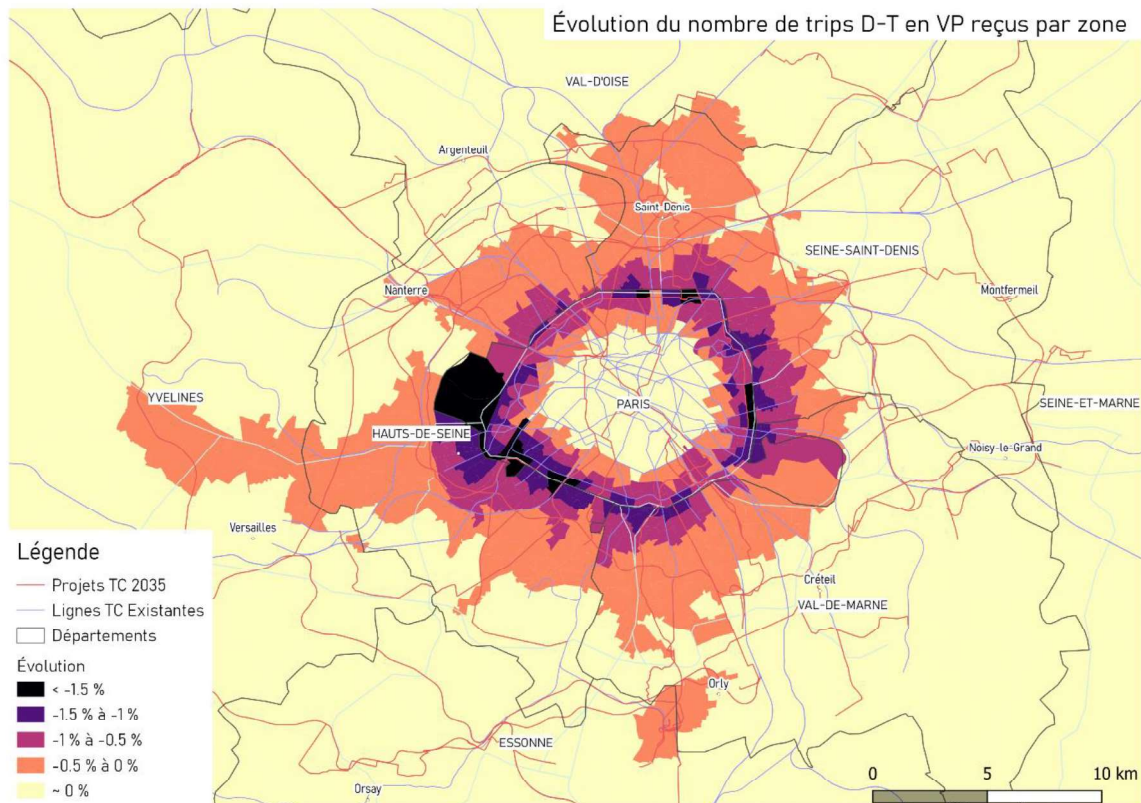


Figure 34 –Home-Work car trips received by zone.

The increased difficulty in the use of a private car makes public transportation more attractive. Figure 35 shows the change in public transit's modal share for the home-work trips received by zone. Although limited once again (in the best case scenario, public transit's modal share gains between +0.2 and +0.3 points<sup>59</sup>), the results prove that a decrease in speed, which is formally an increase in the composite score of the car mode, can lead to an increased public transit demand and a modal shift, similar to other measures such as the implementation of congestion charge zones and other forms of road pricing, parking measures and others.

<sup>59</sup> A +0.3 point increase in this context means that public transit's modal share for a given zone would, for example, pass from 39.7% to 40.0%

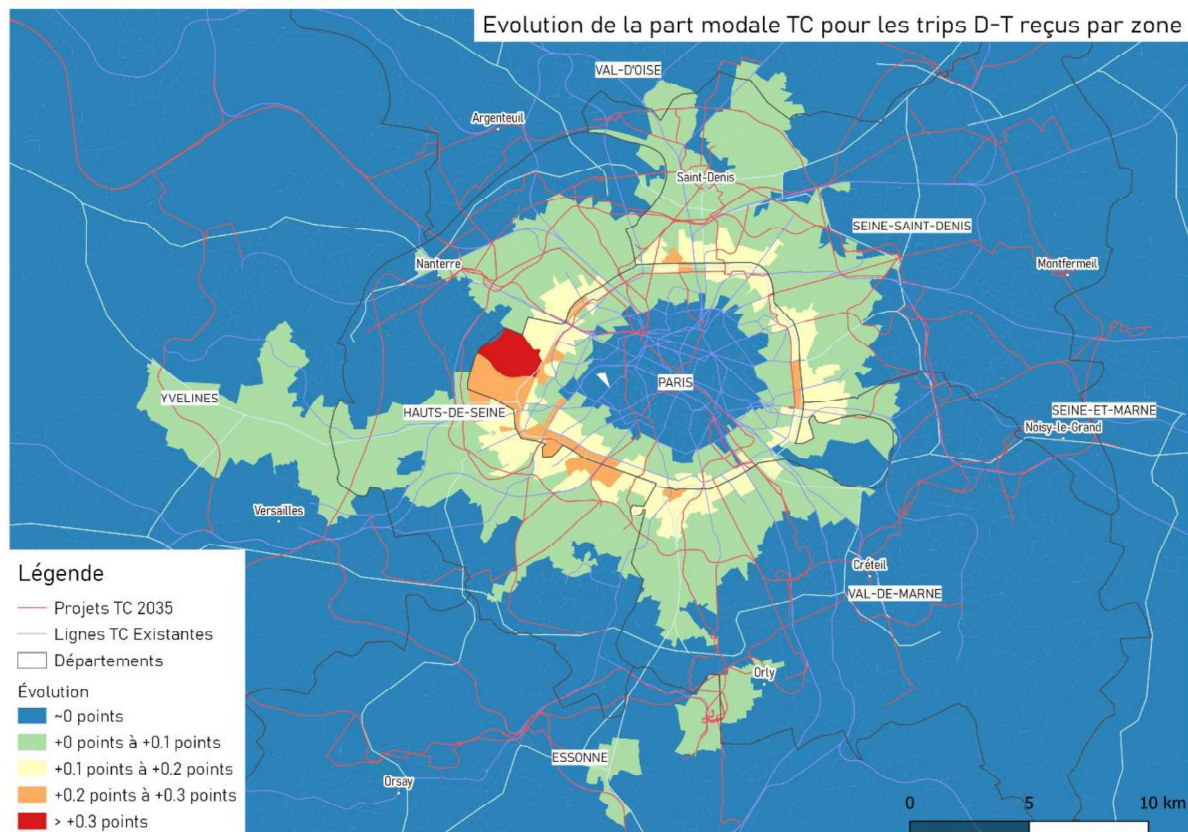


Figure 35 – Evolution of the modal share of public transit for the home-work trips received per zone.

The question that arises though is whether the modal shift to public transport can completely cover for this “loss of attractiveness” of the zones adjacent to the Boulevard Périphérique for car users, presented in the form of a general reduction of received home-work trips. Figure 36 answer this question, by depicting the *total* number of received home-work trips. It is clear that the answer to the previous question is negative: the shift to public transport does not cover for the total loss of received home-work trips, with most of the zones in close proximity to the Boulevard Périphérique losing between 0.25% and 0.5% of the received trips in comparison to the base scenario of 2035. One of the reasons for that is that the public transportation network serving the periphery of Paris is less dense than the one serving the city center and, at the same time, highly directional towards it. This important structural difference is in contrast to the functioning of the Boulevard Périphérique who mainly accounts for the lateral movements of commuters who completely bypass the city center. This qualitative difference means that the road and transport networks are not entirely complementary in this case. (Of course there is the T3 tram line that runs in parallel to the

Boulevard Périphérique, but, aside for the augmented capacity, the rest of its characteristics (average speed, headway etc.) are not so much different than those of a bus line to be able to effectively compensate for the diminished attractiveness of the Boulevard Périphérique). Of course, not all users are ready or able to abandon their car, for reasons that will be discussed shortly.

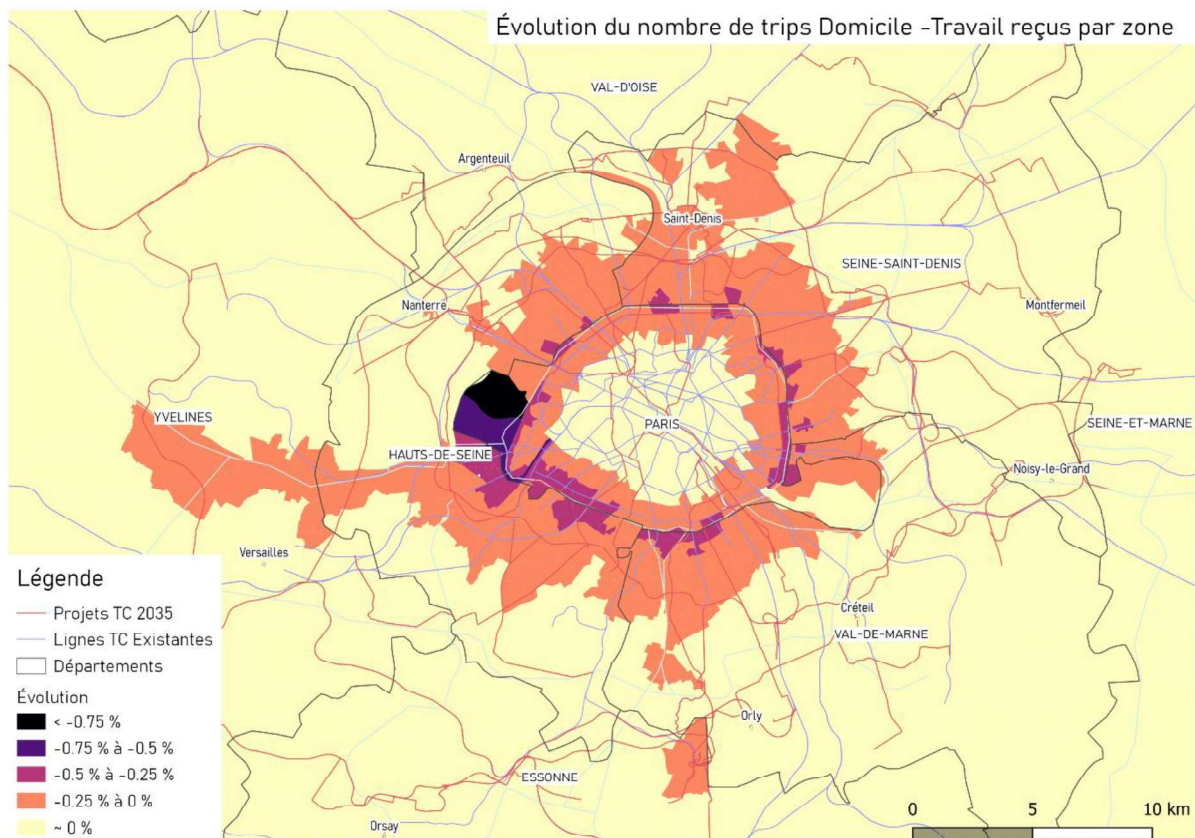


Figure 36 – Total Home-Work trips received by zone.

This reduced overall attractiveness of the zones in proximity to the Boulevard Périphérique is also reflected by the reduced average distance of the received car trips (Figure 37). The increased “difficulty” of reaching the zones in proximity to the Boulevard Périphérique, increases the total composite cost of reaching them, and thus, the distance that one is willing to cover in order to work there is decreased by 0.75% to 1.25% for most sectors.



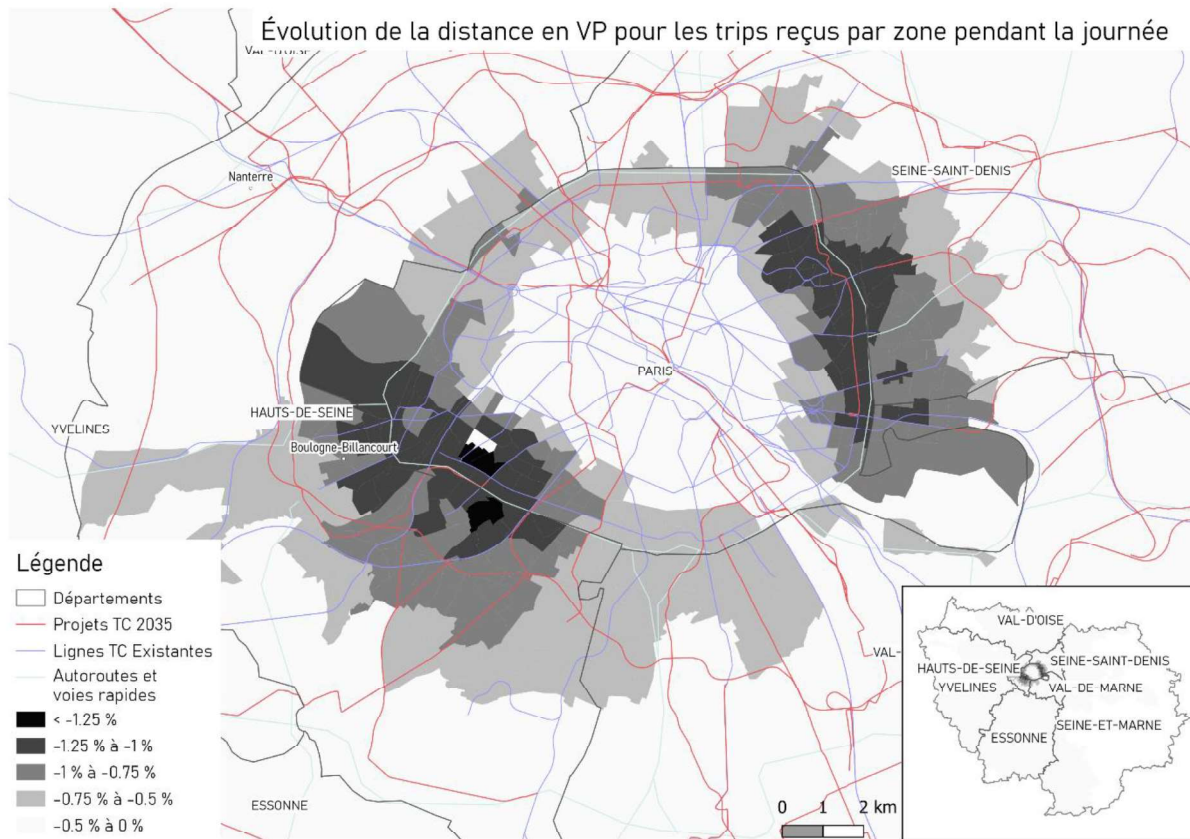


Figure 37 – Change in the average distance for the home-work car trips received by zone.

A final remark of the section would be to note that certain visual homology between Figures 34, 35 and 36: although the metrics and the scale are dissimilar, the zones that are most affected by changes in speed belong to the same geographic regions, if they are not outright the same. And although it is mostly evident that the zones that are completely adjacent to the Boulevard Périphérique will always be affected, it is of interest to record which of the rest of the zones constitute a certain *sphere of influence*, which is prone to get affected even though it is not directly situated on the path of the project. Unsurprisingly, the single most important determinant is position: being close to one of the feeder motorways of the Boulevard Périphérique and inside the A86 means that a zone is highly susceptible to be affected by any change affecting the Boulevard Périphérique.

### Balancing the Est-West employment unbalance

A well-known particularity of the Paris urban area is a certain unbalance in the employment offer between the East and the West suburbs of the city. In total, Île-de-France represents 6.2

million jobs out of the 27 million in mainland France (2016 figures)<sup>60</sup>. Within the region, Paris and the Hauts-de-Seine at the west of Ile de France alone account for nearly half of the jobs with 31.6% and 17.39% of jobs respectively. Those disparities do not seem ready to be reversed: According to the 2018 workforce needs survey carried out by Pôle Emploi<sup>61</sup>, 418,231 recruitment projects were in Île-de-France out of a total of 2.3 million in France. And of these 418,231 projects, 52.60% are located in Paris or in the Hauts-de-Seine while the remaining 6 departments share the remaining 48%. The difference in job disparities is also qualitative: Hauts-de-Seine at the west and Paris respectively account for 42.2% and 34.7% of executives in Île-de-France, against 15.8% in Seine-et-Marne and 17, 8% in Val d'Oise. Statistics also reveal the corresponding imbalance in the location of office property: out of 12.5 million square meters that have been constructed during the 2008-2018 period, more than 6.3 million are located in 92, or 42%. On the other hand, surfaces in the outer suburbs are very low, particularly in Seine-et-Marne, at the East of Île-de-France (only 1% of surfaces). At the same time, housing is equally unbalanced<sup>62</sup>: the eastern parts of Paris urban area and especially the eastern part of Seine-Saint-Denis and the north-east part of Val-de-Marne are highly urbanized, while the western parts of the urban area where the most important employment clusters are situated are less dense (Figure 38)

The obvious question is how this territorial unbalance affects employment and access to opportunities. Gobillon et al. (2011)<sup>63</sup> have shown that only 30% of the differences in unemployment duration between individuals can be explained by their individual characteristics. The remainder is explained mainly by the degree of their neighborhood, as well as, to a lesser extent, by the accessibility to jobs Comparing the unemployment rate between African immigrants and French, carried out by Gobillon et al. (2015)<sup>64</sup> has equally shown that between 17% and 25% of the difference in the unemployment rate could be explained by spatial characteristics, most of it coming from the longer commuting times of African immigrants and therefore from a greater distance from jobs. In the USA, Marinescu

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<sup>60</sup> Chiffres Clés Direccte 2018.

<sup>61</sup> Pôle Emploi. (2001). Enquête sur les besoins de main d'oeuvre 2018

<sup>62</sup> Question orale n° 1531S de M. Christian Favier publiée dans le JO Sénat du 29/09/2016 - page 4125

<sup>63</sup> Gobillon, L., Magnac, T., & Selod, H. (2011). The effect of location on finding a job in the Paris region. *Journal of Applied Econometrics*, 26(7), 1079-1112.

<sup>64</sup> Gobillon, L., & Solignac, M. (2015). Homeownership of immigrants in France: selection effects related to international migration flows.

and Rathelot (2018)<sup>65</sup> showed that American job seekers were 35% less likely to apply for a job located more than 16 kilometers from their place of residence.

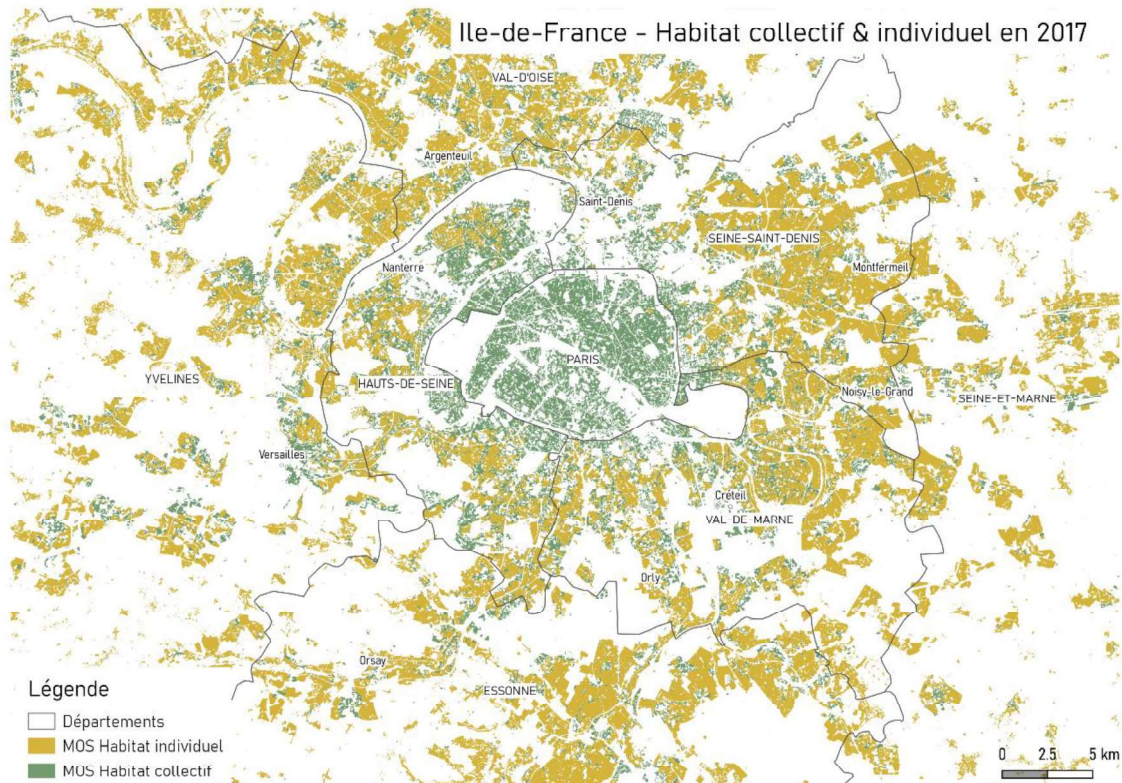


Figure 38 - Individual & collective housing in Île-de-France: note the East-West housing unbalance (2017 MOS data)

Aside from the socioeconomic implication of this imbalance, the effects on the transportation network could also be important: a larger distance between the employment demand and offer might lead to a longer average Home-Work trip, which could correspond to more time spent onboard and to a bigger charge of the public transit network.

In order to shed more light on the effects of this imbalance and observe the possible results of a “rebalance of the territory”, a forecasting scenario has been developed along the following lines: Two zones have been identified at the east and the west parts of the Paris urban area, roughly corresponding to the most densely urbanized parts of Hauts-de-Seine and Yvelines (West), eastern urbanized parts of Val-de-Marne and Seine Saint-Denis, as well as the best

<sup>65</sup> Rathelot, R., & Marinescu, I. (2014). Mismatch unemployment and the geography of job search. Which way now? Economic policy after a decade of upheaval, 80.



part of Marne-la-Valle (East). Using the inputs of the latest available Population+Emploi database for 2025 and 2035, the location of the employment positions in Île-de-France has been altered as it follows:

- At the identified zones of the west of Paris urban area, the change rate of the employment positions has been “frozen”: the total number of the employment positions as well as their allocation is considered to stay unchanged between 2025 and 2035. This leaves a total of 97,300 “unallocated” employment places.
- The unallocated employment places are reassigned at the eastern zones of Île-de-France, in proportion to the employment places that are already in place so as to respect the existing employment polarities of the territory. This gives an average employment places increase of 14.1%.

The zones in the east and west of Île-de-France that are primarily concerned by this unbalance have been defined with the help of Anne-Eole Meret-Conti, head of the Observations & Forecasting department and they are shown in figure 39:

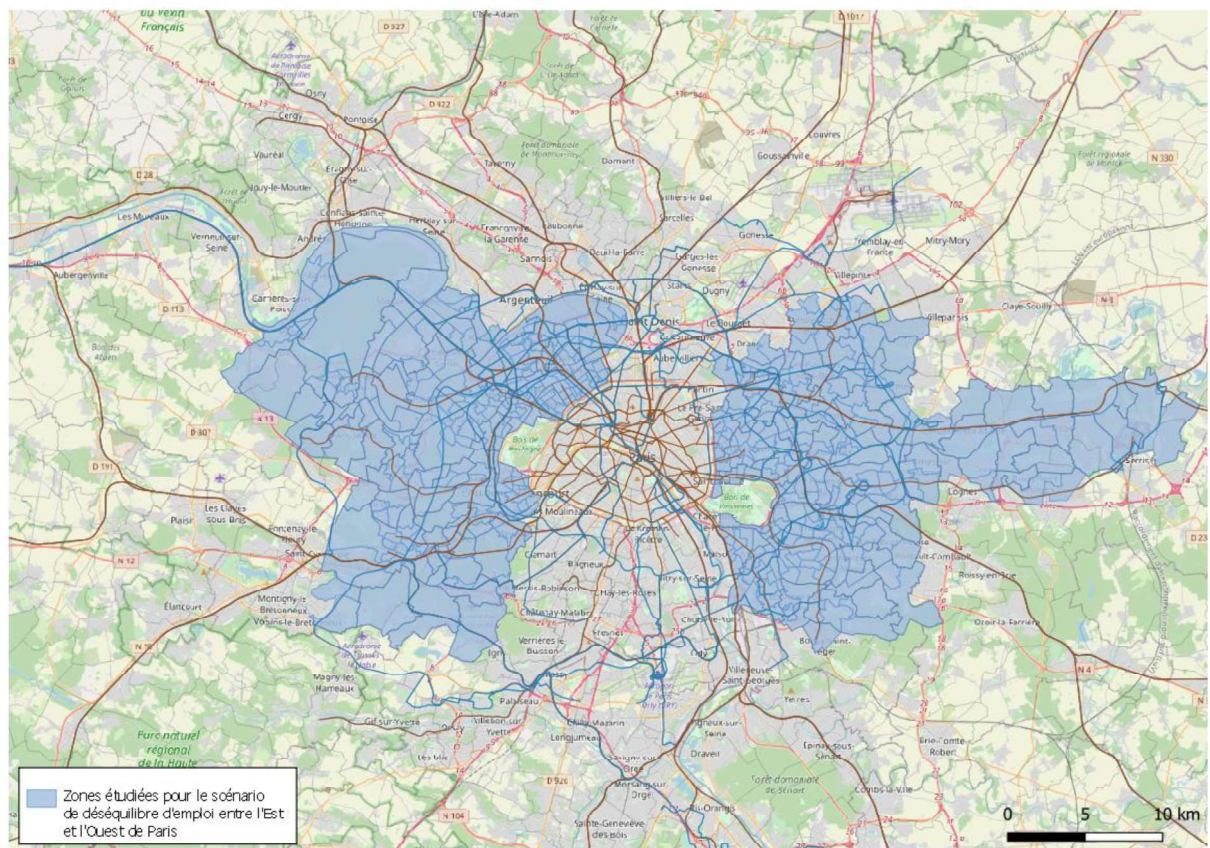


Figure 39 – Identified zones for the Est-West employment unbalance scenario



The first indicator that was calculated is the Home-Work trips by public transit received by zone. The results are intuitive: at the east of the city, the zones that have seen a decrease in their employment positions face an almost equivalent decrease (~1% decrease in employment positions leads to a ~1% decrease in received Home-Work trips). The zones in the east that retain their employment positions also see a very slight increase in their received Home-Work trips since their *relative attractiveness increases due to the decrease in the attractiveness of their neighboring regions*. The results are perfectly symmetrical for the west of Île-de-France, where the increased attractiveness of the employment core of the region acts like a vortex and captures Home-Work trips (and thus commuters) from a wide area (in yellow) that is connected with it both geographically but also in terms of public transportation. Note for example that Arpajon, although geographically at the west, is better connected with the east of Île-de-France due to the trace of railway lines, used by the RER C, which is the main public transportation mode connecting it with Paris.

It might still be a counterintuitive how employment shifts close to Paris can have this far reaching effect to the totality of Île-de-France. Two points are worth noting:

- The econometric nature of Antonin 3 is transcribed in its disaggregated outputs, meaning that, in comparison to the classic 4 steps transportation models, each trip can in fact be divided into an infinite number of parts. Thus, each of the 1805 Antonin zones is connected to every other zone, meaning that there are inbound and outbound trips between them, even if those trips are almost zero. In short, the nature of the model does not allow for a zone of the model to be isolated from the other zones or from the respective changes in them. A change in a zone will cascade all other zones.
- Accordingly, changes in Home-Work trips by public transit in zones far from the focus areas of this scenario are very marginal and almost zero for all practical purposes, but still visible in a cartographical depiction of the area.

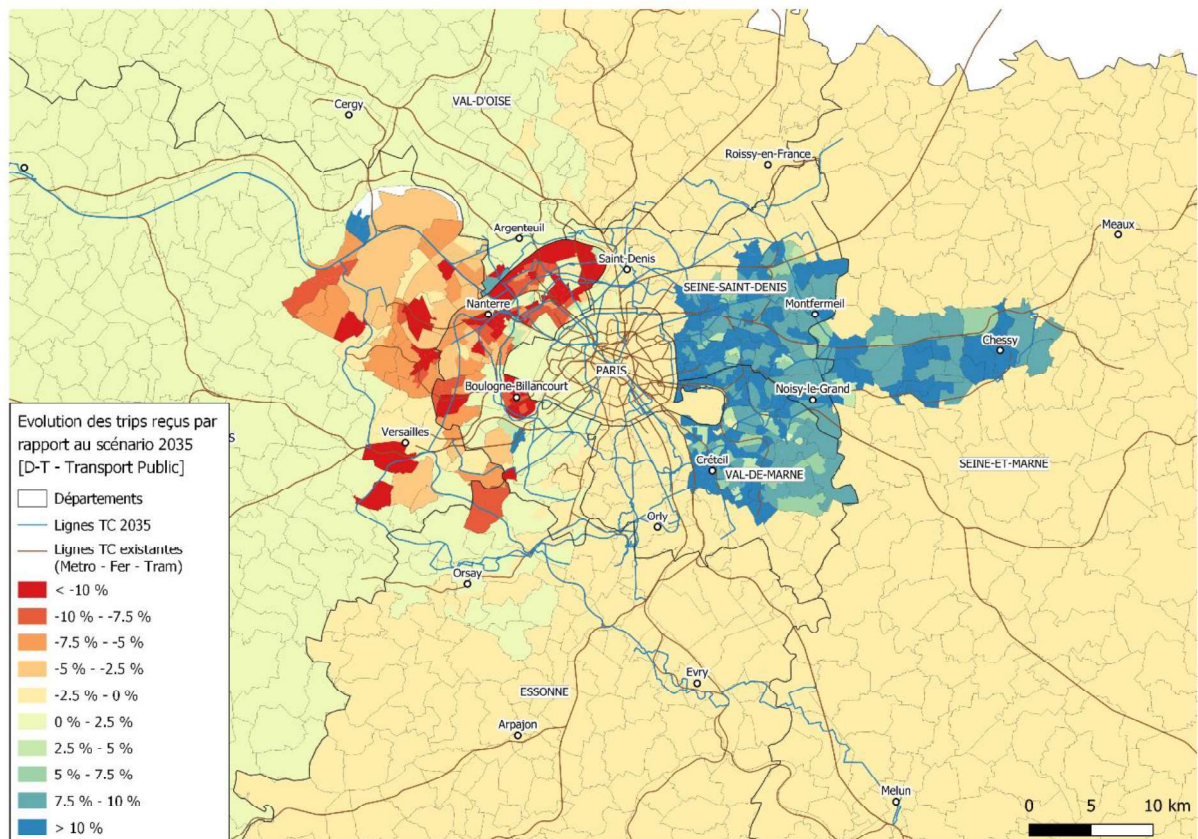


Figure 40 – Evolution of the home-work public transit trips received per zone

After quantifying the change in the employment attractiveness of Île-de-France, the subsequent analysis will need to include changes in the commute pattern, mainly in terms of the average commuting distance. The increased spatial proximity of the employment positions to the more populous communities at the east of Île-de-France could lead to a decrease in the average travelling distance that would imply a possible relief in the pressure on the transportation system, especially during the morning rush hour. For that matter, the relative change in the average morning peak hour distance for the trips emitted and received has been calculated and it is presented in figures 41 and 42.

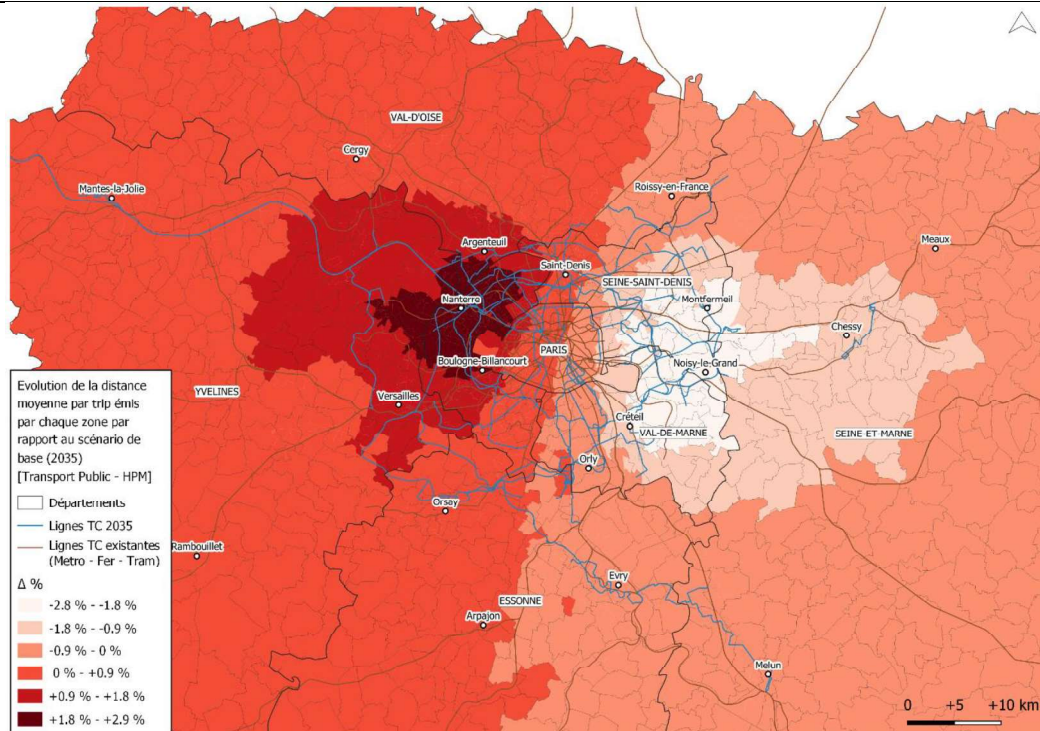


Figure 41 - Evolution of the average distance for public transport trips emitted by each zone during the morning rush hour

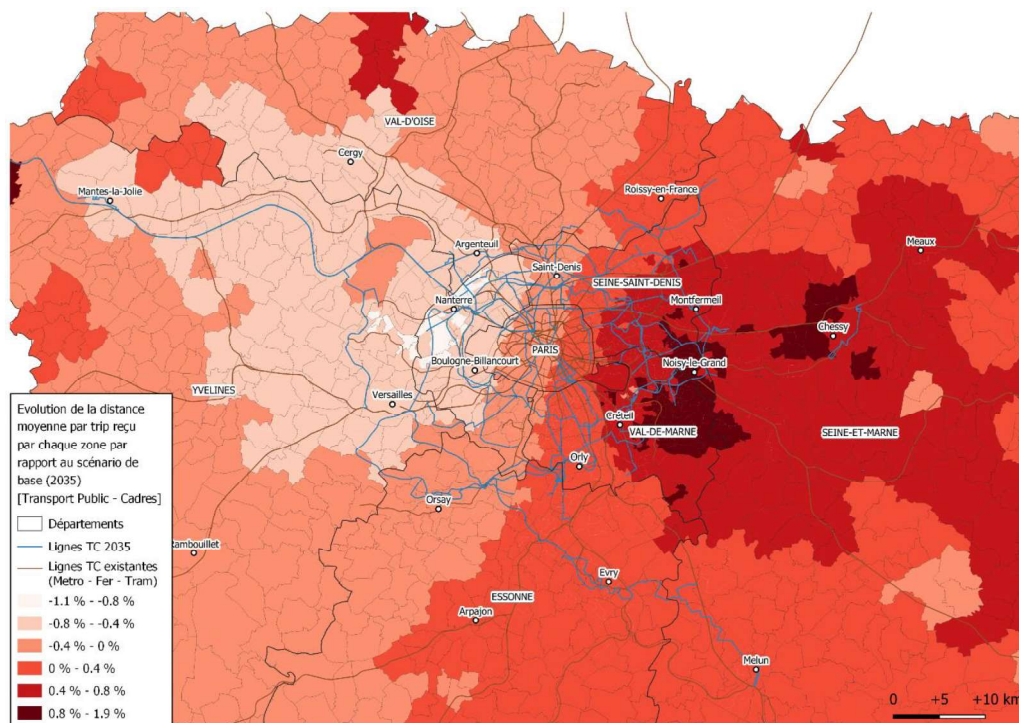


Figure 42 - Evolution of the average distance for public transport trips received by each zone during the morning rush hour



The results are intuitive but the changes are perhaps more limited than one would expect. The regions in the east who see a reinforcement of their employment offer attract commuters from further away (a 1% to 2% relative increase in the average distance for received public transit trips for cadres – figure 41), while the local population of cadres now works somewhat closer to his neighborhood (a 2% to 3% relative decrease in the average distance for emitted public transit trips for cadres – figure 42). The results are perfectly symmetrical for the regions in the west which, under this scenario, lose employment places: the decreased attractiveness in terms of employment positions pushes the local population to search for employment further away and outsiders to come from nearer. In any case though, the differences are marginal, as it can also be attested by the change in the load of the public transport system (figure 43).

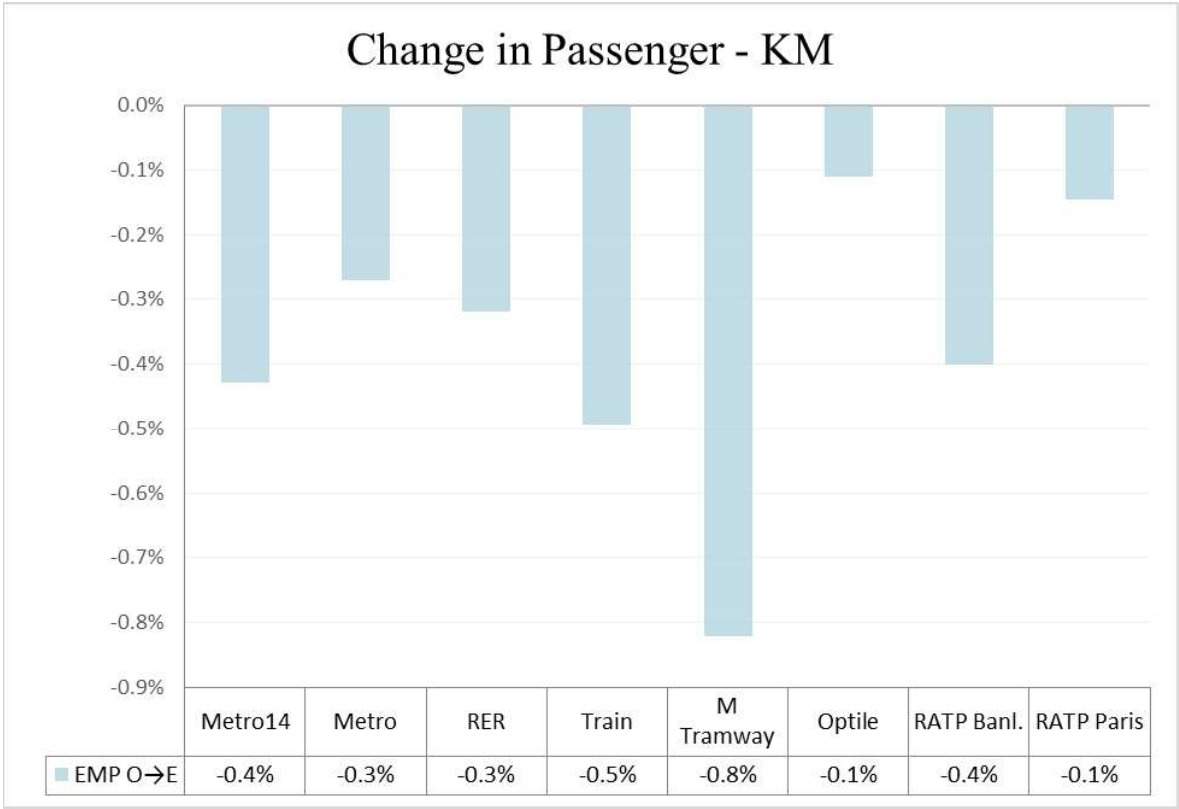


Figure 43 – Change in passenger-km for the public transit network

This last result can be better approached by taking into consideration that Antonin 3 reasons in terms of equilibria and the calculated indicators are referring to the stable transportation patterns that are observed before the modeled territorial rebalance and a long time after it, when the transportation system reaches its ex-post, longterm equilibrium. Consequently, there is no modeling of the transit pattern of an individual in the West that must now e.g.

double his commute because his employment position gets relocated in the East. Instead, in the new equilibrium, this particular employee will find a new employment position at approximately the same distance as the old one, or to be exact, *a little further away in order to account for the lesser employment attractiveness of the region* due to the loss of almost 100,000 employment positions.

This last notion can be interestingly be linked to the notion of a constant "travel time budget", that is, "a stable daily amount of time that people make available for travel". Firstly developed by Yacov Zahavi and this sometimes known as the Zahavi's constant<sup>66</sup>, the concept refers to the empirical observation that the average time spent by a person for commuting each day, is constant and it is approximately one hour.

Although this remark mainly refers to the cancelling out of new transportation project's benefits due to the incentivizing of relocations of commuters in the suburbs, we could easily posit that *“a commuter will not accept spending more time than a certain threshold and thus he will search for available employment opportunities within this time-range”*. At any rate, daily experience supports the notion: the first results of the EGT 2020 for instance, prove that the daily time-budget spent on commuting is identical for all of Île-de-France, at 1h30 per day. In the Grande Couronne, the fact that some of the people do not leave their life basin in order to work compensates for the increased time-budgets of those who do the trip to Paris.

### **Focus on the Val-de-Fontenay**

A better understanding of the before mentioned phenomena can be achieved by performing a “zooming in” in a concerned region and observe the changes of transit patterns on a finer scale. For that, Val de Fontenay has been chosen since it represents one of the most dynamic attractiveness poles at the east of Paris that is prone to increase its territorial importance until 2035. Indeed, according to the latest forecasts, the number of passengers at the Val de Fontenay station, which currently has more than 100,000 commuters, is expected to increase by 70% by 2030. Future developments, amounting at a total budget of 240 million euros, provide for new public transport lines, namely a Tram line as well as metro lines (Line 15 and

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<sup>66</sup> Marchetti, C. (1994). "Anthropological invariants in travel behavior". *Technological Forecasting and Social Change*. 47 (1): 75–88. doi:10.1016/0040-1625(94)90041-8.

extension of line 1)<sup>67</sup>. In addition, new housing projects and office spaces are being planned in order to accommodate for the increased demand. As a reminder, under the scope of this employment rebalance scenario, Val de Fontenay sees an increase of ~ 9% additional employment positions, which leads to ~11% of additional attracted home-work trips.

A first indicator (Figure 44) depicts the evolution of the home-work trips by public transit destined towards Val de Fontenay by public transit means. As it has been mentioned before, the econometric nature of the model becomes immediately apparent: an increase in employment is treated as an increase in the “employment attractiveness” of the zone, which affects all of Île-de-France almost uniformly. The increase of additional trips is smaller (~10%) in the neighboring regions that also profit from an increase in their attractiveness, while the increase in the regions that face a decrease in the employment positions is higher, at ~17%. Spatial relations (proximity to the Val de Fontenay) account for the rest of the variations.

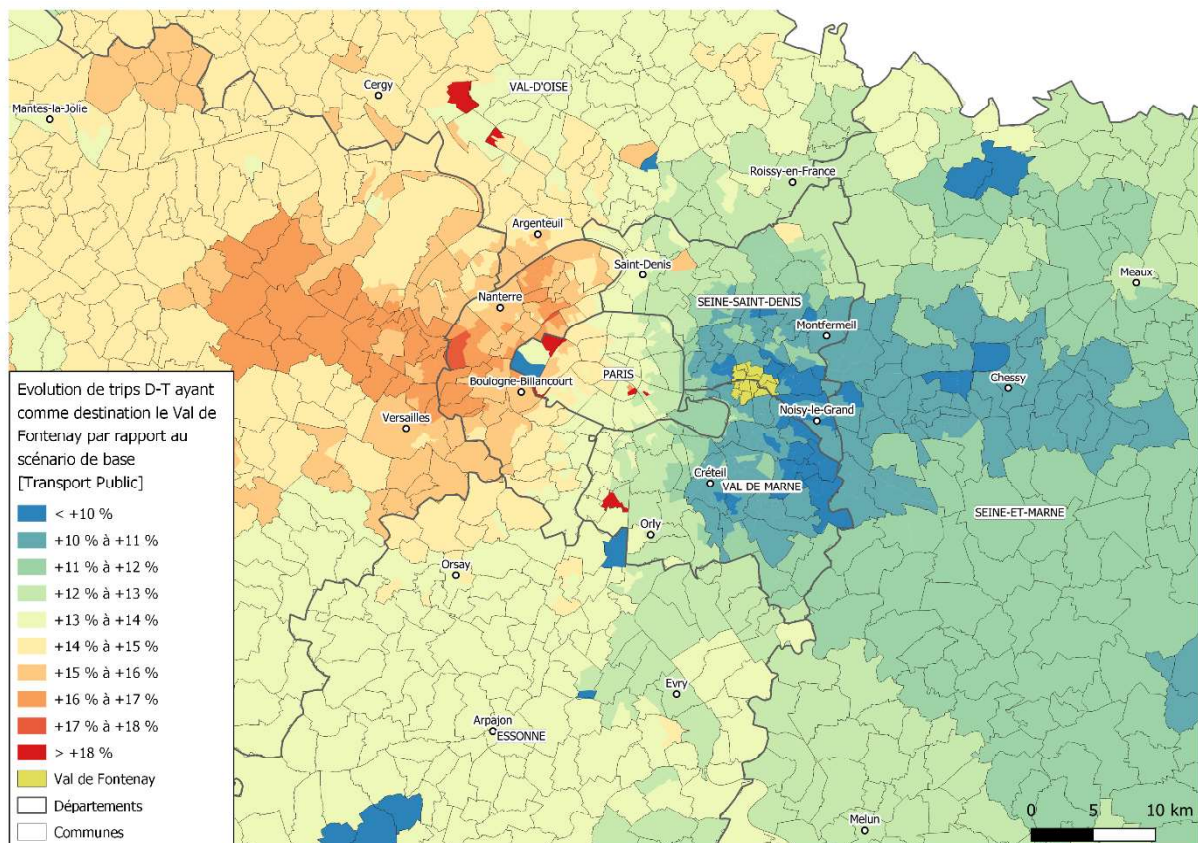


Figure 44 – Evolution of the public transit home-work trips received by the selected zones in Val de Fontenay.

<sup>67</sup> Apur via [blog.geolocaux.com](http://blog.geolocaux.com)

The next indicator refers to the evolution of the total number of the Home-Work trips by public transit destined towards Val de Fontenay, in relation to the total Home-Work trips by public transit that are emitted by every zone (Figure 45). The idea is to evaluate whether the increased employment attractiveness of Val de Fontenay could lead to increased commuter flows from the other zones, *in relation to the potential maximum flows of these zones*. The relative results are once more very marginal, with the most affected zones not exceeding the 0.3%-0.6% range. Passing from the relative to the absolute, the additional number of Home-Work trips that get attracted by Val de Fontenay are shown in figure 46. Two observations can be made:

- Val de Fontenay does not attract a significant number of trips from the newly “less attractive” zones in the west of Paris city center, since *it never did*. There is however a small relative increase in additional trips from the west of Nanterre, as it can be seen in figure 45. This can be obviously mostly attributed to the existence of the RER A that allows a relatively rapid commute between Nanterre and Val de Fontenay, than at the employment attractiveness characteristics of the two regions. Proof for that is that the rest of the concerned zones in the east do not show the same tendency.
- Both in terms of relative and absolute Home-Work trips capturing, it can be inferred that the augmented attractiveness of Val de Fontenay *tends to reinforce the spatial transit patterns that are already in place*. Indeed, the additional home-work trips destined towards Val de Fontenay come from regions that, on the one hand are already organically connected to the area by public transit and, on the other hand, and precisely due to this organic connection, already emit an important number of trips towards the Val de Fontenay. The reader is invited to observe that the additional trips, both in absolute and relative terms, follow the traces of the major transport corridors in the east, namely RER A towards Marne-la-Valle and RER E & Transilien towards Tournan.

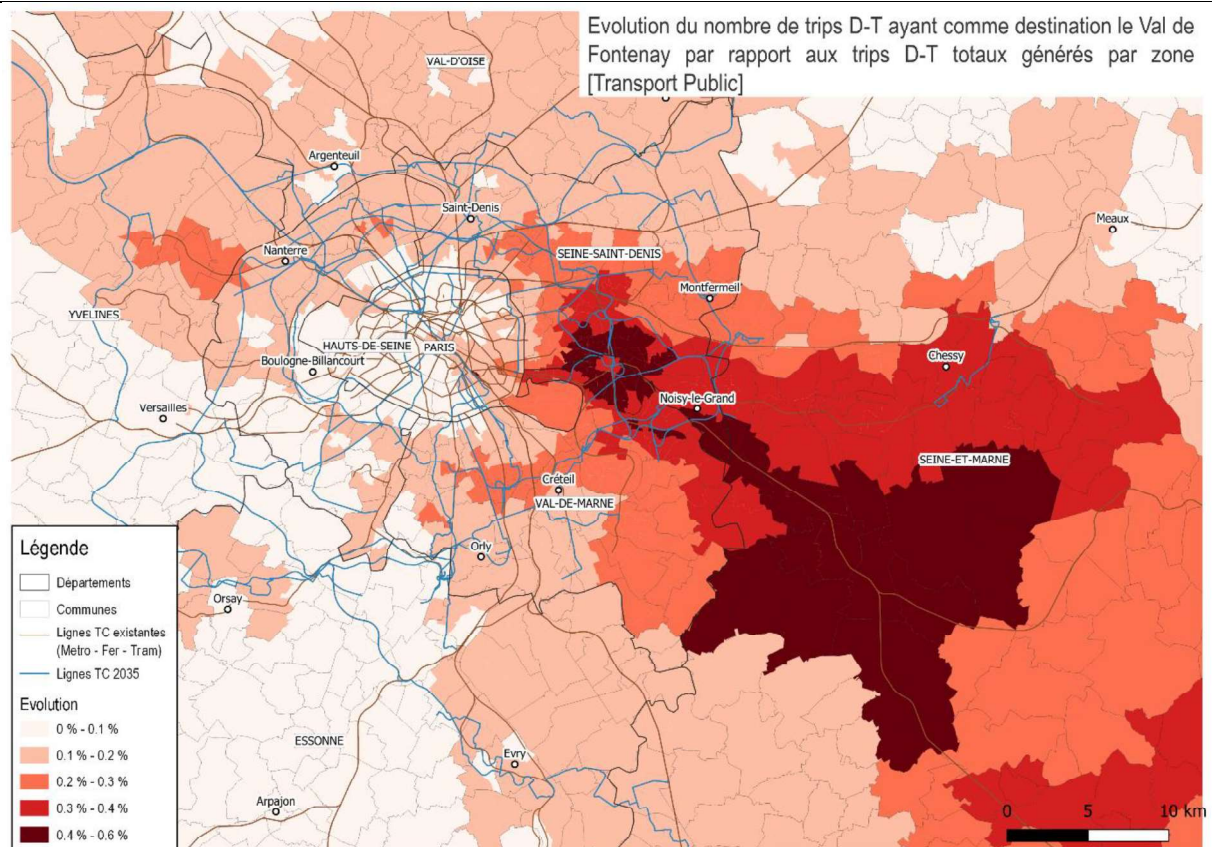


Figure 45 – Evolution of the total number of the Home-Work trips by public transit destined towards Val de Fontenay, in relation to the total Home-Work trips by public transit that are emitted by every zone



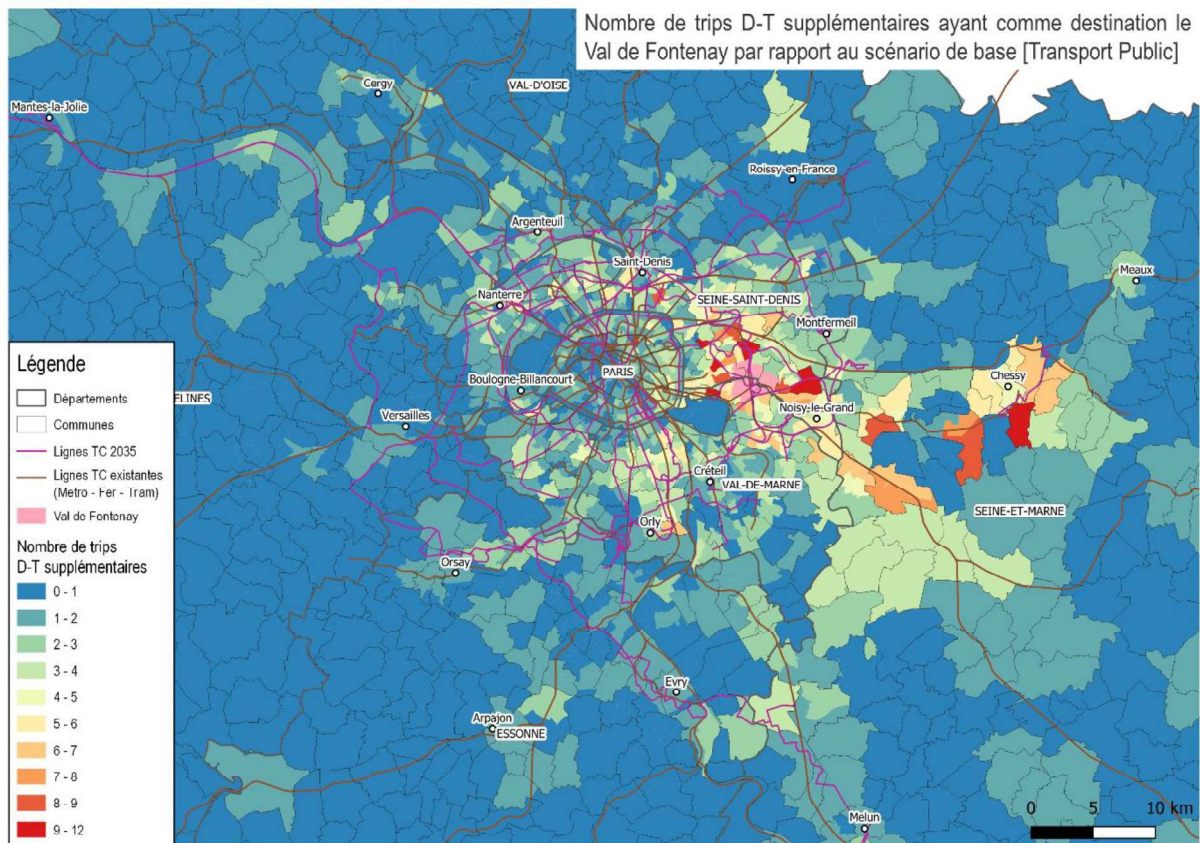


Figure 46 – Absolute number of extra trips attracted by Val de Fontenay under this scenario

## Tightening the availability of parking spaces inside Paris

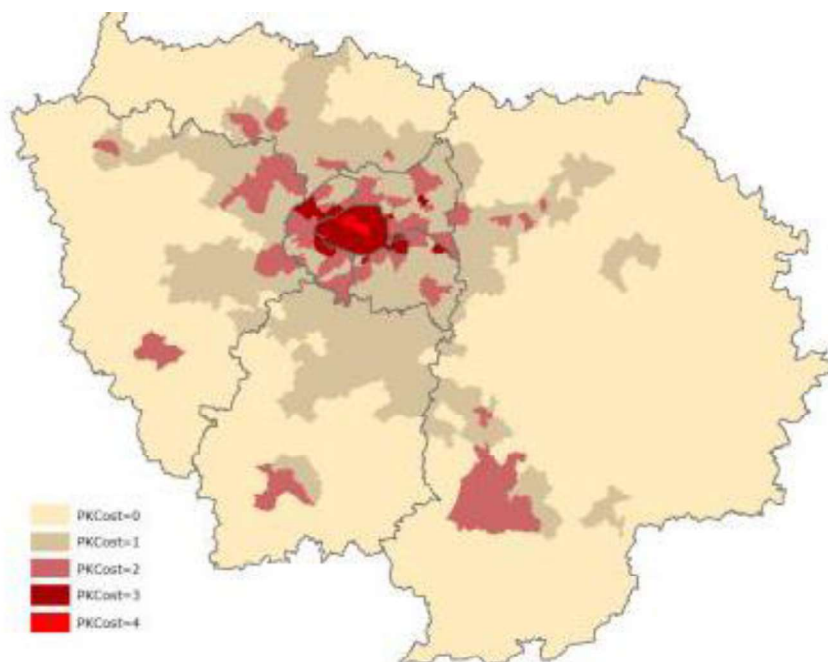


Figure 47 – Different parking cost categories coded in Antonin. Source: Antonin 3 Manual

The availability of parking space, especially when it is expressed in its negative form e.g. the lack of parking lots in an urban setting, can be an important impediment to the use of a private vehicle limiting its usage and, accordingly, its modal share. Super-structure parking lots are undergoing a profound change. A large proportion of commercial garages built on streets or inside blocks are changing or have already changed, under pressure from the real estate market to make way for housing and office operations. Parking spaces are also deeply questioned, in a context of an accelerating decline in household motorization (-17% of the vehicle fleet between 1999 and 2015) and a continuous decrease in the use of the car to get around (-31% of road traffic between 2001 and 2015) in Paris.<sup>68</sup>

In 2016, in order to encourage the use of alternative modes to private cars and meet air quality objectives, the PLU in accordance with the PDUIF introduced an important change by limiting the achievement of parking spaces for offices depending on the arrondissement (1

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<sup>68</sup> Apur (2019). Evolution Du Stationnement Et Nouveaux Usages De L'espace. Public Volet 3 : Evolutions Des Parkings En Ouvrage

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space per 500 m<sup>2</sup> in the central arrondissements, 1 space per 250 m<sup>2</sup> in the peripheral arrondissements)<sup>69</sup>.

The City of Paris has observed a downward trend in the number of visitors to its car parks, on average by -6.87% for hourly visitors and -4.76% for subscribers<sup>70</sup>. With a motorization rate of 0.40 in Paris (0.83 in the inner suburbs, 0.88 in Île-de-France), Parisians are particularly little motorized and are less and less so according to Insee data from 2015. Only 36% of Parisian households on average had at least one car in 2015, compared to 46% in 1990.<sup>71</sup>

The parking cost is directly taken into consideration into Antonin as a component of the composite cost of the use of a private vehicle. Four cost levels are taken into consideration, reflecting the difficulty of finding a parking space and/or the out of pocket costs. The four level are the following:

- Pkcost = 0: No parking constraint
- Pkcost = 1: Free, limited parking
- Pkcost = 2: Charge, less than 2 € / hour
- Pkcost = 3: Charge, more than 2 € / hour
- Pkcost = 4: Charge, very central Paris (arrondissements 1 to 4 + 8).

In order to evaluate the effects of a (not so) hypothetical future context, were the use of private vehicles will become more and more difficult due to the increasing parking constraints, a forecasting scenario for 2035 that has been developed that, in addition to the out-of-pocket costs, every trip towards Paris city center is also subject to a 7-minute delay. The intuition is that the uncertainty of finding a parking space on arrival is a source of stress for the individual, who may then choose to get to their destination via another mode. The feeling of "going in circles" in a neighborhood before being able to park one's vehicle removes any benefits linked to the duration of the journey<sup>72</sup> (Rocci, 2007). Consequently, in this scenario this feeling is concretized and included a priori in every trip towards Paris. This approach is deemed preferable since a simple increase in parking price would be more difficultly internalized by the well-off Parisians.

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<sup>69</sup> Idem

<sup>70</sup> Idem

<sup>71</sup>Insee. (2017). Recensement de la population 2017 - <https://www.insee.fr/fr/statistiques/2011101?geo=DEP-75>

## Modeling results

The proposed changes reflect on the modal split inside Paris, and the private car loses ~18% of its already limited modal share inside Paris (Figure 48), translated to 78,000 less car trips.

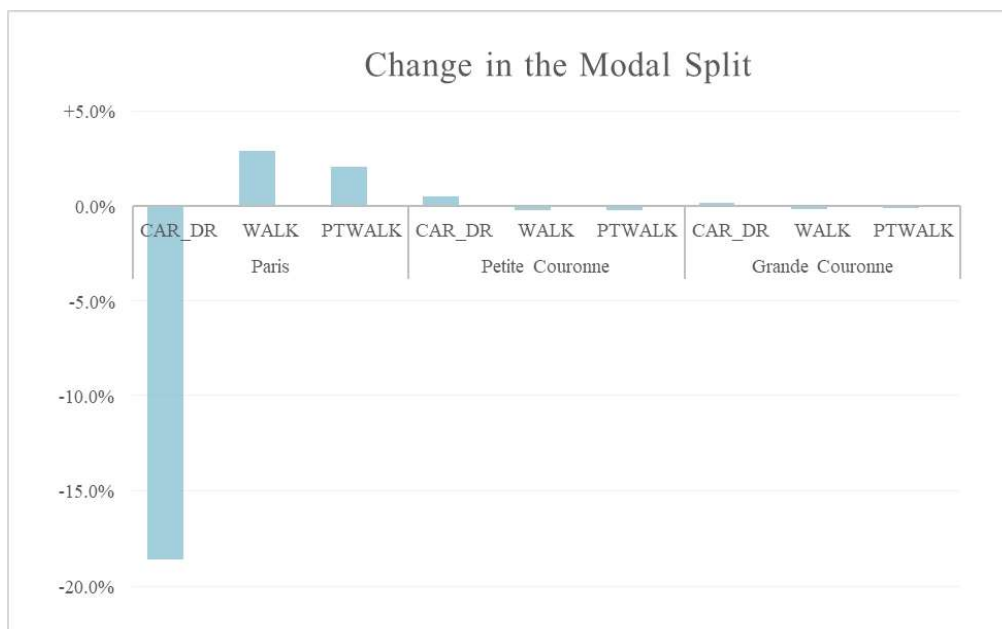


Figure 48 – Change in the modal split

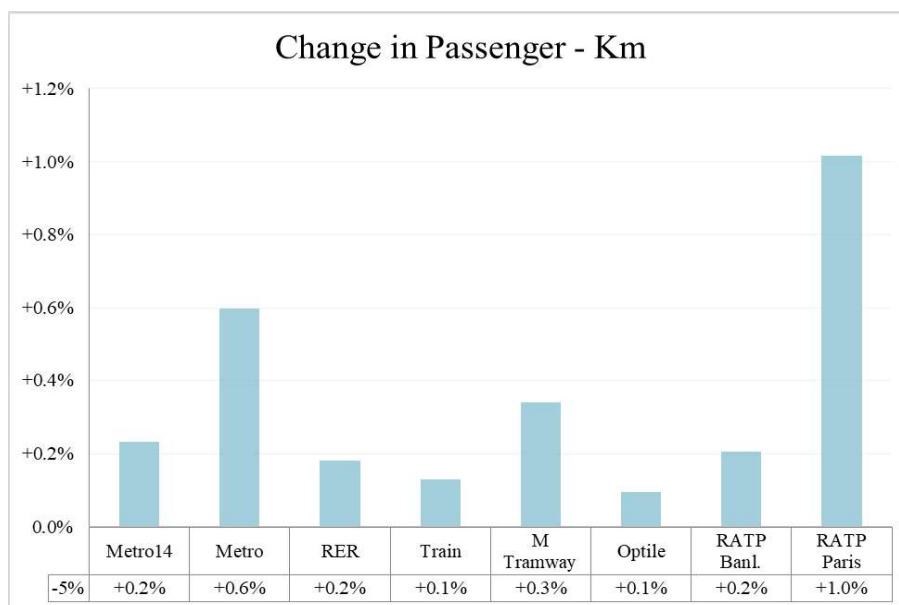


Figure 49 – Change in the daily passenger-km per mode.

<sup>72</sup> Rocci, A. (2007). De l'automobilité à la multimodalité? Analyse sociologique des freins et leviers au changement de comportements vers une réduction de l'usage de la voiture. Le cas de la région parisienne et

As it has been noted before, the decision of whether an individual does a trip or not is dependent only on the socioeconomic characteristic of the households of each zone so there is no variation of the number of total trips. Accordingly, there is a shift towards walking and public transit who gain around 2.5% and 2% in modal share (one should keep in mind that in Paris, the modal share of public transit and walking is already much higher than the modal share of a private car – see figure 50). Due to the relatively small evolution of the public transit modal share, the impact on the network is minimal: figure 49 shows that the additional charge in terms of passenger-km do not exceed 1% in even the worst case, with the RATP bus network being the most elastic since it is operational in Paris city center and thus, in the zone that is affected by the proposed changes.

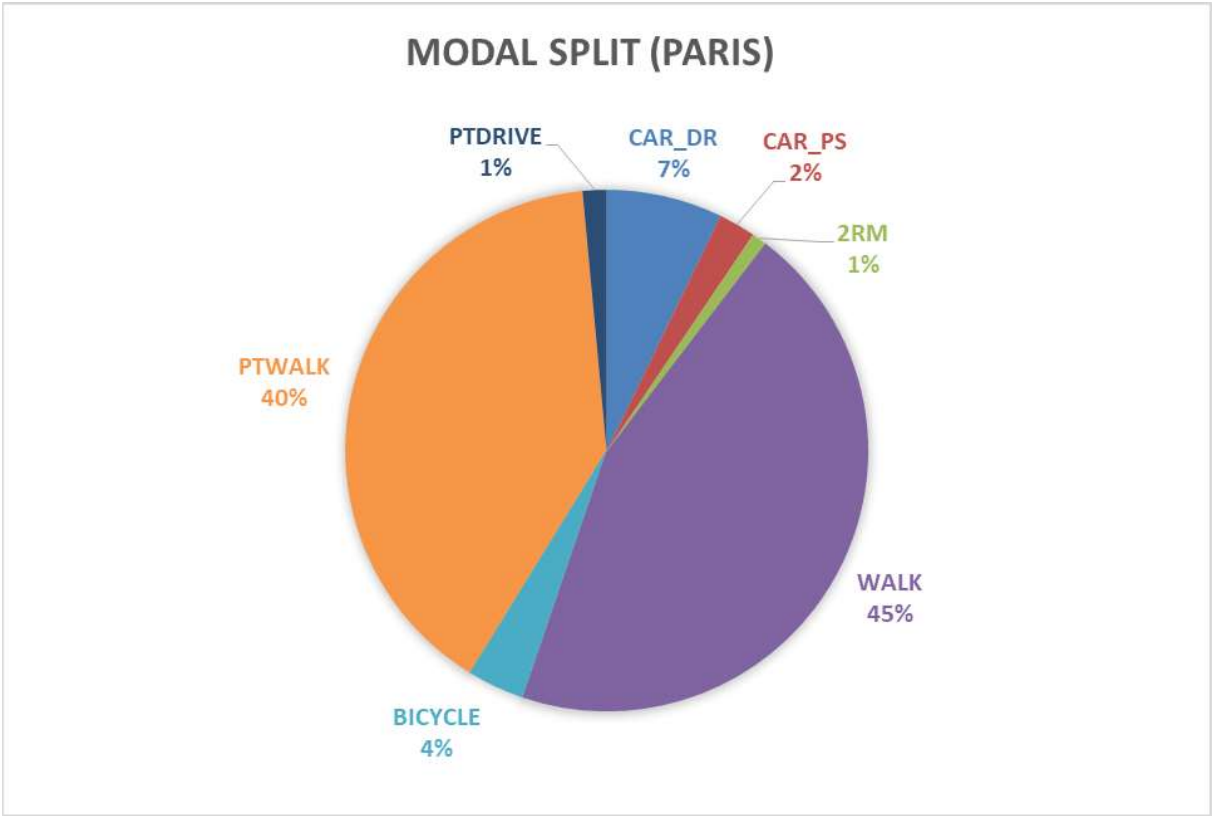


Figure 50 – The modal split of Paris – note the large share of walking and public transit who collectively account for 85% of the total trips



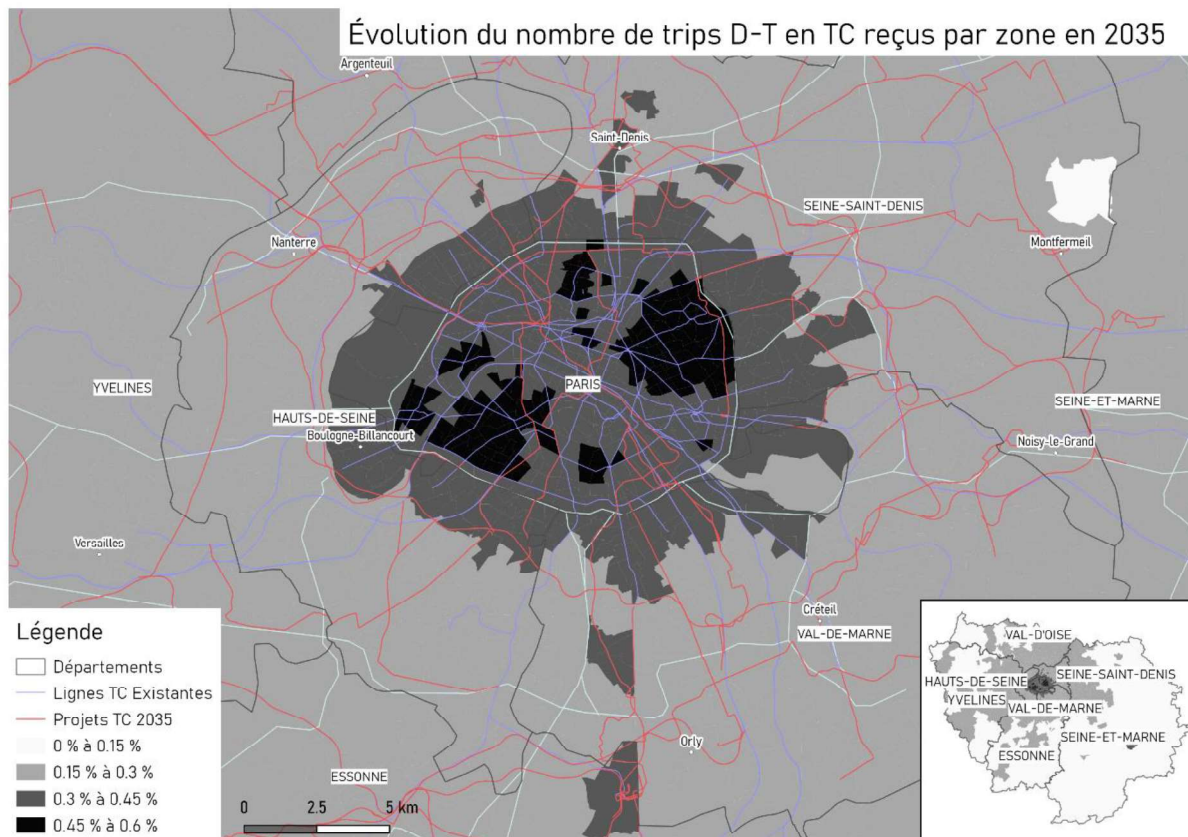


Figure 51 – Evolution of the number of the received, public transit home-work trips

A more detailed representation of the number of the received home-work trips in public transit (Figure 51) proves that the shift to public transportation is minimal (not more than 0.6% in the case of home-work trips) and centered around Paris’center, while it diminishes with the distance from it.)

It is interesting to note the small increase in car usage in the Petite (and somewhat in Grande Couronne), equaling 29,000 car trips, which can be attributed to a certain “car dependency” by a part of Île-de-France citizens. Instead of shifting to the public transit network and continue working in Paris, some commuters chose to keep using their private vehicle and instead work in the Petite Couronne. A mapping of the modal split for the home-work trips equally articulates this phenomenon (figure 52): while inside Paris there is an important decrease in the use of the car use, every other zone sees a small increase in the private car modal share. This is not a surprising result: there are still many regions inside Île-de-France whose inadequate population density does not allow for an efficient deployment of a mass transit system, rendering the local population dependent to a private vehicle. For them, not

using the car is not an option: instead, they will prefer to work to the closest location that is still accessible by private means. This suggests that, introducing car restrictions without a parallel investment in public transit, although locally beneficial, it might simply function as sweep the problem under the carpet, and in this case, Petite Couronne's carpet.

A closer look of figure 52 is even more informative: Paris is standing out of the entire Île-de-France, cordoned off the rest of the territory. The choice of words is not accidental: isn't it as if we have implemented a congestion charge zone for those trips that are traversing the Boulevard Périphérique towards Paris? After all, all costs components are fashioned both mathematically and perceptually (giving rise to the notion of the "trade-off") into a generalized cost which determines the decision making process. Pushing the argument to its limits, could this homology between parking difficulty and congestion charging imply that the two measures can be used interchangeably in terms of their efficacy in discouraging car use in the city center and that the conversation should be oriented towards their secondary effects? For example, in the case of a strong population opposition towards the congestion pricing, increased parking difficulty could yield the same results with the necessary "discretion".

Through this prism, it is interesting to note some of the results of London's congestion pricing scheme. Launched in 2003, it has managed to alleviate part of the city's severe congestion problem and fueled a large shift towards public transit. Since 2002, the percentage of trips made by private car has reduced from 46% to 36%, while public transport has increased from 29% to 37%<sup>73</sup>. Traffic delays inside the cordoned zone have decreased by 30%, powered by a reduction of 15% in traffic circulating within the zone and 18% in traffic entering the zone during charging hours. Journey time has also improved by an average of 30 percent. Obviously, the breadth of these results is much wider than the modeled changes: the already very limited part of the private car inside Paris, the fact that transient traffic is not charged and perhaps the smaller cost implied by the modeled extra trip time lead to much more moderate results.<sup>74</sup>

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<sup>73</sup> Croci, E. (2016). Urban road pricing: a comparative study on the experiences of London, Stockholm and Milan. *Transportation Research Procedia*, 14, 253-262.

<sup>74</sup> Santos, G., & Fraser, G. (2006). Road pricing: lessons from London. *Economic Policy*, 21(46), 264-310.

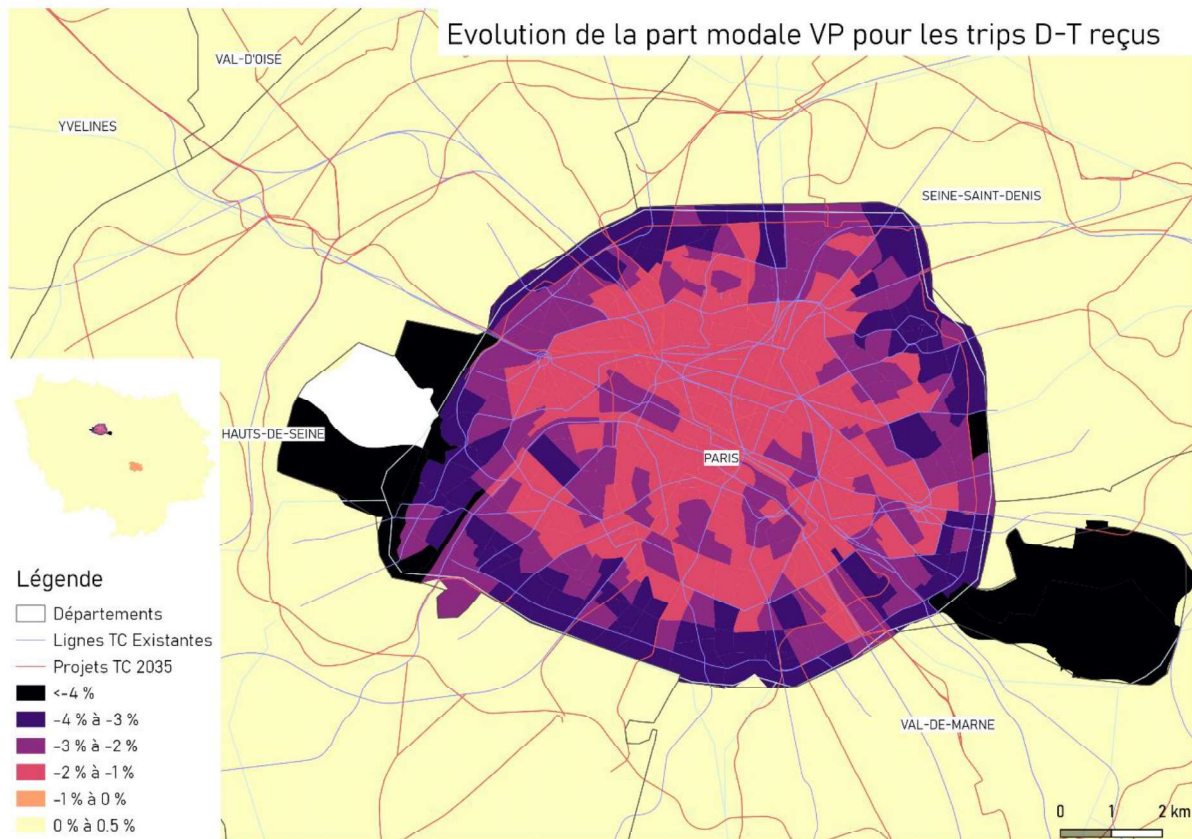


Figure 52 – Evolution of car’s modal share.

Finally, we look into the average distance of home-work car trips that are received by each zone during the rush hour. Figure 53 clearly shows that while the average distance of a home-work trip destined to Paris is increased (since the increased difficulty of finding a parking spot demoralizes the commuters with the lowest utility of working in Paris and leaves those commuters who are willing to pay the extra cost – in the form of distance and thus, travel time), the average distance of all other car trips is diminished.



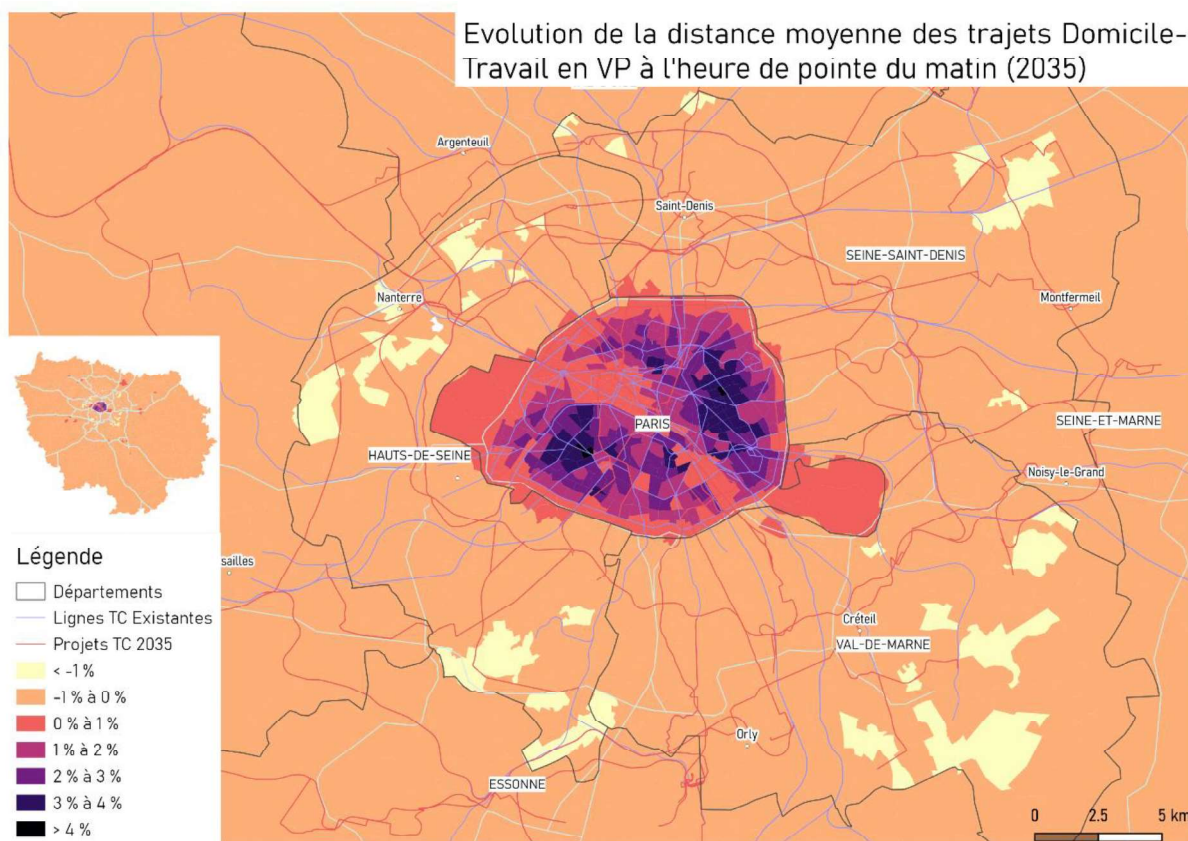


Figure 53 – Evolution of the average distance of car home-work trips

All in all, the results are in strong conformity with the available literature on the topic. Frank, et al. (2011)<sup>75</sup> conclude that parking pricing can have significant impacts on vehicle travel and increasing parking fees from approximately \$0.28 to \$1.19 per hour (50th to 75th percentile) in their study zone reduced vehicle-kilometer travelled by 11.5%. In addition, a 10% increase in the parking costs implies a 1.1% decrease of the received trips in the short-run and a -1.6% decrease on long term, according to the TRACE project<sup>76</sup>.

One important distinction must be made though: while the scenario refers to parking difficulty and cost, the developed methodology actually acts on the *generalized parking cost*, through an increase in the travel time towards Paris. Thus, bibliographically, the results of this

<sup>75</sup> Frank, L. D., Greenwald, M. J., Kavage, S., & Devlin, A. (2011). An assessment of urban form and pedestrian and transit improvements as an integrated GHG reduction strategy (No. WA-RD 765.1). Washington (State). Dept. of Transportation. Office of Research and Library Services.

<sup>76</sup> TRACE was a comprehensive research program, carried out by a consortium of European consultants and Universities, aiming to produce a comprehensive review of empirical and modeling evidence of time and cost elasticities and value of time

scenario are mostly comparable against the discussion of the effects of travel time increases, quantified at an average of 19%, with the average time of a car trip towards Paris being 37 minutes in 2035. Influenced by the previous chapter, we have once more recourse to the elasticity concept. Thus, the elasticity with respect to travel time for the received trips is at  $\varepsilon = -0.73$ , much higher than the average of  $-0.19$  in the European literature, as it has been documented by TRACE. This difference is defensible: TRACE, as most studies on the subject do, calculates the respective elasticities based on data from a much larger geographical area, usually at the scale of the entire urban area of a city. This change of focus affects transit alternatives: it is evident that, in the presence of an efficient public transit system, private car usage is much more elastic than in the case of a large urban area, dotted by public transit gaps.

### **Modeling a fare-free public transport in Île-de-France**

In March 2018, the mayor of Paris, Anne Hidalgo announced an extended public consultation process on the relevance of the implementation of free public transport in Paris. The process follows on from actions carried out over the past few years in Paris and Île-de-France, aimed at reducing the city's ecological footprint and promoting the mobility of people in vulnerable situations. It is the ramp up of a gamut of temporal measures that have been implemented before in order to tackle pollution in Île-de-France, such as free transport during pollution peaks (until 2017) or an anti-pollution package allowing unlimited travel throughout Île-de-France for € 3.90 per day (from 2017 and onwards). The previously mentioned are part of a more global vision: As a member city of the Cities Climate Leadership Group (C40), Paris is committed to neutralizing its carbon footprint by 2050, by promoting the use of low-emission vehicles.<sup>77</sup>

This gratuity scenario is part of a larger discussion regarding the financing of public transport in Île-de-France. As of 2020, the French commuter contributes 28% of the total cost of public transit in Île-de-France. If we compare the price of the subscription to the overall cost of transport, it is the inhabitants of the French capital who pay the least in Europe, according to a study by the Montaigne Institute. In Brussels, the contribution of travelers is 35%, in

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<sup>77</sup> David, Q., Del Fabbro, M., & Vertier, P. (2018). Etude sur la «gratuité» des transports en commun à Paris.

Amsterdam 40%, 41% in Madrid or 52% in London<sup>78</sup>. Regarding the rest of the budget, 20% is financed by the region, department, and another 50% comes from the participation companies with more than 11 employees who are taxed and obliged to reimburse 50% of the subscription of their employees.

With that in mind, in this sub-scenario, in strong complementarity with the equivalent elasticities scenario relating to public transit, the effects on mobility of a possible gratuity of the public transit network in will be discussed. For comparison, two additional variations in the Navigo price will also be modeled: a first one modeling an increase of a monthly Navigo card from the actual 75€ per month to 95 € per month and a second one to 180 € per month. Through these scenarios, two distinct pricing developments will be discussed. In the first scenario, the modeling process has simulated a recent proposition of IDFM's president, Valérie Pécresse, to increase the price of a monthly Navigo card by 20 euros in the wake of the coronavirus pandemic and the subsequent 2.6 billion hole on the revenue of the public transport authority<sup>79</sup>. The second increase models a scenario where the contribution of the final user weights stronger on the income of IDFM, in line with most other European capitals.

The general directions of our results relate well with the existing literature on the topic In the largest example in recent years of significant fare reform, the public transport system in Tallinn, Estonia stopped charging fares to city residents in January 2013. The results have been well documented by Cats et al. (2017), who compared the mobility features in Tallinn ex-post and ex-ante the gratuity measures. They documented an increase of 14 % in the number of trips performed by public transport, a decrease of 10 % in the number of car trips and an important decrease of 40 % in the number of trips for which walking was the main model of travel<sup>80</sup>. A recent study by Kęblowski<sup>81</sup> has shown that a mere 3% of the additional public transit users have switched from a private vehicles. While once again the breadth of the changes is much more limited in our case, the general lines are identical, while it validates our finding that the additional public transit trips come mainly from a decrease in soft transit

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<sup>78</sup> Idem

<sup>79</sup> Valdes, L. (2020). Hausse de 20 euros du Navigo ? La menace brandie par Valérie Pécresse pour faire bouger le gouvernement, in LCI.fr

<sup>80</sup> Cats, O., Susilo, Y. O., & Reimal, T. (2017). The prospects of fare-free public transport: evidence from Tallinn. *Transportation*, 44(5), 1083-1104.

modes. While the benefits of the gratuity policy materialize in terms of the increased equity for public transit users, the influence on the modal choice for daily mobility seems limited. In the various European experiments, this policy resulted in only a slight reduction in the share of the automobile, the modal shift from this mode being rather low. Literature evidence from other cities is also pointing toward the same direction: According to the Danish Board of Technology, between 10 and 20% of the growth linked to the potential introduction of free access in Denmark would come from former motorists, while the first new users of free public transport come mainly from cycling and walking (Fearnley, 2013)<sup>82</sup>.

### Modeling results

The gratuity scenario entails an increase of about 3.2% in the number of the daily trips by public transport, with the parallel decrease of trips by a private car and on foot by 1.3% and 0.8% respectively. Given that the total number of trips does not change (we are once again past the trip generation phase in the modeling), all of the changes can be attributed to a modal shift mainly between walking and car drive on the one hand and public transportation of the other hand.

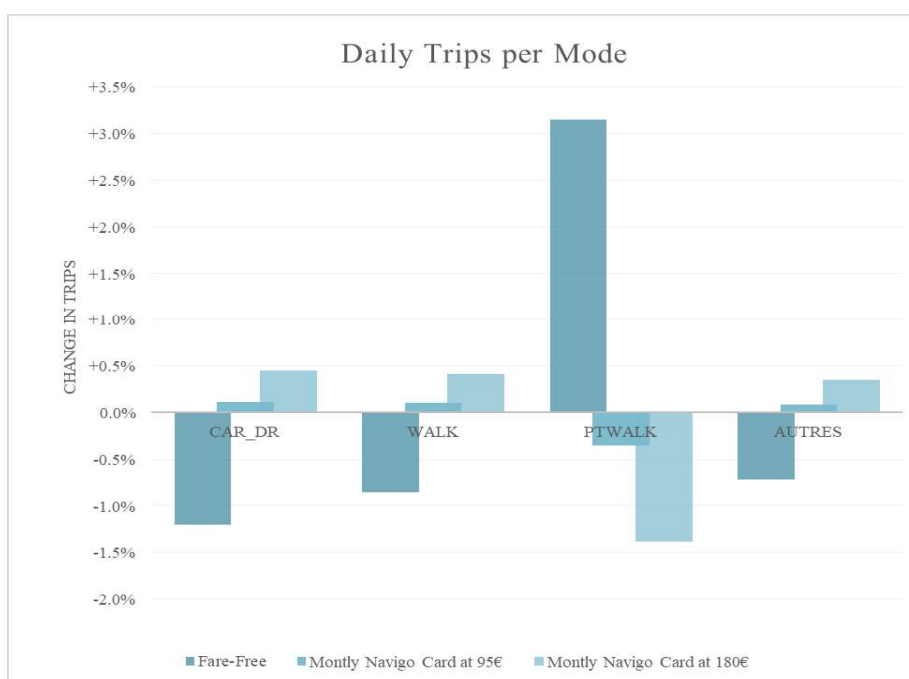


Figure 54 – Daily trips per mode

<sup>81</sup> Kębłowski, W. (2019). Why (not) abolish fares? Exploring the global geography of fare-free public transport. *Transportation*, 1-29.

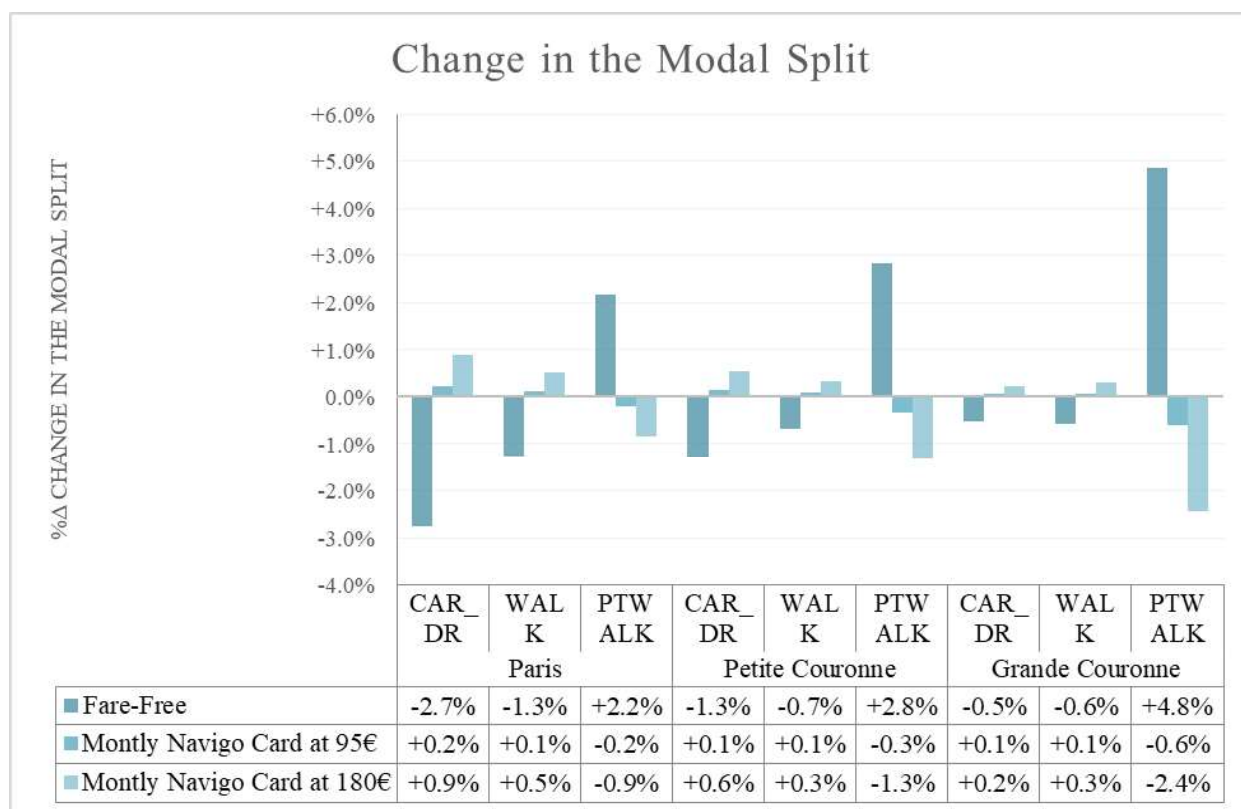


Figure 55 – Change in the modal split in Paris, Petite Couronne & Grande Couronne

The modal split, disaggregated for each of Paris, the Petite Couronne and the Grande Couronne, is presented in figure 55. Free public transportation can reinforce the modal share of the public transit system between 2.1% in Paris and 4.9% in the Grande Couronne, while reducing at the same time the modal share of the private car between 2.7% and 0.4% respectively. Of course, reasoning in terms of percentages can project a false image. A 0.4% decrease of car trips in the Grande Couronne is much more significant in absolute terms than a 2.7% decrease in the equivalent metric in Paris, due to the difference of scale between the trips by each mode in each of the two sectors. In absolute terms, there are about 2,300, 19,000 and 16,000 less car trips and 15,500, 35,500 and 41,000 more public transit trips in Paris, the Petite Couronne and the Grande Couronne respectively. The difference in magnitude between the car trips and the public transit trips quickly becomes evident and it can only be accounted by the decrease in walking trips: on a given day there are 27,000 less trips on foot (7,000 in Paris, 19,000 in the Petite Couronne and 20,000 in the Grande Couronne).

<sup>82</sup> Fearnley, N. (2013). Free fares policies: impact on public transport mode share and other transport policy goals.

In terms of the additional charge in the public transit network, the effects are non-negligible either: the RER and Transilien networks see the biggest increase in terms of passenger-km with increases of 10.7% and 12.4% respectively. This can be attributed to the important absolute modal shift mostly in the Grande Couronne, where the 41,000 additional public transport trips need to be channelized through mainly these two networks. The third largest increase, at almost 6% is posited by the Optile network, which is also exclusively operational in the Grande Couronne. On the other hand, the Metro and Grand Paris Express networks show more moderate increases of about 5%.

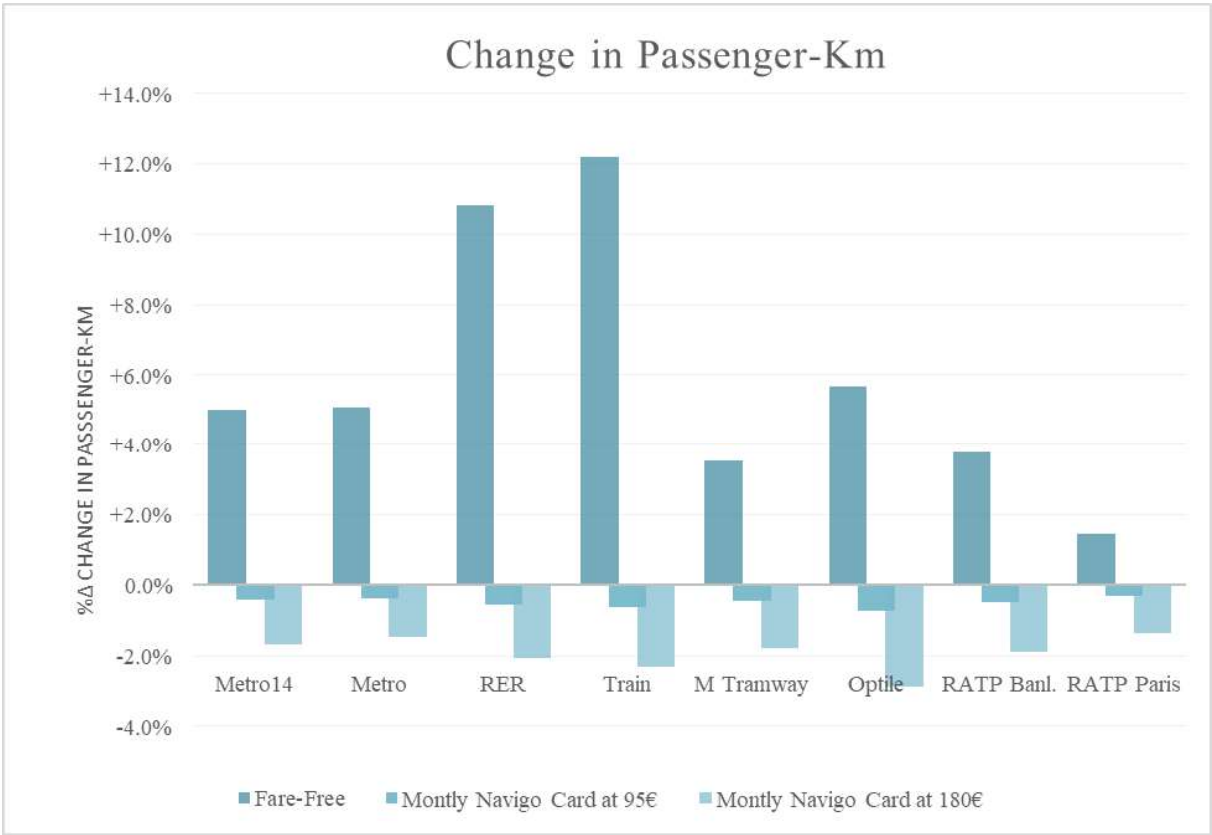


Figure 56 – Change in passenger-km per mode.

As in the previous sections, a detailed mapping “zoom-in” has been developed for the most impactful scenario, which is the gratuity one.



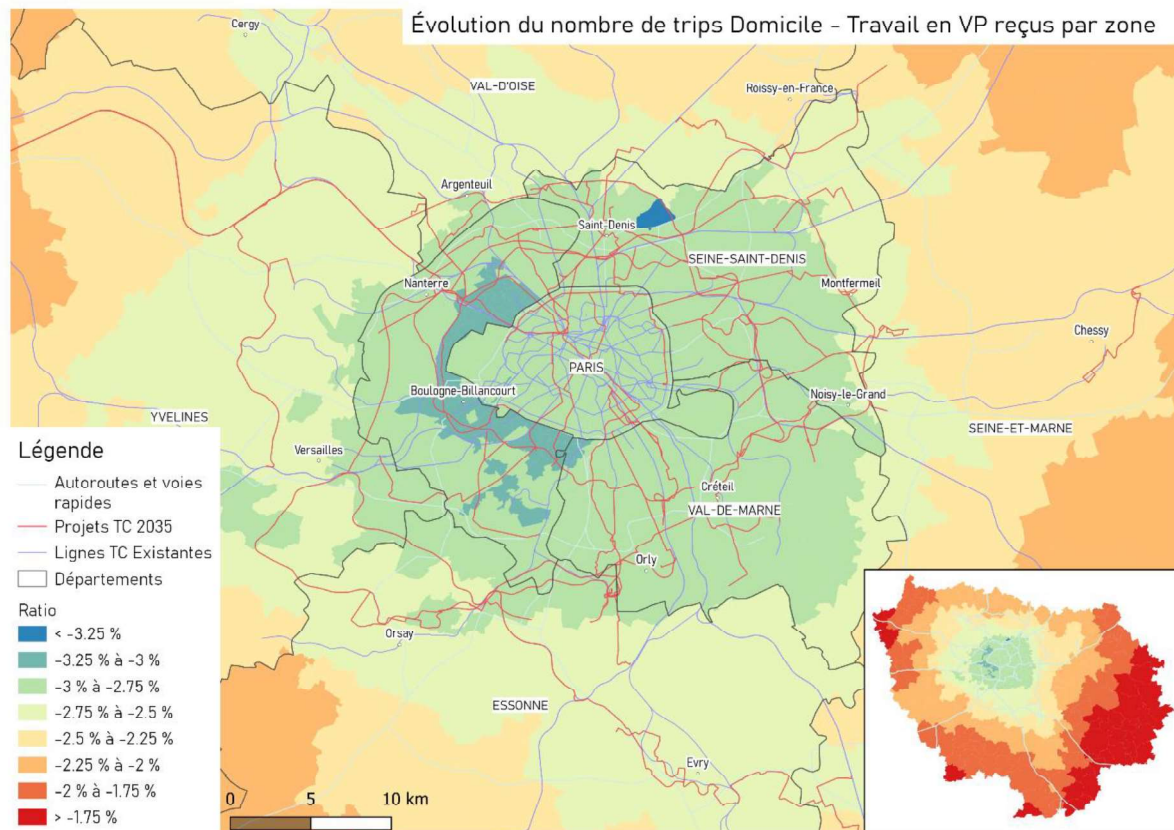


Figure 57 –Evolution of the number of car home-work trips

In terms of the home-work car trips received per zone, figure 57 has a rather concentric texture, which is largely because of the hierarchical and Paris-centered public transit network. The more one approaches Paris, the more transportation options there are and thus, the more probable it is to opt for mass transit, free or not. Accordingly, a ~3% decrease in private car trips usage in central Paris, becomes less than 1.75% in the fringes of Île-de-France who are much less affected by the gratuity scenario, since the lack of a sufficiently dense local population renders the public transit network dependent of a scares bus network which is mostly irrelevant for the highly motorized local population. It is worth noting that in figure 57, the sectors that “pop out” as those where the decrease in private car trips is the largest are those that receive an important number of motorized commuters, even though the public transport is largely efficient. This is mainly due to the fact that it is mainly a business area where the pressure in office space availability is less important than inside Paris, with many companies offering parking spaces to their employees: a strong incitation to use one’s private

car. Not entirely coincidentally, this is also an area that predominately attracts cadres, who are more probable to own a private car

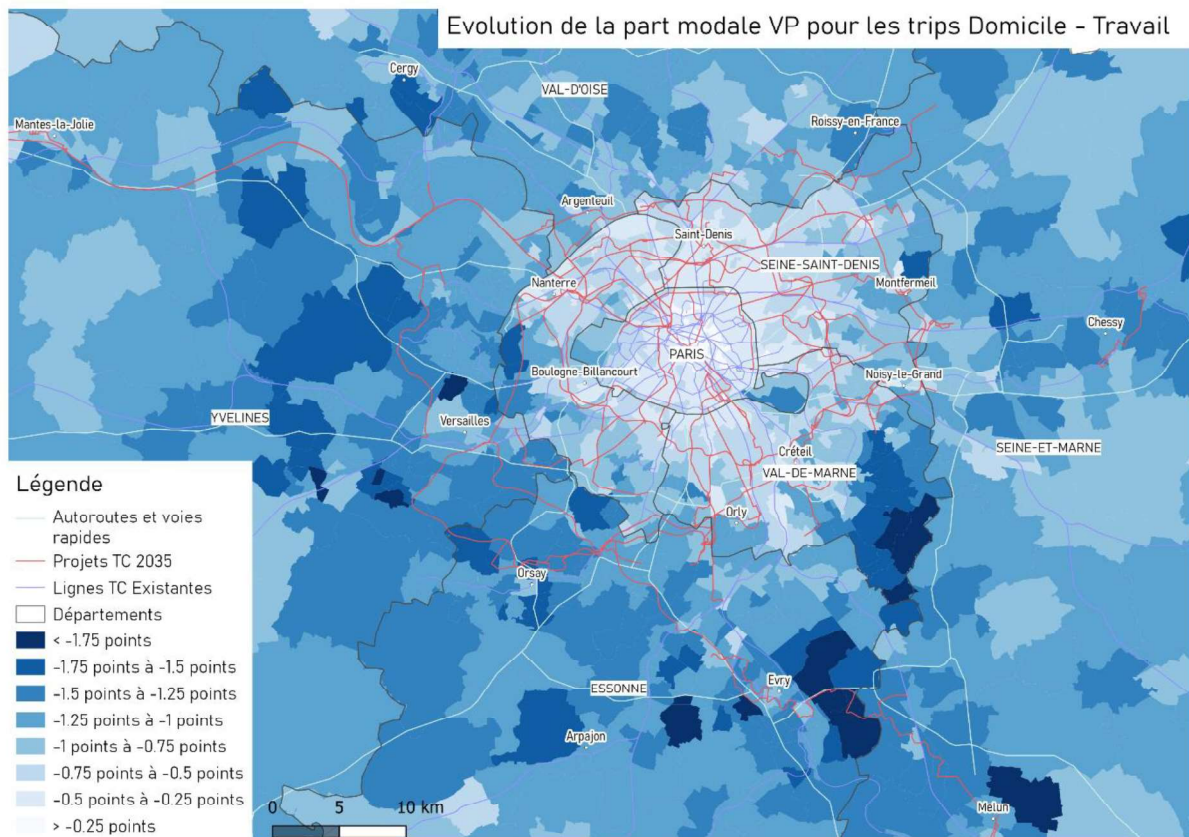


Figure 58 – Evolution of the car modal split for home-work trips

Be that as it may, the public transport offer is sufficient and, in figure 58, these are the regions that show the largest increase in the modal share of public transit (This is debatable of course: the reasons listed above could imply towards a certain reasoning direction where the reason for opting for or against a private vehicle is not linked to its cost.).

One should finally note the strong growth of mass transit around the CDG Airport in Roissy, which, despite the fact that it is very well served by the RER B line, as of today it attracts a large number of motorized passengers and employees.



## Conclusion

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The hope of every intern is that his work is not only appreciated as such, but also used in order to ameliorate the existing practices within the company, with the present document acting as a guide.

The accessibility analysis has identified many sectors that risk being deprived of efficient public transport even after the completion of the big infrastructure projects of the Grand Paris Express in 2035. The methodology that has been developed, could act as a robust tool in convincing reluctant stakeholders of the need of new infrastructure due to its almost complete lack of presumptions and hypotheses. The combination of a public transit accessibility analysis with the analysis of the actual transportation needs succeeds in giving an answer to the “Is it serious?” question, which means identifying whether apparent transportation gaps are due to insufficient offer or they reflect a correct equilibrium point where the low demand induces a low offer. Ex-post cogitation on its results demonstrates that they are highly intuitive, which is a further mark of the method’s efficiency. It is notable that while the methodology is, in a way, ignorant of the position of the 1805 Antonin zones within Ile-de-France, many of the identified zones form larger, coherent sector, respecting the spatiality of transportation gaps that can obviously exceed the limits of the Antonin’s sectoring.

This first part proposes an improvement with respect to the existing literature on the topic. The closest available methodology, applied in the case of Belgium by Fransen et al. (2015), treats the accessibility part in a cruder way, calculating the number of available opportunities (business and other locations “scrapped” from Open Street Maps), within a certain walking distance from each centroid. In comparison, our methodology treats accessibility in a much more comprehensive way, having recourse to the local and global accessibility indicators and combining them for the optimal result. We also feel that the consideration of private vehicle mobility as a sort of “antagonist” to public transit (since better local accessibility by car decreases the need for public transport inside the PCA), reflects correctly the relation of the two modes in an area where there is no evident domination by one of two modes (the reader is reminded that Paris and the rural fringes of Ile-de-France, dominated by public transit and private car usage respectively, are excluded from this study are). Finally, our study mobilizes

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Antonin 3 and the P+E database, two state-of-the-art tools that assure the reliability of the mobility and the socioeconomic previsions in 2035 respectively.

The results of the sensitivity analysis can be used not only to complete the existing documentation of Antonin 3, but also to steer the attention of the agents of Île-de-France Mobilités towards the refining of the variables that weight the most on the final result. We have also been able to shed light on the functioning of Antonin 3 and its econometric nature, especially with respect to the creation of a kind of “synthetic” population in relation to the socioeconomic inputs. While most of the results are intuitive and have been validated by Île-de-France Mobilités, our tests have shown that there is further room of improvement, especially regarding the income and fuel prices inputs, with the latter being almost completely erroneous. On the other hand, the fact that Antonin 3 is based on the results of the EGT 2010 makes it very difficult to model extreme rupture scenarios that would imply a radical change of the mobility tendencies of Parisians, especially in the case of more active seniors.

Finally, the forecasting scenarios, aim at giving indications of how programmed (or not programmed) changes could affect the future mobility patters in Île-de-France. At the same time, they also discuss the functioning of the model. Of particular interest is the Est-West unbalance scenario, which can be seen as complementary to the sensitivity tests and provides further intuition on the functioning of the model. The most notable result is without doubt the fact that the average distance does not change even when the employment positions approach the most populous areas of Île-de-France. This result, attributed to the fact that Antonin 3 reasons in terms of equilibria, can be linked to the constant time-budget concept. The rest of the scenarios, while not complete mobility studies, give comprehensive first take on 3 highly probable future developments inside and around Paris, providing directions and insights for the future team that will be tasked with their detailed elaboration.

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# **Annexes**

## Annex 1 Summary of the identified zones potentially facing PT gaps (Part 1)

Zone Attonin	Premier IRS de la zone Attonin	Commune	Densité de population en individus / km <sup>2</sup>	Taux de motorisation	Taux de chômage	Pourcentage d'habitants entre 0 et 19 ans	Pourcentage d'habitants de plus de 60 ans	Nombre d'adultes	Nombre d'habitants	Nombre d'emplois	Revenu Moyen	Postes d'emploi équivalents accessibles en TC assumant une fonction d'impédance	Score de demande de transport normalisé	Score d'offre de transport normalisé
930	91657	Maignes-sur-Seine	4 436	43%	10,3%	28%	23%	5 567	13 088	948	29 268	6 002	0,20	-1,19
1435	94017	Champigny-sur-Marne	6 153	40%	10,2%	26%	21%	1 887	4 397	427	29 968	16 999	-0,38	-0,79
1436	94017	Champigny-sur-Marne	4 824	47%	10,2%	26%	21%	3 170	7 040	977	36 632	11 946	-0,04	-0,96
1437	94017	Champigny-sur-Marne	27 644	23%	10,2%	26%	21%	2 789	7 596	364	18 551	16 692	-0,88	-0,70
1442	94019	Chamnières-sur-Marne	4 157	30%	10,0%	28%	20%	3 029	7 494	1 532	23 849	9 788	-0,54	-1,07
1545	94060	La Queue-en-Brie	3 948	44%	6,4%	27%	18%	3 459	7 321	786	31 464	8 184	0,16	-0,97
1628	95018	Argenteuil	1 957	49%	14,0%	26%	21%	2 336	5 707	738	37 231	16 821	-0,25	-1,13
1629	95018	Argenteuil	5 387	43%	14,0%	28%	21%	4 003	9 927	1 040	30 556	17 125	-0,64	-1,24
1783	95582	Sannois	3 927	39%	8,4%	25%	27%	3 490	8 135	1 536	26 177	14 352	0,09	-0,96
1281	93047	Montfermeil	3 568	47%	11,7%	29%	20%	3 672	7 613	980	33 542	12 085	-0,30	-1,00
1275	93046	Livry-Gargan	2 973	44%	8,4%	27%	21%	3 490	7 224	2 051	27 893	13 055	-0,17	-0,77
1276	93046	Livry-Gargan	8 488	45%	8,4%	27%	21%	6 067	13 005	2 480	27 479	17 240	-0,26	-0,61
748	78621	Trappes	14 878	28%	14,4%	29%	19%	4 164	10 667	1 607	19 450	9 373	-0,74	-0,51
749	78621	Trappes	6 328	35%	14,4%	29%	19%	2 145	5 178	529	24 014	8 972	-0,49	-0,57
		Moyenne de la zone d'étude:	7 576	0,42	0,09	0,23	0,26	3 546	7 714	3 322	30 600	48 482	0	0

## Annex 2 PCA Factor Loadings

Variable	Dimension 1	Dimension 2
TAUX_CHOM	-0.88	-0.05
MOINS19	-0.62	0.31
PLUS60	0.81	-0.24
REVENU	0.79	0.33
VP_ACCESS	-0.03	0.9