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## Paris: a Desire named Tramway

Working Paper – January 2010

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### Abstract:

On the southern part of the Parisian *Maréchaux'* boulevards, the old bus line *Petite Ceinture* has been replaced by a modern tramway (*T3*). Simultaneously, the road-space has been narrowed by about a third. A survey conducted on 1,000 users of the *T3* shows that the tramway hardly generated any modal report from the private cars (PC) towards the public transit (PT). However, it did generate important intra-modal transfers: from bus and subways towards tramway concerning the PT, surely from *Maréchaux'* boulevards towards the Parisian Ring-Road (*boulevard périphérique*, PRR) and/or adjacent streets for the PC. The various benefits and costs of these changes are evaluated in this research.

The welfare gains made by PT users are more than compensated by the time losses of the motorists, and in particular, by the additional cost of road congestion on the PRR. The same conclusion applies with regard to CO<sub>2</sub> emissions: the reductions saved with the replacement of the busses and some (few) PC are less important than the increased pollution induced by the lengthening of the automobile trips and the increased congestion on the PRR. Even if one ignores the initial investment of 350 M€, the social impact of the *T3* project, illustrated by its Clear Discount Value (CDV), is strongly negative. This is especially true for suburbanites. Concerning the lonely inhabitants (electors) of Paris, our analysis shows that they pocket the main part of the benefits while supporting a weak fraction of the costs.

**Keywords:** Tramway, Costs-Benefits Analysis, Road Congestion, CO<sub>2</sub> Emissions

**JEL Classification:** R41, D62, L92

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## Section 1.Introduction

In December 2006, the municipality of Paris inaugurated an 8 kms long tramway line on the *Maréchaux*' boulevards, i.e. in the south of the commune. The tramways are with the mode: having one is perceived as a symbol of “*modernity*” and as a contribution to the fight against global warming. The desire for a tram was generalized among politicians. That one which occupies us was decided by M. Tiberi, the former mayor (classified on the right), and carried out by M. Delanoé, the current mayor (classified on the left)<sup>1</sup>.

As expected, the municipality presented the tramway as a great success. The media, somewhat surprisingly, sang unanimous praise to the project. The public opinion, including the majority of citizens who had neither seen nor taken the *T3*, was also conquered. As common sense suggests, the reality is however that the tramway project presents benefits and costs. It is legitimate to try to identify and evaluate them in order to produce a better-informed appraisal.

This is the purpose of the research presented here<sup>2</sup>. Section 2 presents the characteristics of the project and examines the induced changes in transportation patterns, which we will refer to as the structure of displacements. This enables us to quantify the monetary benefits and costs related to these changes (Section 3), as well as to the environmental impacts of the tramway (Section 4). Section 5 presents the purely financial data and calculates the CDV of the *T3* project. Section 6 concludes<sup>3</sup>.

## Section 2.The *T3* project and its effects on the structure of displacements

This section will briefly present the *T3* project in order to better understand the impacts it had on the structure of displacements in the area.

### 2.1. *The scene and the components of the T3 project*

The Parisian agglomeration includes 11 M inhabitants and is composed of approximately 1,200 communes. The municipality of Paris, the most central and the most important of these communes, contains 2 M inhabitants. It is girdled by two parallel roadways covering approximately 35 kms: the *Maréchaux*' boulevards which date from the beginning of the 20<sup>th</sup> century and are generally bordered by buildings; the Parisian Ring-Road (*boulevard périphérique*, PRR), one of the most frequented urban highway in Europe whose creation dates back to the sixties. These two roadways are about 300

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<sup>1</sup> This scarce unanimity should protect us from any “*partisan*” disclaim.

<sup>2</sup> This research did not receive any financial support.

<sup>3</sup> As transparency is an essential quality of any credible appraisal, we endeavoured to precisely indicate (with sometimes the risk to weary the reader) the followed methodologies, the parameters used, and the calculations carried out.

meters apart. The Parisian agglomeration is an integrated whole, the exchanges between its various parts are intense, especially between central Paris and the remaining communes. According to the EGT (2002), Paris↔Paris displacements are less important than the suburbs↔Paris correspondents. The former constitutes 45% of the total PT displacements having Paris for origin or destination and 34% of the total PC displacements<sup>4</sup>.

The tramway was built on the *Maréchaux*' boulevards, between *Porte d'Ivry* (13<sup>th</sup> district) and *Pont du Garigliano* (15<sup>th</sup> district). This portion of 8 kms corresponds to about a quarter of the total length of the boulevards and constitutes what we will call the *Ivry-Garigliano (IG)* axis. Displacements on this axis are rather diverse in nature. The majority are parts of much longer trips whose origin and/or destination are outside the area. Some others count more as displacements of proximity. The *IG* axis, well covered by the PC and the trucks, was rather badly served by PT. It did not correspond to any underground line, even if combinations of radial ones made it possible to go from a point of the axis to another. It was mostly served by a bus line called the *Petite Ceinture*, which traversed the whole *Maréchaux*' boulevards and was the most attended bus line of Paris.

The *T3* project had three components. The first was the removal of the *Petite Ceinture* bus line. The second was the construction of a modern tramway, which goes faster and is more comfortable. The new lines placement gives it exclusive priority with respect to other transportation modes. The third component was the reduction of approximately a third of the road-space formerly reserved for the PC and the trucks on the *Maréchaux*' boulevards. To a certain extent, this reduction is the direct consequence of the municipal will to restrict the road-space (Prud'homme and Kopp, 2008). It is difficult to know the relative importance of municipality's motivations for the *T3* project. Therefore, we will first take it here as a whole and, then, discuss the impact of this choice (section 5).

## 2.2 Changes in the structure of displacements on the *IG* axis

The *T3* project involved substantial changes in the structure of displacements on the *IG* axis. Two sources make it possible to measure them. The first one concerns the counting of vehicles on the *Maréchaux*' boulevards. The Observatory of the Displacements of the Parisian municipality measured the daily traffic in 2003 and 2007 for 11 sections of the boulevards, which make up 4.5 kms. One can transform this data into vehicles\*kilometers (vkms) and generalize it to the 7.9 kms of the *IG* axis. The year 2003 is selected as the year "*before*" the project because the *T3* was still under construction during 2005 and 2006. Through the data, one can observe that the number of vkms passes from 152,800 to 89,500 between 2003 and 2007. This reduction of 63,300 vkms corresponds to a decrease of 41% of the PC use on the *IG* axis. It is possible to translate these figures into passengers\*kilometers

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<sup>4</sup> This last figure does not take into account the displacements of the commercial vehicles (mainly suburbs↔Paris) nor inter-suburbs moves that pass by the central city.

(pkms) by multiplying them by the occupancy rate of a vehicle (=1.3). One obtains approximately 198,000 pkms before the project and 116,000 after (= - 82,000 pkms).

The second source comes from an *ad hoc* survey, which we carried out on 1,000 users of the tramway between April and May 2007<sup>5</sup>. To ensure a random selection of the users, the investigators went to a station, waited for a train to leave and questioned the first two users who arrived to catch the following one. The stations and the schedules were selected in a representative way of their use. Generally, the users said they were very satisfied with the tramway. The two most interesting answers for our analysis are related to the average length of their displacement in *T3* (2.56 kms, a third of the length covered by the tramway) and to what these users did before its introduction.

**Table 1 – Modal source from the *T3*'s users**

	%	pkms/day
Coming from:		
subway	50.0	144,000
bus	33.5	96,000
private car	2.6	7,000
bicycle	0.7	2,000
two-wheels	0.5	1,000
walk	-	-
mix	12.8	-
Total	100.0	256,000

*Source:* Author's survey. The «mix» answers include the users who realized their displacements with several transportation means.

Table 1 presents the answers to the question: “*before the tramway, how did you realize this commute?*” It appears that the majority of users come from the bus (50%), which is not a surprising result. More astonishing perhaps is the prevalence of the former subway users (33.5%). It is finally seen that the *T3* generated a very weak modal report (2.6%)<sup>6</sup>. The others changes are negligible. These figures make it possible to highlight the impact that the tramway had on modal transit.

A certain number of the commuters (denoted as M) realised their displacements on the *IG* axis with the subway. A little less than 40,000 of them gave up the subway for the *T3*, where they now realize 100,000 pkms per day. On one hand, these travellers must have improved their situation, or else they would not have changed. On the other hand, they relieved congestion in the subway. The 56,000 people who used the bus are in the tramway now, where they make 144,000 pkms. As we will demonstrate, their situation also improved. They equally join the 2,700 individuals (=7,000 pkms) who gave up PC for the *T3*, as well as some 1,000 people who formerly used the bicycle or the two-wheels. The 100,000 users of the *T3* all benefited with the project.

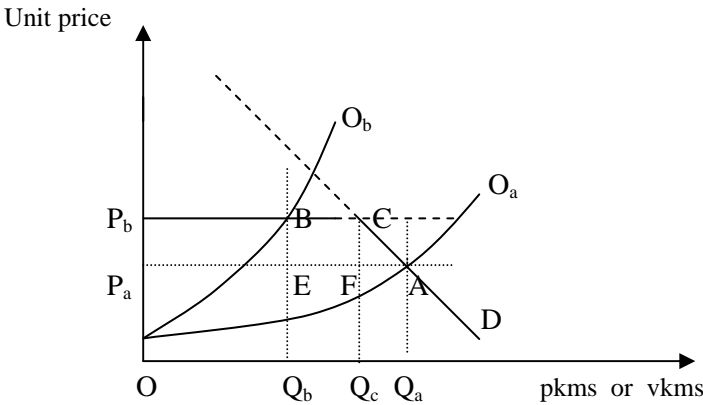
<sup>5</sup> A detailed presentation of this survey is available on [www.pierrekopp.com](http://www.pierrekopp.com)

<sup>6</sup> The number of motorized displacements having Paris as origin and/or destination is equal to 2.3 M per day (EGT, 2002). The modal report induced by the *T3* corresponds to a retreat minor than 1 per 1000 of the total Parisian displacements realized by car.

What about the people who used cars or trucks on the *Maréchaux*' boulevards? It is known that they made 198,000 pkms there. A small number of these pkms, approximately 7,000, are now found in the *T3*. A little more than the half is still carried out on the *IG* axis. Considering the 40% decline in usage of the boulevards, their conditions must now be worst. Other pkms are eliminated by the evolution of circulation's terms in Paris during the period, in particular by the rise of the fuel price and the road-restriction policy led by the municipality. The retreat of the traffic in Paris between 2003 and 2007 is estimated at 5% by the Observatory of the Displacements. It gives a measurement of the impact of this general evolution. In the absence of *T3* project, the PC traffic on the *Maréchaux*' boulevards would have decreased by 10,000 pkms. There are thus 65,000 pkms (=198,000–7,000–116,000–10,000) which miss the call.

Some of displacements corresponding to these 65.000 pkms were undoubtedly eliminated, generating a decline of the mobility. Others were undoubtedly just detoured away from the *Maréchaux*' boulevards. One obvious candidate for this detour is the PRR. Others are the streets more or less parallel with the *IG* axis. In both cases, this change increases the congestion on alternative roads. The assumption will be made that the level of congestion on these two alternatives is comparable<sup>7</sup>. For the needs of the analysis, we will consider that these missing pkms are carried out now on the PRR. Figure 1 helps to understand and estimate these changes.

**Figure 1 – Behaviour of the PC users on the *Maréchaux*' boulevards**



The bent line PbCA represents the demand curve for motorized displacements on the *Maréchaux*' boulevards while the PbC line is the price of alternative displacements on the PRR. There is no reason for a user of the *Maréchaux*' boulevards to pay more than the price of the alternative way on the PRR.

<sup>7</sup> It is equalized at the margin by the motorists' behaviour.

In addition, the  $O_a$  curve classically describes the phenomenon of road congestion on the *Maréchaux*' boulevards. When the number of users increases, the road congestion increases too: the traffic speed decreases and the cost of a displacement, mainly composed by its time opportunity cost, becomes more expensive. The intersection of  $O_a$  and  $D$  defines the situation before the project, with a price  $P_a$  and a quantity  $Q_a$ .

What are the consequences of the  $T3$  project? By narrowing the road-space on the *Maréchaux*' boulevards, it moves  $O_a$  to  $O_b$ . For the same level of use, there is thus more road congestion on the  $IG$  axis and PC users face a higher unit price. The intersection of  $O_b$  and  $P_bCD$  defines a new equilibrium, with the price  $P_b$  and the quantity  $Q_b$ . Hence,  $Q_b$  travellers continue to use the *Maréchaux*' boulevards,  $BC (=EF=Q_cQ_b)$  travellers are now on the PRR (or somewhere else), and  $FA (=Q_aQ_c)$  travellers reduced their mobility, at least on the  $IG$  axis.

### 2.3. The allowance of the missing pkms

To deduce the allowance of the 65,000 pkms eliminated from the *Maréchaux*' boulevards, we can directly estimate  $F$  by means of the supposed elasticity ( $\epsilon$ ) of the demand curve. Indeed,  $\epsilon = (\Delta q/q)/(\Delta p/p)$ , or equivalently  $\Delta q = \epsilon * q * \Delta p/p$ . If one refers to Figure 1:  $\Delta q = FA$ ,  $q = Q_a$ ,  $p = P_a$  and  $\Delta p = P_a P_b$ .

We already know  $Q_a (=152,300 \text{ vkms}^8 \text{ per day})$ . By postulating a speed of 20 km/h on the *Maréchaux*' boulevards before the  $T3$ , it is possible to calculate  $P_a$ . For that purpose, one needs the value of the time opportunity cost. For 2000, it was fixed at 9.3 €/hour (*Instruction-cadre*, 25<sup>th</sup> March 2004) for urban transport in *Ile-de-France* region. The same official text makes the recommendation to up-date this value according to the consumer's expenditures affected by a 0.7 coefficient. For 2007, supposing an increase in consumption of 2% a year, one therefore obtains a time opportunity cost equal to 10.2 €/hour. Knowing the fixed monetary cost of PC use ( $=0.12 \text{ €/vkm}$ ), we find  $P_a = 0.783 \text{ €/vkm}$  ( $=0.12 + 10.2 * 1.3/20$ ).

We also need  $P_a P_b$ . It is logical to think that this over-cost is equal to the one generated by the detour towards the PRR<sup>9</sup>. We can calculate  $P_a P_b$  by means of several assumptions. First, the average length of trips on the *Maréchaux*' boulevards is half of the total length of the tram, that is to say 4 kms. Second, the detour lengthens the displacement by two times 400 meters<sup>10</sup>. Third, this distance is

<sup>8</sup> It is preferable to lead the analysis in terms of vkm and to return then to figures in pkm (by a multiplication of 1.3).

<sup>9</sup> Or, if one prefers, the welfare loss resulting from the change of road pulled by the  $T3$ . This loss is quite real; if not everyone would have used the PRR.

<sup>10</sup> 300 meters is the distance as the crow flies separating the two roadways.

driven at an average speed of 20 km/h. It is then calculated that the over-cost corresponds to 0.6 minutes per km driven, i.e.  $PaPb=0.133 \text{ €/vkm} (= (102/60)*1.3*0.6/20)^{11}$ .

For the demand elasticity, one will start from Litman (2009) or Goodwin (1992) who propose values ranging between -0.6 and -0.8. These elasticities were calculated for whole trips. They are therefore not appropriated for the analysis of the displacements on the *Maréchaux*' boulevards, which frequently constitute an under part of longer displacements (approximately two or three times). The demand on this section is consequently more inelastic. It is thus advisable to retain a demand elasticity (approximately two or three times) lower in absolute value. We made calculations for elasticities ranging between -0.4 and -0.2. The estimated retreat of mobility lies between 5,175 and 10,350 vkms per day (between 6,700 and 13,400 pkms). By considering a decrease in the mobility (FA) of 10,000 pkms, we deduce the number of reported displacements on the PRR (BC=55,000 pkms).

Table 2 finally synthesizes the changes in transportation patterns on the *IG* axis induced by the tramway.

**Table 2 – Displacements on the *IG* axis, by transportation modes**

	Before (2003) (pkms/day)	After (2007) (pkms/day)	Difference (pkms/day)	Consequences
Public transportation (PT)				
Subway	M	M-97,000		Decongestion
Bus & tramway	144,000	256,000		$\Delta$ surplus
Total PT	M+144,000	M+161,000	+7,000	
Private cars (PC) and trucks				
<i>Maréchaux</i> ' bvd	198,000	116,000		$\Delta$ surplus
PRR	P	P+55,000		Congestion
Total PC	P+198,000	P+171,000	-27,000	
General total	P+M+352,000	P+M+332,000	-20,000	

*Note:* To find again the 198,000 pkms for 2003, one has to sum the 7,000 pkms that are now in the tramway, the 10,000 pkms eliminated by the transportation policy of the municipality and the 10,000 pkms corresponding to the retreat of mobility with the 116,000 pkms still realized on the *Maréchaux*' boulevards and with the 55,000 pkms that have been reported on the PRR.

One sees that the *T3* project involved (I) important intra-modal transfers (inside the PT's means), (II) practically no modal report and (III) important road transfers for the cars. The increase in the supply of PT did not induce an increase in the frequentation of the PT. The whole mobility on the *IG* axis even recorded a reduction of a little less than 6%.

<sup>11</sup> One can deduce from  $PaPb$  the traffic speed on the *Maréchaux*' boulevards after the *T3* project. In fact, since  $Pb=Pa+PaPb$ , it is possible to rewrite it as  $(0.783+0.133)=0.12+10.2*1.3/s$  and, then, to find  $s=16.7 \text{ km/h}$ .



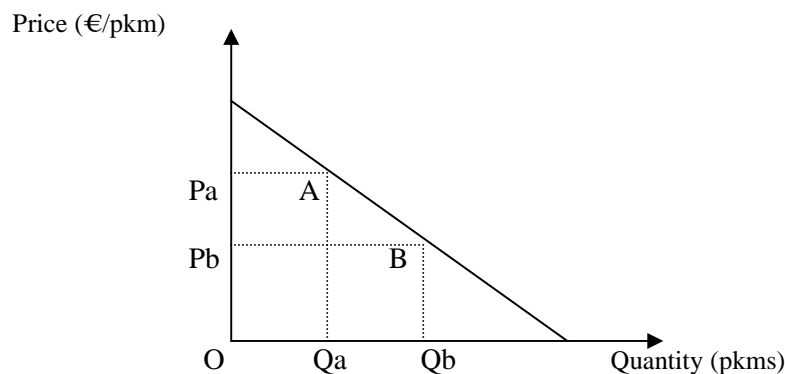
### Section 3. Surplus variations of travellers on the IG axis

We can now estimate the various benefits and costs associated with the changes in the structure of displacements on the IG axis. These impacts are diverse. The main part corresponds to the evaluation of time gains and/or losses.

#### 3.1. Surplus variation of the PT's users

Let us start with the most obvious benefits: those of the T3's users, or more exactly of the PT's users. It is represented by Figure 2 where AB is the line of joint transport demand on the IG axis: the lower the price, the higher the demand. The situation before the tramway is indicated by the point A. It was seen that Qa was equal to 144,000 vkms. The unit price is Pa, which one does not need to know. The situation after the tramway is indicated by the point B with Qb equal to 256,000 vkms and a unit price Pb. To say that the T3 is better than the old bus is similar to recognize that  $P_b < P_a$ . Of how much? The improvement of the PT supply, i.e. the substitution of the bus by the tramway, has two advantages: it saves time and generates benefits in comfort.

**Figure 2 – Surplus of PT's users**



One can easily calculate the variation of surplus generated by the time-savings. It is represented by the PaABPb surface. Speed increased from 16 km/h (by buses) to 20 km/h (by tramway)<sup>12</sup> which corresponds to 0.633 minute saved per pkm. On the other hand, the latency has increased since it passed from 3.5 minutes with the bus to 4 minutes with the T3. For a trip of 2.56 kms, the corresponding waste of time equals 0.195 minute. On the whole however, the length of a displacement on the IG axis has decreased by 0.438 minute per pkm. As a consequence, the cost in time declines by 0.0745 €/pkm ( $=0.438 \cdot 10.2/60 = PaPb$ ). With  $Q_a = 144,000$  and  $Q_b = 256,000$ , the PaABPb surface is equal to 14,900 € per day. By counting 300 days a year, we obtain 4.47 M€.

<sup>12</sup> 20 km/h was the official target but we cannot be sure that it has been reached. We will take it for granted, even if such doing may lead to over-estimate time-savings.

It is much more difficult to estimate the benefits due to the better comfort of the tramway. Doing so would necessitate complex and expensive contingent evaluations of the willingness to pay for increased comfort (or reduced discomfort). However, one cannot neglect these benefits. We will thus make the assumption that they are in the same order of magnitude as the time-savings<sup>13</sup>, while noting the very fragile character of these beliefs. For this reason, we retain our previously calculated benefit of 4.47 M€ a year.

### 3.2. Surplus variation of the motorists on the *Maréchaux*' boulevards

The variation of the PC users is easy to calculate. It is equal to the sum of the wastes of time of the motorists who still remain on the *Maréchaux*' boulevards and who can no longer drive as fast as before (surface PbBEPa on the Figure 1), added to those of PC users who make the turning by the PRR (surface BCFE) and to the welfare loss of the individuals who reduced their mobility because of the tram (surface CAF). It is thus equal to 7.02 M€ a year ( $=0.133*(171,000+10,000/2)*300$ ). This cost is distributed between the motorists who remain on the *Maréchaux*' boulevards with 4.63 M€, those who refer on the PRR with 2.18 M€, and with 0.21 M€ for those who have reduced their mobility.

However, this estimate does not take into account the fact that part (estimated at 20 %) of the vehicles are commercial ones whose the time opportunity cost is higher than that of PC. According to the *Instruction-cadre* (25<sup>th</sup> March 2004) the time opportunity cost for the transportation of goods is fixed at 31.4 € per hour<sup>14</sup>. A simple calculation shows that it is then advisable to increase the figure calculated on the basis of the value of the time of the travellers by 27.3% ( $=((31.4*0.2)+(10.2*1.3*0.8))/(10.2*1.3)$ ). Therefore, the true cost is 8.91 M€ a year rather than 7.02 M€.

### 3.4 Congestion externality on the PRR

The PRR is a crowded road (Koning, 2010). Each additional vehicle slows down the traffic flow and thus affects all the vehicles. This cost is thus a marginal cost of congestion. As suggested in section 2, we have good reason to believe that a possible consequence of the *T3* project was an increase in the traffic on the southern PRR (55.000 pkms=42.300 vkms).

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<sup>13</sup> Litman (2007) offers a review of studies related to the qualitative attributes of PT and to their valorizations. He concludes that the welfare gains associated with qualitative improvements in the PT supply may reach the same order of magnitude than those associated with an increase in the traffic speed.

<sup>14</sup> This value should not be up-dated over years (*Instruction-cadre*, 2005).

For the marginal cost of road congestion, the most used estimate comes from INFRAS (2000)<sup>15</sup>. It values this marginal cost at 2.70 €/vkm in the event of “dense” traffic and at 3.10 €/vkm in case of “true congestion”. The PRR is at least in situation of “dense” traffic. If one applies the corresponding value to the 42,300 additional vkms, he will find that the external cost of the tramway is equal to 114,210 €/day, i.e. 43.62 M€ a year. This estimate, financed by the International Union of the Railroads, is however probably a little exaggerated. It has the great disadvantage of being aggregated and of using single marginal cost<sup>16</sup>. We therefore prefer to apply the method used for the PRR in Prud’homme and Sun (2000) or Koning (2010).

For 2007, we lay out of approximately 25,000 data relating to flow, speed and concentration of the traffic on the *IG* portion of the PRR. A simple regression makes it possible to get an equation describing the traffic speed (s) as a function of the density (q):

$$s(q) = \alpha + \beta * q = 85.3 + 0.264*q$$

(0.001) (0.140) R2 = 0.73

One is then able to deduce the private cost (I(q)) according to the density:

$$I(q) = 0.12 + 10,2*1.3/ v(q)$$

The marginal costs of road congestion are equal to the derivative of I(q) multiplied by the number of affected vehicles (i.e. the density) :

$$Cm(q) = 3.5*q/(85.3 + 0.264*q)^2$$

These costs vary considerably according to the density (q) and thus, the associated speed. Being very weak and almost negligible when the traffic speed is higher than 50 km/h (0.1 €/vkm), it becomes more consequent for low speeds (18 €/vkm with a 7.5km/h traffic speed).

The data used in Koning (2010) enable us to know the traffic distribution by speed class on the southern part of the PRR. By making the assumption that the reported vkms are distributed as those which normally attended the PRR, we can calculate the marginal costs of road congestion for each speed class ranging between 2.5 km/h and 75 km/h. It is enough to multiply these costs by the number of vkms additional to the different classes. While adding, one obtains the additional cost of congestion

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<sup>15</sup> It was often taken by the European Commission, and French organizations such as the French Institute of the Environment (2004, p. 94).

<sup>16</sup> Whereas this one varies, in considerable proportions, according to the traffic conditions.

caused by the vehicles which the *T3* project rejects towards the PRR<sup>17</sup>. With a daily report of 55,000 pkms, this external effect of the tramway rises to 24.99 M€ a year. It is also necessary here to take into account the 20% of commercial vehicles. By using the 1.273 coefficient, one finally obtains an additional cost of congestion on the PRR equal to 31.82 M€.

Even minor than those calculated with values coming from INFRAS (2000), these additional costs appear thus very expensive for society. Since they represent the main consequence of the *T3* project, in monetary terms at least, we will equally carry out the final calculation of the CDV (section 5) without taking into it account<sup>18</sup>.

### 3.5. *The deceleration of the vehicles entering Paris*

A certain number of the radials used by the motorists to enter Paris are perpendicular to the *Maréchaux*' boulevards, and thus to the line of tramway. These intersections are regulated by traffic lights. With the difference of the buses *Petite Ceinture* which it replaces, the *T3* enjoys the right of way at these traffic lights. This slows down a certain number of the vehicles entering or outgoing of Paris.

According to EGT (2002), the number of travellers Paris ↔ suburbs by car rose to 1.63 M per day in 2001. The tramway line makes up about the quarter of the circumference of Paris. Thus, one can estimate that about one quarter of these travellers (=407,000 per day) is affected. Let us estimate the average wait imposed by the tramway to be 20 seconds (=1/180 of hour). Given that the frequency of the *T3* is of 3.5 minutes (210 seconds), we can postulate that the probability of being stopped is of approximately 1/10. We should also double this figure to take into account the fact that the tramway circulates in the two directions. The slow-down thus concerns 81,400 daily travellers. With the usual parameters, one finally calculates that the loss induced is of 1.83 M€ a year.

### 3.6. *Clearing's externality of the subway*

The *T3* created an intra-modal transfer of 96,000 pass\*km from the subway towards the tramway. It may decrease the congestion in the subway, a phenomenon which implies a benefit of the project. Unfortunately, this benefit is very difficult to estimate. Despite the existence of hundreds of studies on the automobile congestion, there is practically nothing (nothing published at least) on the congestion in the PT. Works of Armelius (2006) and Litman (2007) are notable exceptions. However, one does not have a function representing the cost of congestion in PT according to its use. In addition, the ratio of the intra-modal transfer pulled by the *T3* on the whole number of pkms in the Parisian subway

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<sup>17</sup> The details of calculation can be found in Appendix.

<sup>18</sup> As well as the other consequences on PC's users surplus of the road-space narrowing necessary to introduce the tramway on the *Maréchaux*' boulevards.

(0.4%) or on the whole places offered (0.1%) is not very significant since the report is concentrated on a small section of the network<sup>19</sup>.

We will nevertheless try to propose an estimate of this surplus gain. Litman (2007, p.11) advances an elasticity of the cost in time compared to the frequentation equal to 0.4. When the frequentation increases by 10%, the comfort (measured by the time opportunity cost) decreases by 4%. The reduction of 0.4 % of the subway's frequentation generates thus an improvement in comfort equal to 0.16 % of the value of the time spent in the subway. Knowing that the time spent is approximately 280 Mh a year, the reduction of 0.4 % in the frequentation results in a comfort gain equal to 0.448 Mh, i.e. 4.57 M€ a year. As we said, this figure is to be taken with precaution. But it is not impossible. It belongs to the same order of magnitude as the time savings and also the benefits of comfort met by the *T3*'s users.

## **Section 4.Environmental impacts of the *T3* project**

The *T3* project has 5 impacts concerning the CO2 emissions. Two are positive. They come from the replacement of buses by the tramway and, very modestly, from the modal report. Two others are negative. They come from the lengthening of trips and the reduction in speed for the motorized vehicles. The last, which is generated by the retreat of the mobility, is unspecified. It is necessary to try to measure these effects. Before, it is helpful to consider the link between traffic speed and CO2 emissions.

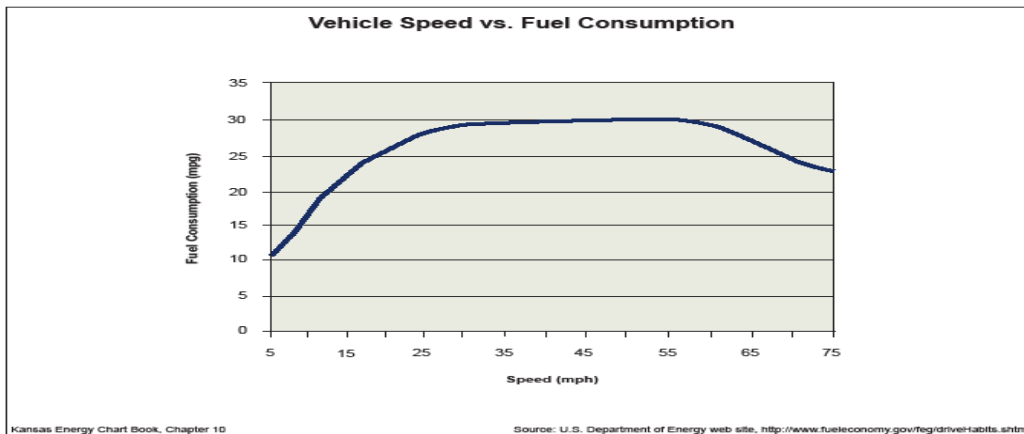
### *4.1. Emissions-speed function*

It is known that fuel consumption is a function of the velocity. It is infinite when speed is zero and decreases regularly when speed increases, up to 40-50 km/h. It stagnates then between 40-50 km/h and 90-100 km/h and increases again beyond this limit. The graph hereafter, which comes from the website of the Department of the Energy of the United-States, shows it clearly:

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<sup>19</sup> Where one does not know if it is congested or not.

**Figure 3 – Fuel consumption as a function of traffic speed**



*Source:* [www.fueleconomy.gov/feg/drive-Habits.shtml](http://www.fueleconomy.gov/feg/drive-Habits.shtml)  
*Note:* the fuel’s consumption is measured in miles per gallon (i.e. in kilometer per liter). This explains the inversed form with respect to a graph expressed in liters per kilometer. We have searched (without any success) such a graph on the web-sites of French institutions such as ADEME, the Ministry of finance (energy) or *Institut Français du Pétrole*.

It is easy to determine the function that connects fuel consumption and speed by considering the point where the curve cuts the y-axis<sup>20</sup> and the point that corresponds to a speed of 30 miles/hour<sup>21</sup>. Once this function derived, one multiplies it by the CO2 emissions associated with a fuel consumption of one liter (=2.35 kg)<sup>22</sup>:

$$\text{For } s < 50 \text{ km/h (expressed in kg/km): } \text{CO}_2(s) = 0.624 - 0.00925 * s$$

$$\text{For } s > 50 \text{ km/h: } \text{CO}_2(s) = 0.16$$

This function is derived for PC. Actually, the traffic includes approximately 20% commercial vehicles which emit, on average, twice as much CO2 than PC. In that case, it will be then advisable to multiply the obtained estimate for emissions by a coefficient of 1.2.

#### 4.2. Replacement of the buses

The frequency of the replaced buses was at the peak period of 17 buses per hour. By liberally counting 18 rush hours, there were 306 buses per day which traversed 2,417 bus\*kilometers (=306\*7.9, bkm). According to the *Statistiques Annuelles* (p.32) of the RATP<sup>23</sup>, the buses consume 0.567 liters of gas

<sup>20</sup> s=5 miles/h=8.04 km/h ; fuel consumption=10 miles/gallon=0.23 liter/km

<sup>21</sup> s=48.27 km/h ; fuel consumption = 30 miles/gallon=0.078 liter/km

<sup>22</sup> We do not have found any similar equation for the French case. But Renault communicated to us that, in urban areas, passing from 10 km/h to 20 km/h induced an “economy” equal to 25%. Our estimate results in a 17% economy, amount not so far away.

<sup>23</sup> The company which organizes the PT on the regional scale.

per bkm. Thus, the removed buses consumed 1.370 liters of gas and emitted 3.22 (=1.370\*2.35) tons of CO<sub>2</sub> per day (=966 tons per year). The tramway, which operates with (nuclear) electricity, saved these emissions.

#### *4.3 Modal report*

A reduction in 7.000 pkms corresponds to 5.380 fewer vkms daily driven. By postulating a traffic speed of 20 km/h before the tramway, i.e. a CO<sub>2</sub> emission of 0.439 kg/km, these vehicles emitted 2.36 tons of CO<sub>2</sub> per day (=709 tons per year) on the *Maréchaux'* boulevards. This is the amount of CO<sub>2</sub> emissions saved by the *T3* which attracted PC users.

#### *4.4 Reduction in speed for the remaining vehicles on the Maréchaux' boulevards*

The number of PC which continue to use the *Maréchaux'* boulevards on the *IG* axis fell by 36%, but still rose by 89,500 vkms per day. As demonstrated, this reduction comes from an increase in the cost necessary to use the *Maréchaux'* boulevards. One previously estimated this cost to be 2.4 minutes for an average trip of 4 kms on the boulevards. With a speed of 20 km/h, this increase corresponds to a reduction of 16.7 km/h, that is to say a variation of approximately 17%<sup>24</sup>. The emissions-speed equation gives us the unit emissions associated with 20 km/h (=0.439 kg) and 17 km/h (=0.467 kg). The product of this difference by the number of vkms (=89,500) equals to a CO<sub>2</sub> increase of 2.5 tons per day (=752 tons per year). Since the traffic in question includes commercial vehicles, we have to use the 1.2 coefficient. We thus obtain an estimate of 902 tons per year.

#### *4.5 Reduction of the mobility*

One could say that the people who experience a reduction in mobility on the *IG* axis do not consume any more gasoline. This daily economy attains 10,000 daily pkms, that is to say 7,692 vkms. By taking the same parameters as before, we find an annual CO<sub>2</sub> benefit of 720 tons. Actually, the vkms eliminated on the *IG* axis are undoubtedly in many cases replaced by others displacements which might be as long as or even longer than the initial ones. Therefore, we will not thus count any profit nor loss for this reason.

#### *4.6 Lengthening of the trips for the vehicles transferred towards the PRR*

The vehicles transferred from the *Maréchaux'* boulevards to the PRR travel at least 800 meters more than before. Some certainly travel much more. Therefore, they consume more fuel and emit more CO<sub>2</sub>. Assuming a 100% report (=42,300 vkms) and a range of 4 kms, we obtain an amount of 10,575 displacements of 0.8 km (=8,460 vkms). At 20 km/h, the corresponding unit emission is equal to 0.439 kg/km. With the usual parameters, one finds additional CO<sub>2</sub> emissions of 1,337 tons per year.

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<sup>24</sup> See note 11.

#### 4.7. Decrease in speed on the PRR

The principle environmental impact of the T3 project comes from the deceleration on the PRR due to the transferred vkms. These additional vehicles indeed slow down the whole flow on the infrastructure and thus increase the emissions of all the vehicles (all things being equal). This phenomenon is just the reverse side of the congestion's externality studied previously.

This consequence can be calculated with rather good precision. It is indeed possible to cross the emission-speed equation with the speed-density relation. One obtains the quantity of CO2 emitted as a function of the density of the road:

$$\text{CO2} = f(s) = \lambda + \mu * v \quad (\text{with } \lambda = 0.624 \text{ and } \mu = -0.00925)$$

$$s = g(q) = \alpha + \beta * q \quad (\text{with } \alpha = 85.3 \text{ and } \beta = -0.264)$$

This gives us:

$$\text{CO2} = h(q) = \lambda + \mu * \alpha + \mu * \beta * q$$

The marginal emission (CO2M), which in other words is the additional quantity of CO2 caused by one vehicle added to a flow of density q, is the derivative of this function multiplied by q:

$$\text{CO2M} = h'(q) * q = \mu * \beta * q = 0.0024 * q$$

It is easy to calculate the marginal CO2 emission for each speed class and the associated density. Then, one just has to multiply this marginal emission by the number of additional vehicles in the speed class and to sum it<sup>25</sup>. With 42,300 veh\*km displaced each day, the reduction of speed on the PRR reveals a surplus in emission by 8.4 tons of CO2 per day. It is also advisable to multiply this figure by the 1.2 coefficient in order to take into account the commercial vehicles. Finally, one obtains an increase in CO2 emissions by approximately 2,900 tons per year.

**Table 3 – Impacts of the T3 project on CO2 emissions**

	(in tons of CO2 per year)		
	Before	After	Variation
Bus suppression	966	Zero	-966
Modal report	709	Zero	-709
Decrease in speed on the <i>Maréchaux</i> ' bvd's	14,144	15,046	+902
Trips' lengthening	Zero	1,337	+1,337
Decrease in speed on the PRR			+2,900
<b>Total</b>		<b>+ 3,464</b>	

*Source:* authors' calculations

<sup>25</sup> These calculations are presented in the Appendix.



Table 3 shows the various environmental impacts of the *T3* project. All things being equal, the tramway contributes to an increase in CO<sub>2</sub> emissions by more than 3,400 tons per year<sup>26</sup>. By retaining a conventional value of 25 € per ton, one obtains a cost less than 0.1 M€ per year with the bond of the greenhouse effect. This amount is rather negligible compared to the other profits and costs.

## Section 5. Financial data and CDV of the *T3* project

### 5.1. Exploitation and capital costs

Published information on the pure monetary costs associated with the *T3* project is rather rare. One has only the *ex ante* costs envisioned in the official *Enquête Public*: 341.8 M€ for the initial investment and 43.9 M€ for the exploitation of the *T3*. The experiment suggests that the *ex post* costs are appreciably higher. However, let us suppose that the *T3* was an exception and that the effective cost was equal to what had been anticipated. Being financed with budgetary funds, it is appropriate within the framework of the costs-benefits analysis to multiply this expenditure by the opportunity cost of the public funds (officially fixed at 1.3). There is thus an initial investment of 443.3 M€.

For the operational costs, we are only interested in the difference between the costs of the buses and that ones of the tramway. The operating costs of the buses are not published. The *Statistiques Annuelles* of the RATP give the average costs of operation by trip, which is at 1.07 €. The removed buses ensured 55,000 trips per day. This would suggest that the operating costs for the *Petite Ceinture* were approximately equal to 17.78 M€ per year. If this calculation were followed, the operational costs of the *T3* would be 2.4 times higher (an over-cost of 26 M€). It is however necessary to be careful because these costs are certainly higher for the bus than that for the subway, so that average costs probably underestimate the operating costs of the buses. Therefore, it will be considered that the operating costs of the tramway are comparable with those of the buses<sup>27</sup>.

The users' payments are hardly affected by the *T3*'s introduction. In fact, the large majority of the travellers paid already the same amount before. However, it was seen that the tramway attracted 3,850 new displacements. If they all paid the flat rate of 1.07 €/trip, that would increase the receipts of the RATP by 1.26 M€ per year. Actually, much of them undoubtedly profited a transport pass and took the tramway at a zero marginal price. Hence, one will liberally retain an additional receipt induced by the *T3* equal to the two thirds of this 1.26 M€, that is to say 0.84 M€.

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<sup>26</sup> Even if one takes into account the CO<sub>2</sub> savings associated to the retreat of mobility, the environmental balance remains negative.

<sup>27</sup> By deploring the scarcity of available information.

## 5.2. Economic appraisal of the T3 project

Table 4 presents the various components of our economic appraisal. They relate to the changes induced by the T3 project with reference to the *ex ante* situation (and to the former roadway system). Some of these estimates are more uncertain than others. Three in particular may be considered fragile: the comfort gains in the T3, the benefit of clearing the subway and the wastes of time of the vehicles entering/leaving Paris. In these cases, the available data does not allow to produce very solid figures. Even if one could have foregone using these estimates for this reason, it seemed that a bad estimate was better than no estimate at all.

From the socio-economic point of view, the T3 project appears to be deplorable. Not only did it require a significant investment. It also yearly costs more than it benefits to the society. We are not able to calculate any Internal Rate of Return (IRR) for the project since there does not exist any discount rate that could equalize the sum of the cash-flows. Let us repeat for non-specialists that this issue is not strictly a question of financial flows, but also of social and environmental resources. The CDV of the T3 project, calculated with the official rate of 4% over 30 years is established to -930 M€. It is a measurement of the resources' wastes induced by the T3 project.

Another way, perhaps more telling, to illustrate this consists in synthesizing these results by considering the annual cost of the investment and adding it to the benefits and costs of operation. The annual cost of the investment is equal to the opportunity cost of the capital and its amortization. With an opportunity cost of 4% and an amortization period of 30 years, one obtains an annual cost in capital equal to -59.24 M€. Added to the annual costs and benefits of -28.29 M €, one obtains a total cost of -87.53 M€.

**Table 4 – Costs and benefits of the T3 project**

	Initial (M€)	Yearly (M€)
Initial investment	-444.34	
Operating costs		pm
Variation operator's surplus		+0.84
Variation PT's users surplus:		
Time savings		+4.47
Comfort gains		+4.47
Decongestion of the subway		+4.57
Variation PC's users surplus		
Time loses on the <i>Maréchaux</i> ' bvd		-8.91
Time loses of the vehicles entering Paris		-1.83
Externalities		
Additional congestion on the PRR		-31.82
Over-emissions of CO2		-0.08
Totals	-444.34	-28.29

*Sources and notes:* authors' calculations. PT = public transit; PC = private cars

One could argue that the costs, directly or indirectly, inflicted on PC users because of the road-space narrowing on the *Maréchaux*' boulevards should not be taken into consideration during the CDV's calculation<sup>28</sup>. To size this assumption, it is enough to be unaware of the costs relating to the wastes of time for PC users on the *Maréchaux*' boulevards, as well as the increased congestion on the PRR<sup>29</sup>. The conclusions do not strongly differ. Even if a yearly benefit of 12.6 M€ can be found, this amount is unfortunately not enough to cover the initial investment of 444 M€. In fact, the CDV is still negative (-227 M€)<sup>30</sup>. Even if the tramway did not obstruct the automobile displacements, the project still would not be economically justified.

## Section 6. Conclusion

This research does not claim to be the last word on the appraisal of the Parisian tramway. It nevertheless underlines the theoretical and factual gaps concerning the *T3* while leaving open the possibility to improve our estimates. However, it appears sufficiently reasonable to draw some conclusions.

The tramway line, opened on the *Maréchaux*' boulevards in December 2006, is an apparent success. It welcomes the users of the bus line that it replaced, as well as part of the subway users. These travellers profit from the project: they move more quickly than before, under better conditions of comfort, and the decongestion of the subway improves the situation of a larger number of people. These benefits represent, according to our estimates, approximately 15 M€ per year.

In the same time, the tramway was accompanied by an important reduction of the road-space on the *Maréchaux*' boulevards. This increased the road congestion on the *Maréchaux*' boulevards and reduced approximately by 40% the circulation. One estimated thus a 8.9 M€ loss to those who still use PC on the *Maréchaux*' boulevards. Despite the improvements in the PT supply and this worsening of traffic conditions, it appears that the drivers have not given up their car for the tramway. In fact, only 2 or 3 percent of the actual *T3*'s users are former drivers<sup>31</sup>. Therefore, where did they go?

Some are discouraged and do not travel any more on the *Maréchaux*' boulevards. The majority of them are now on roadways parallel to the *Maréchaux*' boulevards and, probably, on the PRR. Here lies the devil. By doing so, they use longer routes and they waste time compared to the former situation. But the worst effect of the *T3* project may come from the increased congestion on the PRR.

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<sup>28</sup> The road-space contraction was not necessarily imposed by the tramway and these losses therefore exaggerate the effects of the *T3* project.

<sup>29</sup> But not those of the travellers entering/outgoing from Paris.

<sup>30</sup> In annual terms, the net loss becomes about 46.70 M€.

<sup>31</sup> This real experiment shows once again the limits of the modal report policies.

An additional vehicle on this infrastructure in fact slows down the whole traffic and generates an important incremental cost of congestion. This could rise to an amount about 30 M€. Finally, the T3 project does not appear to deserve the chorus of praises that it received. It was expensive, its costs outweigh its benefits, in particular with regard to the fight against the greenhouse effect.

The trams are with the mode. But “*the fashion, said Jean Cocteau, is what becomes obsolete*”. In terms of political economy, the project is however probably interesting for the municipality of Paris. Its principle recipients are the T3’s users, who are mainly (57%) the Parisians, i.e. voters. The costs are for the motorists, who are mainly commuters and do not vote in Paris. The cost of capital was paid by the city of Paris only at a 15% level, and anyway, the municipal taxes are mainly paid by firms. As a result, the costs seem to be relatively painless for the voters. The environmental balance is in the negative, but this impact can be difficult to observe. It is in fact easier to notice that there are fewer cars on the *Maréchaux*’ boulevards than to notice the ones that are now on the PRR.

It is thus not very surprising that the T3 project had, and keeps, the favour of the Parisian elected officials. The idea to prolong the tramway on the remainder of the *Maréchaux*’ boulevards at an estimated cost of more than 600 M€ raises little opposition and has just been confirmed by the officials.

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## Appendix

**Table 5 – Additional road congestion and environmental costs on the PRR**

Classes	Speed	Distrib.	Density	uMCC	Report	MCC	uMRP	MRP
0-5	2.5	0.4	314	175.636	158	27,719	0.785	124
5-10	7.5	3.2	295	18.337	1,363	24,999	0.738	1,006
10-15	12.5	6	276	6.177	2,556	15,791	0.691	1,765
15-20	17.5	5.1	257	2.935	2,159	6,336	0.643	1,388
20-25	22.5	4.5	238	1.645	1,920	3,158	0.596	1,144
25-30	27.5	4.6	219	1.013	1,943	1,969	0.548	1,065
30-35	32.5	3.6	200	0.663	1,527	1,012	0.501	765
35-40	37.5	2.6	181	0.451	1,098	495	0.453	498
40-45	42.5	2.1	162	0.314	885	278	0.406	359
45-50	47.5	2.2	143	0.222	937	208	0.359	336
50-55	52.5	2.9	124	0.158	1,243	196	0	0
55-60	57.5	5.6	105	0.111	2,382	266	0	0
60-65	62.5	9.6	86	0.077	4,074	315	0	0
65-70	67.5	14.9	67	0.052	6,303	326	0	0
70-75	72.5	18.3	48	0.032	7,753	250	0	0
> 75	85	14.2	0	0.000	6,006	0	0	0
Total/d.		100			42,308	83,319		8,452

Speed: average speed of the correspondent class (km/h)

Distrib.: distribution, in % and for each speed-class, of the observed vkms on the southern part of the PRR

Density: (veh/km), calculated through the speed-density relation  $q=(85.3 - v)/0.264$

uMCC: unitary marginal cost of congestion (€/vkm), calculated with  $C_m(q)=3.5*q/(85.3 + 0.264*q)^2$

Report: in vkm, product of Distrib. with the total number of vkm daily reported on the PRR

MCC: marginal cost of congestion (€), product of Report with uMCC

uMRP: unitary marginal rejection of pollutant (kg/vkm), calculated with  $CO2M= 0.0024*q$  if speed < 50 km/h,  $CO2M=0$  otherwise

MRP: marginal rejection of pollutant (kg), product of Report with uMRP