Paris: a Desire named Streetcar

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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On the southern part of the Parisian *Maréchaux'* boulevards, the old bus line (*Petite Ceinture*) has been replaced by a modern streetcar (*T3*). Simultaneously, the road-space has been narrowed by about a third. An investigation conducted on 1.000 users of the *T3* shows that it 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 benefits and the costs of these changes are evaluated in this research.

The gain of welfare made by PT users is more than compensated by the loss of the motorists, and in particular, by the possible external costs of congestion on the PRR. The same conclusion applies with regard to CO2 emissions: the reductions induced by the replacement of the busses and some (few) cars are less important than the increased pollution caused by the lengthening of the automobile trips and the increased obstruction. Even if one ignores the 350 M € of initial investment, the overall societal impact of the *T3* project is strongly negative. This is especially true for suburbanites. Concerning to 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, Modal Report Policy, Costs-Benefits Analysis, Road Congestion, CO2 Emissions

JEL Classification: R41, D62, L92

Section 1. Introduction

In December 2006, the municipality of Paris inaugurated in the south of the commune an 8 km long streetcar line on the *Maréchaux*' boulevards. 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[1].

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 one of the majority of citizens who had neither seen nor taken the tram) was conquered. All that was heard was that the *T3* is a great success. Circulate (if one could say), there is nothing to see.The reality, as common sense suggests, is that the tramway presents benefits and costs. It is legitimate to try to identify and evaluate these benefits and costs in order to produce a better-informed appraisal.

This is the purpose of the research presented here[2]. Section 2 presents the characteristics of the project before examining the induced changes in transportation patterns, which we refer to as the structure of displacements. This enables us to quantify the external effects related to the changes in the length of displacements (Section 3), as well as to the environmental impacts of the tramway (Section 4). Section 5 presents the purely financial costs/benefits and calculates the Clear Discount Value (CDV) of the *T3*'s project. Section 6 concludes[3].

Section 2. The project and its effects on the displacement's structure

This section will briefly present the *T3* project in order to better understand the impacts it has on the structure of displacements (i.e. commuter behaviour) in the area.

The scene and the components of the project

The Parisian agglomeration includes 11 M inhabitants and is composed of approximately 1.200 communes. The municipality of Paris, which is the most central and most important of these communes, contains 2 M inhabitants. It is girdled by two parallel roadways covering approximately 35 km: the *Maréchaux*' boulevards which date from the beginning of the 20th century and are generally

[1] This scarce unanimity should protect us from any "*partisan*" disclaim.
[2] This research did not receive any financial support.
[3] As transparency is an essential quality of any credible evaluation, we endeavoured to precisely indicate (with sometimes the risk to weary the reader) the followed methodologies, the parameters used, and the calculations carried out in order to allow possible critics to retake measurements and formulate precise critiques.

bordered by buildings; the Parisian Ring-Road (*boulevard périphérique,* PRR) whose creation dates back to the sixties. These two roadways are about 300 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 *Enquête Générale des Transports* (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. Note that 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.

The tramway was built on the *Maréchaux*' boulevards, between *Porte d'Ivry* (13th district) and *Pont du Garigliano* (15th district). This portion of 8 km corresponds to about a quarter of the total length of the boulevards. It constitutes what we will call the *Ivry-Garigliano* 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. But some others count more as displacements of proximity. This 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 lines 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's* 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 modes of transportation. The third component was the significant reduction of approximately a third of the road space formerly reserved for the cars and the trucks on the *Maréchaux*' boulevards. To a certain extent, this reduction is the direct consequence of the municipal's will to restrict the road space. It is difficult to know the relative importance of municipality's motivations for the *T3* project. It is neither possible (nor useful) to break them up into negotiable instruments between its various components. We therefore will take it here as a whole.

Changes in the displacements' structure

The *T3* project involved substantial changes in the structure of displacements on the *Ivry-Garigliano* axis. Two sources make it possible to measure these changes. 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 km of the total. One can transform this data into vehicles*kilometers (veh*km) and generalize it to the 7.9 km of the axis considered. The year 2003 is selected as the year "*before*" the project because during 2005 and 2006 the tram was still under construction. Through the data, one can observe that the number of veh*km passes from 152.800 to 89.500 between 2003 and 2007. This reduction of 63.300 veh*km corresponds to a decrease of 41 % of the PC use. It is possible to translate these figures into passengers*kilometers (pass*km) by multiplying them by the occupancy rate of a vehicle (1,3). One obtains approximately 198.000 pass*km before the project and 116.000 after (-82.000 pass*km).

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[4]. To ensure a random selection of the users, the investigators went to a station, waited for a tram to leave and questioned the first two users who arrived to catch the following train. The stations and the schedules were selected in a representative way of their use. Generally, the users said they were very satisfied with the tram. The two most interesting answers for our analysis are related to the average length of their displacement in *T3* (2.56 km, a third of the total length covered by the tram) and to what these users did before its introduction.

Table 1 – Modal source from the tramway's users

	%	pass*km/j
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 tram, 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* attracted very few car users (2,6 %). The tram generated a very weak modal report[5]. The others movements are practically negligible.

The data makes it possible to highlight the impact that the tram had on modal transit. A certain number of the *T3* users (denoted as M) realised their displacements on the *Ivry-Garigliano* axis with the subway. A little less than 40.000 of them gave up the subway for the tram, where they now realize 100.000 pass*km 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

[4] A detailed presentation of this survey is available on www.pierrekopp.com

[5] 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.

people who used the bus are in the tram now, where they make 144.000 pass*km. As we will demonstrate, their situation also improved. They join the 40.000 users who preferred the subway and the 2.700 individuals (making 7.000 pass*km) who gave up PC for the tram 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.

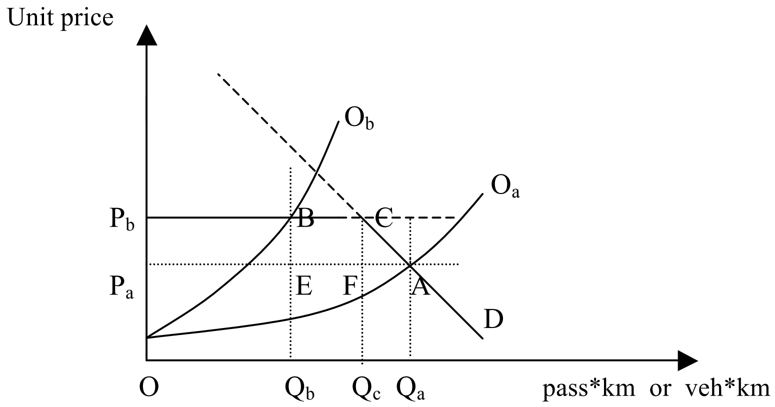
What about the people who used cars or trucks on the *Maréchaux*' boulevards? It is known that they made 198.000 pass*km there. A small number of these pass*km, approximately 7.000, are now found in the tramway. A little more than the half, 116.000, are still carried out on the *Ivry-Garigliano* axis. Considering their 40 % decline in usage of the boulevards, their conditions must now be worst than before the tram. Other pass*km 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 project, the traffic on the *Maréchaux*' boulevards would have decreased by 10.000 pass*km. There are thus 65.000 pass*km (=198.000 – 7.000 – 116.000 – 10.000) which miss the call.

Some of displacements corresponding to these 65.000 pass*km were undoubtedly eliminated, generating a decline of the mobility. Others were just detoured away from the *Maréchaux*' boulevards. One obvious detour is the PRR. Others are the streets more or less parallel with the *Ivry-Garigliano* axis. In both cases, this change increases the congestion on these alternative roads. The assumption will be made that the level of congestion on these two alternatives is comparable[6]. This allows us to consider (for the needs of the analysis) that these "*missing*" pass*km (or a part of them) are carried out now on the PRR.

Figure 1 helps to understand and estimate these changes. The demand curve for the motorized displacements on the *Maréchaux*' boulevards is represented by the bent line PbCA. The PbC line is the unit price of alternative displacements on the PRR, the point C corresponds to Qc use of the system. There is no reason that a user of the *Maréchaux'* boulevards pays more than the price of the alternative way on the PRR. In addition, the Oa curve describes (classically) the phenomenon of congestion on the *Maréchaux*' boulevards. When the number of users increases, the congestion increases too, speed decreases and the cost of the displacement increases. The intersection of Oa and D defines the situation before the project, with a price Pa and a quantity Qa.

Figure 1 – Behaviour of the PC users on the *Maréchaux*' boulevards (before and after the project)

[6] It is equalized at the margin by the motorists' behaviour.



What are the consequences of the *T3*'s introduction by narrowing the road-space on the *Maréchaux*' boulevards? It moves Oa to Ob. For the same level of use, there is more congestion and a higher unit price. The intersection of Ob and PbCD defines a new equilibrium, with the price Pb and the quantity Qb. There are thus Qb travellers who continue to use the *Maréchaux*' boulevards, BC=EF=QcQb travellers who are now on the PRR (or somewhere else), and FA=QaQc travellers who simply reduced their mobility, at least on the *Ivry-Garigliano* axis. To estimate the allowance of the 65.000 pass*km eliminated from the boulevards, between BC (reported on the peripheral) and F (retreat of the mobility), two complementary approaches are available.

Calculation from the demand elasticity

The first approach consists in directly estimating F by means of the supposed elasticity (ε) of the demand curve. Indeed, $\varepsilon = (\Delta q/q)/(\Delta p/p)$, or equivalently $\Delta q = \varepsilon * q * \Delta p/p$ with Δq = FA, q = Qa, p= Pa, Δp = PaPb. It is preferable to lead the analysis in terms of veh*km and to return then to figures in pass*km (by a multiplication of 1,3). One knows Qa (152.300 veh*km per day). By postulating a speed of 20 km/h on the *Maréchaux*' boulevards before the tramway, it is possible to calculate Pa. We obtain 0,783 €/veh*km which is primarily a cost in time (for details, see Appendix A).

We can also estimate PaPb, the difference between the cost on the PRR and the cost on the parallel boulevards before the project (or if one prefers the welfare loss which results from the change of road pulled by the *T3*). This loss is quite real; if not everyone would have used the PRR. It is logical to think that this over-cost is equal to the over-cost generated by the turning, which involves the use of the PRR. We can estimate it 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 km. Second, the change of route lengthens the displacement by two times 400 meters (300 meters is the distance as the crow flies separating the two ways). This makes 800 meters. Third, this distance is traversed at an average speed of 20 km/h. It is calculated that the over-cost is equal to 0,6 minutes, that makes 0,133 € per veh*km (see Appendix A). This is the value PaPb.

For the demand elasticity, one will start from Litman (2007) which proposes sensibilities of the roads use ranging between -0,6 and -0,8. These elasticities were calculated for whole ways. They are not appropriate 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 an elasticity (approximately two or three times) lower in absolute value. We made calculations for elasticities ranging between -0,4 and -0,2. The implementation of this approach results in estimating a retreat of mobility between 5.175 and 10.350 veh*km per day (which makes between 6.700 and 13.400 pass*km). By considering a decrease (FA) of 10.000 pass*km, we deduce the number of reported displacements on the peripheral (BC) equal to 55.000 pass*km.

Observation of the traffic on the ring-road

In a recent work, Koning (2009) studied the evolution of the congestion costs on the peripheral between 2000 and 2007. His analysis is based on a database which makes it possible to disaggregate the observations with respect to the geographical scale[7]. The nature of the decrease in recorded traffic is controversial, especially on the southern part of the PRR (the one parallel to the *Maréchaux*' boulevards). Indeed, the traffic's regime on this section was already saturated in 2000[8] and the congestion costs are now bigger (33 % of the total congestion losses). As a consequence, every new arrival on the PRR should disrupt the flow and decrease "*mechanically*" the number of veh*km driven. Even if the traffic experienced a decline of 3,9 % between 2000 and 2007, the decrease by 10 % of the average speed[9] is not incompatible with the possible daily road report of 55.000 veh*km from the *Maréchaux*' boulevards.

As we will see later, these *"reported"* veh*km become important in the final calculation. As a consequence, we will test the sensibility of the results with respect to the number of veh*km that could be now realised on the PRR. We will assume three variants: 100 % of the 55.000 veh*km, 50 % and 0 %. Doing so allows us not to neglect the effect of the *T3*, but equally to moderate it. For reasons of commodity, we will nevertheless present the results that are associated with a 100 % report. Others will be remembered in Section 5.

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[7] Although the global traffic has declined by 2,2 % during this period, the decrease in average speed (- 5 %) and the increased opportunity cost of time (+ 8 %) result in a more significant congestion loss on the PRR in 2007 (130 M€).
[8] The bliss point of the speed-flow relation describing the PRR's physical capacity is equal to 42,7 km/h.
[9] 37,9 km/h in 2000 and 33,9 km/h in 2007.

Table 2 synthesizes the changes potentially induced by the tramway. One sees that it involved (*I*) important intra-modal transfers (inside the PT's means), (*II*) practically no modal report (from PC to PT) 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 axis even recorded a reduction of a little less than 6 %.

Table 2 – Displacements on the *Ivry-Garigliano* axis, by transportation modes, before and after the project

	Before (2003) (pass*km/day)	After (2007) (pass*km/day)	Difference (pass*km/day)	Consequences
Public transportation (PT)				
Subway	M	M-97.000		Decongestion
Bus & tramway	144.000	256.000		Δ surplus
Total PT	M+144.000	M+161.000	+7.000	
Private cars (PC) and trucks				
Maréchaux' bvds	198.000	116.000		Δ surplus
Peripheral	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 pass*km for 2003, one has to sum the 7.000 pass*km that are now in the tramway), the 10.000 pass*km eliminated by the transportation policy of the municipality and the 10.000 pass*km corresponding to the retreat of mobility with the 116.00 pass*km that are still realized on the *Maréchaux*' boulevards and with the 55.000 pass*km that have been reported on the PRR.

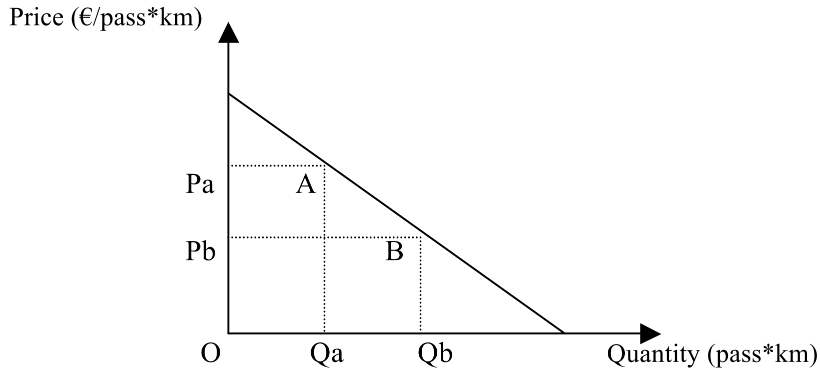
Section 3. Variation of the surplus of commuters on the *Ivry-Garigliano* axis

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

Variation of the surplus of the tram'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. AB is the line of joint transport demand on the *Ivry-Garigliano* axis: the lower the price, the higher the demand. The situation before the tram is indicated by the point A. It was seen that Qa was equal to 144.000 pass*km. The unit price is Pa, which one does not need to know. The situation after the tram is indicated by the point B. We saw that B was associated with Qb equal to 256.000 pass*km and a unit price Pb. To say that the *T3* is better than the old bus is similar to recognize that Pb < Pa. 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 TC users



One can easily calculate the variation of surplus generated by the time-savings. Speed increased from 16 km/h (by buses) to 20 km/h (by tram)[10]. This corresponds to 0,633 minutes saved per pass*km. On the other hand, the latency has increased since it passed from 3,5 minutes with the bus to 4 minutes with the tram, which for a trip of 2,56 km corresponds to a 0,195 minutes waste of time. On the whole, the cost in terms of time has decreased by 0,438 minutes per pass*km.

The value of time for the urban transport in Ile-de-France is fixed at 9,3 €/hour for 2000 in the *Instruction-cadre* of the Ministry for the Equipment (25th March 2004). The same official text makes the recommendation to increase 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 obtains a value of the time equal to 10,2 €/hour, a value which we will retain here. As a consequence, the cost in time decreases by 0,438*10,2/60 = 0,0745 € per pass*km. Thus PaPb=0,0745 €. With Qa= 144.000 and Qb=256.000, the PaABPb surface, which gives us the variation of surplus, is equal to 14.900 € per day. By counting 300 days a year, we obtain **4,47 M €**.

It is much more difficult to estimate the benefits due to the better comfort of the tram. 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, while noting the very fragile character of these beliefs. For this reason, we retain our previously calculated benefit of **4,47 M €** a year.

Variation of the surplus of the motorists

The variation of the PC users, or more precisely of the motorists who used the *Maréchaux*' boulevards, is easy to calculate (others are affected by the project only by the increase in congestion

[10] 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.

that it involved, see estimation below). It is equal to the sum of the wastes of time of the motorists who still remain on the 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 ((0,133/1,3)*(171.000+10.000/2)*300 =) 5,40 M € a year. This cost is distributed between the motorists who remain on the *Maréchaux*' boulevards with 3,56 M €, those who refer on the PRR with 1,68 M €, and with 0,16 M € for those who have reduced their mobility.

This estimate does not take into account the fact that part (estimated at 20 %) of the vehicles are commercial ones whose value of time is higher than that of PC. According to the *Instruction-cadre* (25th March 2004) the value of time for the vehicles of transportation of goods is fixed at 31,4 € per hour. A simple calculation shows that it is then advisable to increase the figure by 27,3 % calculated on the basis of the value of the time of the travellers. Therefore, the true cost is **6,87 M €** a year rather than 5,40 M €.

Congestion externality on the Parisian ring-road

The PRR is a crowded road. Each additional vehicle slows down the traffic flow, and thus affects all the vehicles. This cost is an incremental cost of congestion. A probable consequence of the *T3* project was an increase in the traffic on the ring-road by a certain amount of veh*km (55.000 pass*km = 42.300 veh*km per day at the maximum). To get the externality external cost of congestion, it is then enough to multiply these costs by this amount.

The most commonly used estimate comes from INFRAS (2000). It was often taken by the European Commission, and French organizations such as the French Institute of the Environment (2004, p. 94). It estimates the cost of urban congestion at 2,70 €/veh*km in the event of "*dense*" traffic and 3,10 €/veh*km in case of "*true congestion*". The PRR is at least in situation of "*dense*" traffic. If one applies this estimate to the 42.300 additional veh*km, he will find that the external cost of the tramway is equal to 114.210 €/day (i.e. of 43,62 M € a year). By tacking just 50 % of the turning veh*km, this amount becomes 21,81 M €. However, this estimate, financed by the International Union of the Railroads, is probably a little exaggerated. It has great disadvantages of being aggregated and of using single congestion cost (whereas this one varies, in considerable proportions, according to the traffic conditions).

Speed-density relation on the ring-road – We prefer to apply our own method used for the PRR in Prud'homme and Sun (2000) or Koning (2009). We lay out for 2007 of approximately 25.000 data sets relating to flow, speed and concentration of the traffic on the *Ivry-Garigliano* portion of the

PRR. A simple regression makes it possible to get an equation describing the speed (v) as a function of the density (q). Koning (2009) obtains:

$$v(q) = \alpha + \beta * q = 85,3 - 0,264*q$$
$$(0,001) \quad (0,140) \qquad\qquad R2 = 0,73$$

Congestion costs – Knowing the fixed monetary cost of a veh*km (0,12 €/veh*km), the value of time (10,2 €/hour for a passenger) and the occupancy rate of a vehicle (1,3), one is able to deduce the private cost (I(q)) according to the density :

$$I(q) = 0,12 + 10,2*1,3/ v(q)$$

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

$$Cm(q) = 3,5*q/(85,3 - 0,264*q)^2$$

This cost of congestion varies considerably according to the density (q) and the associated speed. Being very weak and almost negligible when the traffic speed is higher than 50 km/h (0,1 €/veh*km), it becomes more consequent for low speeds (18 €/veh*km with a 7,5 km/h speed).

The data used in Koning (2009) enable us to know the traffic distribution by speed class on the southern part of the PRR. By making the assumption that the reported veh*km are distributed as those which normally attended the PRR, we can calculate the costs of congestion for each speed class ranging between 2,5 km/h and 75 km/h. It is enough to multiply the cost of congestion of the class by the number of veh*km additional to this class. While adding, one obtains the cost of congestion caused by vehicles which the tramway may reject on the PRR[11]. With a full report of the 55.000 pass*km, this externality linked to the *T3* rises to 24,99 M € a year. It is also necessary here to take into account the fact that 20 % of the considered vehicles are commercial ones. By using the 1,273 coefficient, one then obtains a final cost of congestion equal to **31,82 M €**. If we just consider 50 % of the 55.000 missing pass*km on the *Maréchaux*' boulevards, the bill still remains at a 15,91 M € level.

The additional costs of congestion generated by the tram (and especially the restrictions of roadway space which accompanied it) are thus very expensive in terms of time for society. As it seems to be the most important effect of the tram, we will carry out the final calculation of the Clear Discount Value by considering that this report could be equal to zero. It will give us a measure of the sensitivity of the results with respect to the assumptions made.

[11] The details of calculation can be found in Appendix B.

The deceleration of the vehicles entering Paris

A certain number of the radials used by the motorists (from suburbs or Paris) to enter the "*ville lumière"* are perpendicular to the *Maréchaux*' boulevards, and thus to the line of tram. These intersections are regulated by traffic lights. With the difference of the buses *Petite Ceinture* which it replaces, the tramway enjoys the right of way at these traffic lights. This priority causes to slow down a certain number of the vehicles entering or outgoing of Paris.

According to the *Enquête Générale des Transports* (2002) the number of travellers Paris ↔ suburbs by car rose to 1,63 million per day in 2001. The tram line makes up about the quarter of the circumference. Thus, one can estimate that a about quarter of these travellers, 407.000 per day, is affected. Let us estimate the average wait imposed by the tram to be 20 seconds (=1/180 of hour). Given that the frequency of the tram is 3,5 minutes (210 seconds), we can postulate that the probability of being stopped is of approximately 1/10. But 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 travellers per day, without counting the commercial vehicles. With the usual parameters, one calculates that the loss induced is of **1,83 M €** a year.

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. There must indeed be a loss of comfort comparable with the wasted of time caused by the congestion of the roads. Works of Armelius (2006) and Litman (2007) are notable exceptions. One does not have a function representing cost of congestion in PT according to use. In addition, the ratio of this transfer on the whole number of pass*km in the subway (0,4 %) or on the whole places offered (0,1 %) is not very significant since this report is concentrated on a small section of the network (where one does not know if it is congested or not).

We will try to propose an estimate of this surplus gain without contributing to the illusion of the solidity of the results. 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 cost in time, decreases by 4 %). The reduction of 0,4 % of the subway's frequentation generates 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 M hours a year, this reduction of 0,4 % in the frequentation results in a gain in comfort equal to 0,448 M hours (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.

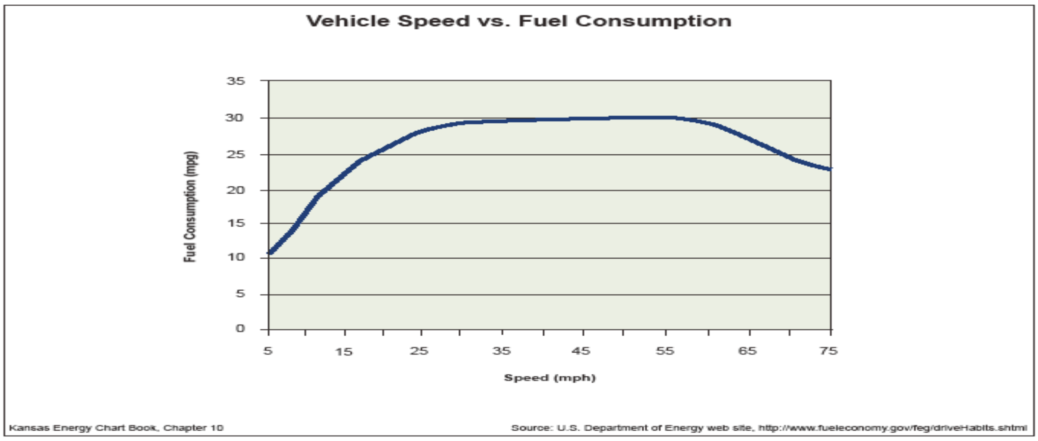
Section 4. Environmental impacts of the *T3* project

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

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 web-site of the Department of the Energy of the United-States, shows it clearly:

Figure 3 – Fuel consumption as a function of speed



Source: www.fueleconomy.gov/feg/drive-Habits.shtml

Note: the fuel's consumption is measured in miles per gallon (i.e. in kilometer per liter) which 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[12] and the point that corresponds to a speed of 30 miles/hour[13]. Once this function derived, one multiplies it by the CO2 emissions associated with a 1 litter fuel consumption (2,35 kg)[14] :

For v < 50 km/h (expressed in kg/km): CO2(v) = 0,624 – 0,00925*v

For v > 50 km/h: CO2(v) = 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 cars. In that case, it will be advisable to multiply the obtained estimate for emissions by a coefficient of 1,2.

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 (306*7,9 =) 2.417 bus*km. According to the *Statistiques Annuelles* (p.32) of the RATP (the company which organizes the PT on the regional scale), the buses consume 0,567 litters of gas per bus*km. Thus, the removed buses consumed 1.370 litters of gas and emitted (1.370*2,35=) 3,22 tons of CO2 per day (966 tons per year). The tramway, which operates with (nuclear) electricity, saves these emissions.

Modal report

A reduction in 7.000 pass*km per day correspond to 5.380 fewer veh*km per day. By postulating a speed of 20 km/h before the tram (i.e. a CO2 emission of 0,439 kg/km), these vehicles emitted 2,36 tons of CO2 per day (709 tons per year). This amount is equal to the amount of CO2 emissions saved by the tram, which attracted drivers from these vehicles.

The reduction in speed for the remaining vehicles

The number of PC which continue to use the *Maréchaux*' boulevards on the *Ivry-Garigliano* axis fell by 36 %, but still rose by 89.500 veh*km per day. As was demonstrated, this reduction comes from an increase in the cost of time of the use of this axis (i.e. a reduction of speed which is limited by the cost of the using the PRR). One previously estimated this cost to be 2,4 minutes. 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%.

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[12] v = 5 miles/h = 8,04 km/h ; fuel consumption = 10 miles/gallon = 0, 23 litter/km

[13] v = 48,27 km/h ; fuel consumption = 30 miles/gallon = 0,078 litter/km

[14] We do not have found any similar equation for the French case. But Renaut 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.

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 veh*km/day (89.500) equals to a CO_2 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 and we obtain an estimate of 902 tons per year.

Reduction of the mobility

One could say that the people who experience a reduction in mobility on the *Ivry-Garigliano* axis have stopped their transport activity, and thus do not consume any more gasoline. This daily economy attains 10.000 daily pass*km, that is to say 7.692 veh*km. By taking the same parameters as before, we find an annual CO_2 benefit of 720 tons. Actually, the veh*km eliminated on the *Ivry-Garigliano* axis are undoubtedly in many cases replaced by others displacements which might be as long or perhaps even longer than the initial ones. Therefore, we will not thus count any profit nor loss for this reason.

Lengthening of the trips for the vehicles transferred to 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. They consume more fuel and emit more CO_2. Once again, the calculations will depend on the assumptions made concerning the amount of road transfer. Assuming a 100 % report (i.e. 42.300 veh*km) and a range of 4 km, we obtain an amount of 10.575 displacements of 0,8 km (8.460 veh*km). At 20 km/h, the corresponding unit emission is equal to 0,439 kg/km. With the usual parameters, one finds CO_2 emissions of 1.337 tons per year. With a 50 % report, the result rises to 669 tons per year.

Decrease in speed on the PRR

The principle impact of the project on the CO_2 emissions may come from the deceleration on the PRR due to the transferred veh*km. These additional vehicles indeed slow down the flow of all vehicles, thus increasing their own emissions (all things being equal). This phenomenon is jus the reverse side of the congestion's externality studied previously. One can calculate this consequence with rather good precision. It is indeed possible to cross the emission-speed equation with the speed-density relation. One obtains the quantity of CO_2 emitted as a function of the density of the road:

$$CO2 = f(v) = \lambda+\mu*v \quad (\text{with } \lambda = 0,624 \text{ and } \mu = -0,00925)$$

$$v = g(q) = \alpha+\beta*q \ (\text{with } \alpha = 85,3 \text{ and } \beta = -0,264)$$

This gives us:

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

The marginal emission (CO2M), which in other words is the additional quantity of C02 caused by a vehicle added to a flow of density q, is the derivative of this function multiplied by q:

$$CO2M = h'(q)*q = \mu*\beta*q = 0{,}0024*q$$

It is easy to calculate the marginal CO2 emission for each speed class and the associated density. One just has to multiply this marginal rejection by the number of additional vehicles in the speed class, and then to sum it. These calculations are presented in the Appendix. With 42.300 veh*km displaced each day, the reduction of speed on the ring-road reveals a surplus in emission by 8,4 tons of CO2 per day. It is 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 emissions by approximately 2.900 tons per year. Naturally, with a 50 % report, the environmental bill rises to 1.450 tons only.

Table 3 – Impacts of the tramway 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 *Maréchaux*' bvds	14.144	15.046	+902
Trips' lengthening (100%)	Zero	1.337	+1.337
Decrease in speed decrease the peripheral (100%)			+2.900
Total		+ 3.464	

Source: authors' calculations

Table 3 shows the various impacts of the T3 project on CO2 emissions. On the whole with all things being equal, the tram contributes to increase in emissions by more than 3.400 tons of CO2 per year. If one retains a value of 25 € per ton, one obtains with the bond of the greenhouse effect a cost less than **0,1 M €** per year, amount rather negligible compared to the other profits and costs.

Section 5. Financial costs and benefits, Clear Discount Value

Exploitation and capital costs

Published information on the pure monetary costs associated with the project is rather rare. One has only the *ex ante* costs envisioned in the official *Enquête Public*: 341,8 M € for the investment; 43,9 M € for the exploitation. The experiment suggests that the *ex post* costs are appreciably higher. Let us suppose however that the *T3* was an exception and that the effective cost was equal to what had been anticipated. This being an investment financed with budgetary funds, it is appropriate, within the framework of a costs-benefits analysis, to multiply the expenditure by the opportunity cost of the public funds (officially fixed at 1,3). There is thus an 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 voyage, which is at 1,07 € per voyage. The removed buses ensured 55.000 voyages per day, which would suggest that the operating costs for the line are 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 than those of the bus it replaces (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. It will be considered that the operating costs of the tramway are comparable with those of the buses (by deploring the scarcity of available informations on this subject).

The users' payments are hardly affected by the introduction of the *T3*. The large majority of the travellers paid already the same amount before. However, it was seen that the tram attracted 3.850 new displacements (coming from cars, bicycles, or two-wheels). If they all paid the flat rate of 1,07 €/voyage, that would increase the receipts of the RATP by 1,26 M € per year. Actually, much of them undoubtedly profit a transport pass and take the tram at a zero marginal price. 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 €**.

Economic appraisal of the tramway

Table 4 presents the various elements of our economic appraisal. They relate to the changes introduced by the project with reference to the *ex ante* situation and to the former roadway system. Some of the estimates presented above are more uncertain than others. Three in particular are very fragile: the estimate of the comfort gains, the estimate of the profit 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. One could have foregone using these estimates for this reason but 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, but it also costs more than its benefit to the society. We are not able to calculate any Internal Rate of Return 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 Clear Discount Value of the tram, calculated with the official rate of 4% over 30 years is established to **– 900 M €** (by considering a full report on the PRR, -620 M € with a 50 % report). It is a measurement of the loss of resources induced by the project.

Table 4 – Costs and benefits of the T3's 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 *Maréchaux*' bvds		-6,87
Time loses of the vehicles entering Paris		-1,83
Externalities		
Additional congestion on the peripheral (100%)		-31,82
Over-emmissions of CO2 (100%)		-0,08
Totals	-444,34	-26,25

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

Another way, perhaps more telling, is to synthesize 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 -26,25 M €, one obtains a total "*cost*" of -85,49 M €.

A good part of this waste comes from the costs inflicted on the motorists because of the contraction of the *Maréchaux*' boulevards. One can say that this contraction was not necessarily imposed by the tram and that these losses exaggerate the clean negotiable instrument of the *T3*. To size this negotiable instrument, it is enough to be unaware of the costs relating to the wastes of time for the users of the *Maréchaux*' boulevards and the increased congestion on the PRR (but not those of the travellers entering/outgoing from Paris). One then finds a benefit of 12,6 M € for each year. It is unfortunately not enough to cover the initial investment of 444 M €. The Internal Rate of Return is still negative as well as the Clear Discount Value (- 227 M €). In annual terms, the net loss is about 46,70 M € (= -59,24 + 12,5). 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 tram. It underlines the theoretical and factual gaps concerning the *T3* project while leaving open the possibility to improve our estimates. But it appears sufficiently reasonable to draw several conclusions.

The tram 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 much larger number of people. These benefits can be measured (with difficulty especially with regard to the last two). They represent, according to our estimates, approximately 15 M € per year. In spite of these improvements, the tram did not engender any modal report. Only 2 or 3 percent of the actual users of the *T3* are former drivers. This real experiment shows once again the limits of so-called "*modal report policies*".

However, the tramway was accompanied by an important reduction of the road-space on the *Maréchaux*' boulevards. The question of whether this contraction was necessarily caused by the tram's implementation can be asked. It is always presented as happening simply because it was a part of the project. This contraction has increased the road congestion on the *Maréchaux*' boulevards and reduced approximately by 40% the circulation on this road.

It appears that the displaced drivers have not given up their car for the tram. Therefore, where did they go? Some are discouraged and do not travel any more on the *Maréchaux*' boulevards. The majority of them are on roadways parallel to the *Maréchaux*' boulevards and probably on the PRR. It is here the problem. By doing so, they use longer routes, and they waste time compared to the former situation. The motorists who remained on the *Maréchaux*' boulevards also waste about as much time as the others (if not, those on the PRR would return to these boulevards). One estimated a 6,9 M € loss to those who used cars and commercial vehicles on the *Maréchaux*' boulevards before the project. This is in addition to a relatively low loss for those who commute to/from Paris who are delayed by the priority given to the tram.

But this might not be the most serious consequence. The worst effect of the *T3* project could come from the potential road transfers that increase the congestion on the PRR. An additional vehicle on the ring-road slows down all the traffic and generates an incremental cost of congestion. Data coming from Koning (2009) and, especially, the "*missing*" veh*km on the *Maréchaux*' boulevards clearly highlight this possible external effect of the tramway. The congestion costs could rise to an amount between 15 and 30 M € and could equally worsen the traffic conditions on the southern part of the PRR.

Finally, the *T3* project does not appear to deserve the chorus of praises that it received. It was expensive. Its costs outweigh the benefits that it generates, 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 probably interesting for the municipality of Paris. The principle recipients are the users of the tram, who are mainly (57 %) the Parisian ones, 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 invisible and relatively painless for the voters. The environmental balance is in the negative, but this impact can be deceptively difficult to observe especially as it is a pre-existing common belief among voters that it is in fact positive. It is 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 elected officials of Paris. 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 A – *Details for the calculations concerning the road-report on the peripheral trough the demand elasticity*

We first have to calculate Pa: the price of a displacement on the *Maréchaux*' boulevards before the project. As we have seen, we will retain a value of time equal to 10,2 €/hour. By making the assumption that the *ex ante* speed was of 20 km/h, one can calculate that:

Pa = 0,12 + 1,3*10,2/20 = 0,783 €/veh*km.

For PaPb, we have seen that the lengthening of the trip was equal to 0,6 min. With the same value of time, we find PaPb = (10,2/60)*0,6*1,3 = 0,133 €/veh*km.

Appendix B – *Calculations of the additional congestion and environmental costs on the ring-road (induced by a full road-transfer, 55.000 pass*km = 42.308 veh*km)*

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 veh*km on the southern part of the ring-road
Density: (veh/km), calculated trough the speed-density relation q = (85,3 – v)/0,264
uMCc: unitary marginal cost of congestion (€/veh*km), calculated with Cm(q) =3,5*q/(85,3 + 0,264*q)^2
Report: in veh*km, product of the Distrib. column with the total number of veh*km daily reported on the peripheral
MCC: marginal cost of congestion (€), product of Report by uMCC
uMRP: unitary marginal rejection of pollutant (kg/veh*km), 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