Substituting a Tramway to a Bus Line in Paris: Costs and Benefits

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Abstract:

In Paris, an old bus line on the *Maréchaux* Boulevards has been replaced by a modern tramway. Simultaneously, the road-space has been narrowed by about a third. A survey of 1,000 users of the tramway shows that the tramway hardly generated any shift from private cars towards public transit mode. However, it did generate important intra-mode transfers: from bus and subway towards tramway, and from *Maréchaux* boulevards towards the *Périphérique* (the Paris ring road) for cars. The various benefits and costs of these changes are evaluated. The welfare gains made by public transport users are more than compensated by the time losses of the motorists, and in particular, by the additional cost of road congestion on the *Périphérique*. The same conclusion applies with regard to CO2 emissions: the reductions caused by the replacement of buses and the elimination of a few cars trips are less important than the increased pollution caused by the lengthening of the automobile trips and increased congestion on the ring road. Even if one ignores the initial investment of 350 M€, the social impact of the project, as measured by its net present value is negative. This is especially true for suburbanites. The inhabitants (and electors) of Paris pocket the main part of the benefits while supporting a fraction of the costs.

Keywords: Tramway, Costs-Benefits Analysis, Road Congestion, CO2 Emissions

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Section 1. Introduction

In December 2006, the municipality of Paris replaced a bus line by a tramway line. Several authors have already discussed the merits - or lack of - light rail or tramways, in absolute or relative to buses, mostly on the basis of American or Australian examples. Some (Litman 2007; Kenworthy 2008) see them as cost-effective and environmentally friendly. Many others (Gomez-Ibanez 1985; Kain 1988; Pickrell 1992; Moore 1993; Richmond 1999: Hensher 1999; Carmona 2001; Castelazo and Garret 2004; Winston and Maheshri 2007) are much more critical and denounce the uneconomic efficiency of this mode as well as an ideological bias in favour of tramways.

The Paris tramway line offers a chance to re-open this debate. Tramways are presently fashionable in France (Stambouli 2007): for a municipality, having one is perceived as a symbol of "*modernity*" and as a contribution to the fight against global warming. This is a by-partisan attitude. The tramway line considered here 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) – which should protect us from certain criticisms. "A desire named streetcar": if this beautiful title had not yet been utilized (Pickrell 1992), we would have been pleased to use it for this paper.

The municipality presented the tramway as a great success. The media unanimously praised the project. Echoing Richmond's (1998) statement on the "mythology" of tramway's successes, public opinion, including the majority of citizens who had neither seen nor taken this tramway, was also favourable. However, as common sense suggests, the reality is that the project presents benefits and costs, which it is legitimate to identify and evaluate in order to produce a better-informed appraisal. This aspect is particularly critical because an important extension of the Paris tramway is under way.

This is the purpose of the research presented here[1]. Section 2 presents the characteristics of the project and examines the changes it produced in transportation patterns. This makes it possible to quantify the benefits and costs generated by these changes (Section 3), as well as the environmental impacts of the tramway (Section 4). Section 5 presents all costs and benefits, including investment and operation costs, in a quasi cost-benefit framework. Section 6 concludes.

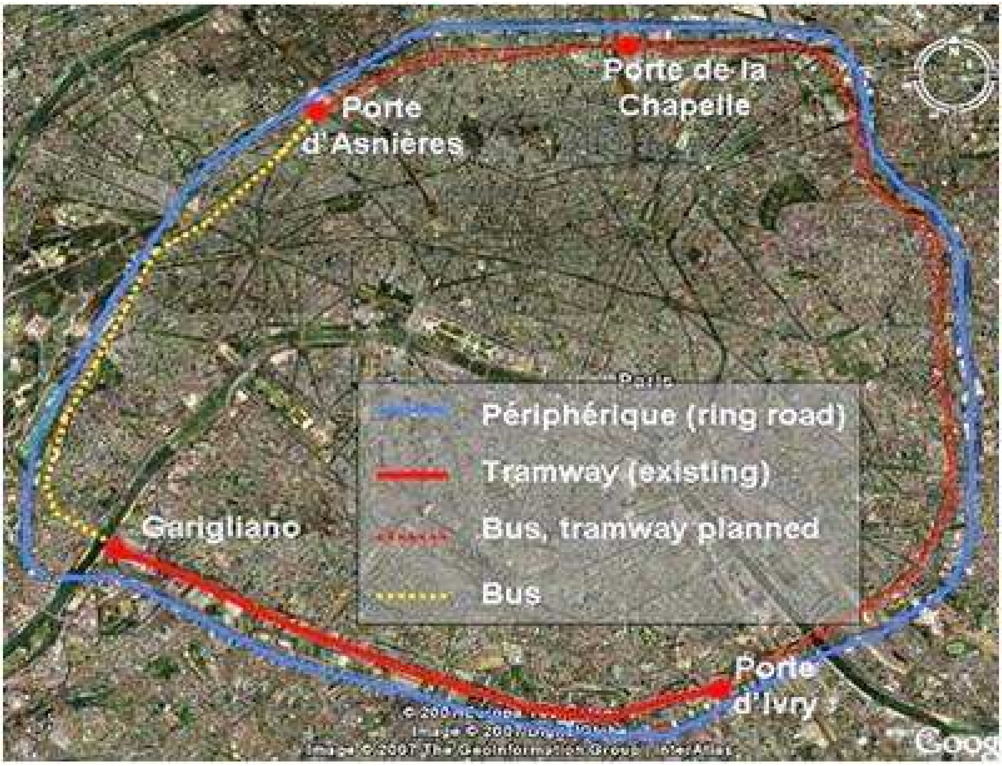
[1] This research did not receive any financial support.

Section 2. The project and its impacts on the structure of trips

2.1. Setting and components of the project

The Paris 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, is home to 2 M inhabitants. As shown on Figure 1, it is encircled by two parallel roadways of about 35 km each: (a) the *Maréchaux* boulevards which date from the beginning of the 20th century and are generally bordered by buildings; and (b) the Paris ring road (*Périphérique*), one of the most frequented urban highways in Europe, created in the sixties. These two roadways are about 300 meters apart. The Paris agglomeration is an integrated whole, with intense exchanges between its various parts, especially between Paris commune and the remaining communes (often referred to as suburbs). According to a 2002 transport survey (EGT 2002) Paris↔Paris trips are much less numerous than suburbs↔Paris trips.

Figure 1 – Area of Study



The tramway was built on a 7.9 km section of the *Maréchaux* between *Porte d'Ivry* and *Pont de Garigliano* which constitutes what we shall call the *Ivry-Garigliano* (*IG*) axis. Movements on this axis are rather diverse. The majority are part of much longer trips with origin and/or destination outside the area. A minority consists of proximity trips. The *IG* axis, well served by cars and trucks, did not benefit from any direct underground line and was mostly serviced by a bus line, which was the most patronized bus line of Paris.

The tramway project had three components. The first was the elimination of the bus line. The second was the construction of a modern tramway, faster and more comfortable than the bus. The third was the reduction of approximately a third of the road-space formerly used by cars and trucks on the *Maréchaux,* in line with the overall policy to reduce road-space in Paris municipality (Prud'homme and Kopp, 2008). This evaluation considers the project as a package.

2.2. Data sources

The project led to substantial changes in the structure of movements on the *IG* axis. Two sources make it possible to measure them. The first one consists of counts of vehicles on the *Maréchaux*, by an Observatory of Movements controlled by the Paris municipality, which provides daily traffic in 2003 and 2007 for 11 sections (4.5 km) of *Maréchaux*. This data can be transformed into vehicle*kilometers (vehicle*km) and extrapolated to the 7.9 km of the *IG* axis. Year 2003 is selected as the year "*before*" the project because the tramway was under construction during 2005 and 2006. The number of vehicle*km declines from 152,800 per day in 2003 to 89,500 in 2007. This is a decrease of 41% of car (and truck) usage on *Maréchaux*. These numbers can be translated into passengers*kilometers (passenger*km) by multiplying them by the average vehicle occupancy rate, estimated to be 1.3[2]. One obtains for car travel 198,000 passenger*km before the project, and 116,000 after the project.

The second source is an *ad hoc* survey, which we carried out on 1,000 users of the tramway between April and May 2007. To ensure a random selection of 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 tram. The high frequency of tramways, and the fact that they are not scheduled, mean that users come when they are ready, and wait for next train to come, which ensures randomness. Stations and hours were selected as a function of usage. Generally, users said they were very satisfied with the tramway. The two most interesting answers for our analysis relate to the average length of their trip on the tramway (2.56 km, a third of the tramway line length) and to what users did before its introduction, as shown in Table 1.

The first column of Table 1 presents the answers to the question: "*before the tramway, what means of transport did you use for that trip*?". Nearly 13% of respondents cite: "several modes". We allocated these responses to the other modes pro-rata the stated origins, to construct column 2. The majority of users come from the bus (57%), which is not a surprising result. More surprising perhaps is the importance of former subway users (38%). Very few tramway users abandoned the car for the tramway (3%)[3]. Other changes are negligible[4]. It is reported that the number of tramway users is

[2] See for instance the official Ministry of Transport. 2009. *Les comptes des transports en 2008 (tome 2),* p. 45.

[3] The number of motorized trips having Paris as origin and/or destination is equal to 2.3 M per day (EGT, 2002). The modal shift induced by the tramway represents a little more than 1 per 1.000 of this number.

100,000 per day which - unlike what happens many transportation projects (Flyvbjerg et al. 2002; Pickrell 1992) - is about what was forested. With an average tramway trip of 2.56 kms, this amounts to 256,000 passenger*km done on the tramway. The last column presents the origin of tramway use in passenger*km.

Table 1 – Modal Origin of Tramway Users

	%	% after[a]	passenger*km/day
Coming from:			
bus	50.0	57.3	147,000
subway	33.5	38.4	98,000
private car	2.6	3.0	8,000
bicycle	0.7	0.8	2,000
two-wheels	0.5	0.6	1,000
walk	-		-
mix	12.8	-	-
Total	100.0	100.0	256,000

Source: Authors survey.
Note: [a] The « *mix* » answers include the users who previously utilized several transportation means. They have therefore been allocated to the other modal origins pro-rata their relative importance.

2.3 Impacts on Structure of Trips

Before the tramway, a certain number of commuters (denoted as M) travelled on the *IG* axis by subway. A little less than 40,000 of these subway trips are now done by tramway, and they account for 98,000 passenger*km per day. These travellers must have improved their situation, or else they would not have changed. On the other hand, they relieved congestion in the subway for remaining subway users. The 57,000 trips that used to be done by bus are now done by tramway, and represent 147,000 passenger*km. As we will see, the situation of these (forced) shifters also improved. Some 3,000 trips that used to be done by car are now done by tramway, and they account for about 8,000 passenger*km. There are also some 1,000 trips formerly done by bicycle or two-wheelers, which are now done by tramway. The people who undertake these 100,000 trips by tramway all benefited from the project.

What about the people who previously used cars or trucks on the *Maréchaux* boulevards? As mentioned above, they accounted for 198,000 passenger*km. After the tramway, about 59% of them continue to drive on *Maréchaux*. There was, in the entire Paris area (as a result of higher fuel prices, and of the road space reduction conducted by the municipality) a decline in auto usage, estimated by

[4] Some interviewees answered that they were not undertaking that trip before the tramway. This raised the question of a possible induced traffic. Most of them - as some of them mentioned although the question was not explicitly asked - did not live in Paris, or in that part of Paris, "before the tramway". One has to consider that tramway trips are short trips, and in many cases, only a segment of a longer trip, i.e. according to the survey about 70% of tramway users declared that they used one other transportation mode during their trips, and that they concern an axis which was already serviced by a good bus line. The advantage of the tramway over the bus is real, as we shall see, but rather small, too small to generate additional trips, particularly in the short term. In other words, we did not find evidence of induced traffic. Consequently the answers of those who were not undertaking the trip before the tramway are ignored in Table 1.

the municipality at 5%. In the absence of the tramway project, car usage on the *Maréchaux* would have declined by that percentage. There is also the modal shift from car to tramway described above that accounts for a 3.5% decline in car usage. But an important 33% of the 2003 car users, accounting for 64,000 passenger*km, are missing.

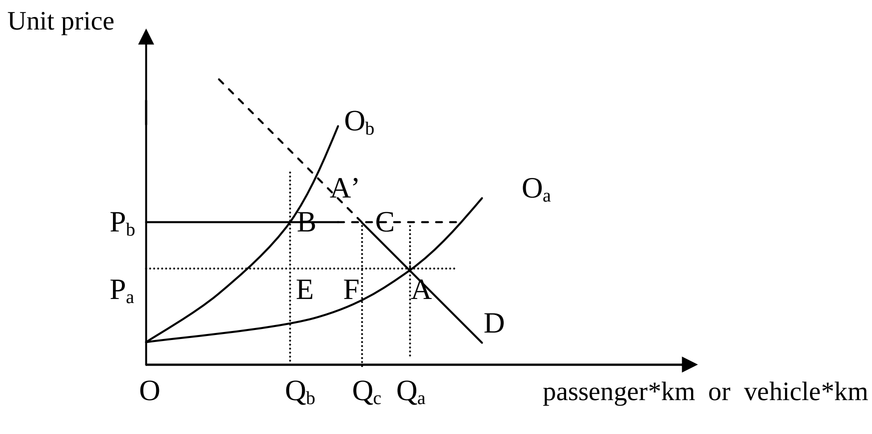
Table 2 – Impact of the Tramway Project on Car Traffic

	Before (2003) (in pkms)	After (2007) (in pkms)	After (2007) (in%)
On Maréchaux Bld	198,000	116,000	58.7%
Overall Paris traffic decline		10,000	5.0%
Shift to tramway		8,000	4.0%
Missing		64,000	32.3%

Source: Authors calculations

Some of these 64.000 passenger*km were merely eliminated, generating a decline in mobility. Other continue to be done by car, on other roads. As depicted on Figure 1, one obvious candidate for alternative roads is the nearby and parallel *Périphérique*. Other candidates would be the streets more or less parallel to the *IG* axis. But there are not many such streets, and most of them are quite narrow. A significant additional increase in usage could not be absorbed without very serious episodes of congestion – that would induce users to take *Périphérique* instead. For the needs of the analysis, we will consider that these missing passenger*km are now carried out on the *Périphérique*. Figure 2 helps understand and estimate these changes.

Figure 2 – Behaviour of the Car Users on *Maréchaux* Boulevards



Curves O_a and O_b are classical road usage cost curves as a function of road usage: when the density of cars increases, speed declines, time spent increases, and cost increases. Curve O_a describes the situation on the *Maréchaux* boulevards before the project; curve O_b after the project. Because road space was reduced, O_b is to the left of O_a ; congestion increased, and for a given number of cars, speed is lower. D is the demand curve for the *Maréchaux* usage. Before the project, there was an equilibrium in A, at a price, or cost, P_a. After the project, there could be an equilibrium in A'. This equilibrium, however, ignores the possibility of alternative routes. Utilizing *Périphérique* has a cost P_b (obviously higher than P_a; otherwise car users would have used it rather than *Maréchaux* before the project). After the project, the demand curve becomes P_bCD. It intersects with cost curve O_b in B. Before the project, there were Q_a cars on *Maréchaux* (198,000 passenger*km). After, there are Q_b cars on *Maréchaux* (116,000 passenger*km). The difference corresponds to trips which are eliminated (Q_a-Q_c) and to trips which are now undertaken on the *Périphérique* (Q_c-Q_b). For the sake of simplicity, and because the numbers involved are relatively small, we have ignored in this graphical presentation the shift from car to tramway and the overall decline in car usage in Paris : they could easily be introduced as a shift of the demand curve to the left.

To go further, we need to allocate the 64,000 passenger*km missing (Q_a-Q_b) between trips eliminated (Q_a-Q_c), and trips shifted to *Périphérique* (Q_c-Q_b). This can be done by considering the triangle CAF. Q_a-Q_c, or FA, the number of trips eliminated, is a function the elasticity ε of the demand curve D, and of the relative price increase $(P_b-P_a)/P_a$: $FA=\varepsilon*CF*Q_a$. Annex A explains in more detail the values of ε retained, and the procedure used to estimate CF (equal to 0.102 € per passenger*km), and P_a (equal to 0.602 € per passenger*km). With a demand elasticity of -0.4, the number of passenger*km eliminated Q_a-Q_c is equal to 5,175. With a demand elasticity of -0.2, it is equal to 10,350. We will assume it to be around 10,000 passenger*km. This implies that the number of car trips shifted onto *Périphérique* is 54,000 passenger*km[5]. Table 3 synthesizes the changes in transportation patterns on the *IG* axis induced by the tramway project.

One sees that the project induced: (*a*) important intra-modal transfers in public transport (from bus and subway to tramway), (*b*) a very limited modal shift from cars to public transport, and *(c*) important route transfers for cars. The increase in the supply of public transport did not induce a significant increase in public transport usage. The overall mobility on the *IG* axis recorded a reduction of a little less than 5%. We can now estimate the various benefits and costs associated with these changes.

[5] This assumption is supported by two arguments. First, according to Koning's calculations (2010) based on a data set provided by Observatory of Movements of the Paris Municipality, the travel speed on the relevant section of the *Périphérique,* i.e. the south part adjacent to the tramway line (see Figure 1), decreased by 10% between 2000 and 2007 (37.9 km/h and 33.9 km/h) while the decrease is equal to 5% on the entire *Périphérique* (45.9 km/h and 43.5 km/h). This does not quite prove, but suggests strongly, in the absence of other plausible explanations, a cause-effect relationship. Second, many witnesses of the public hearing on the extension of the tramway to *Porte de la Chapelle* testified their fears to see an analogous shift increasing the congestion on Eastern *Périphérique*. (http://cpdp.debatpublic.fr/cpdp-extension-tram-paris/debat/debat-public.html).

Table 3 – Movements on the *IG* axis, by Transportation Modes Before and After the Project

	Before (2003) (pkms/day)	After (2007) (pkms/day)	Difference (pkms/day)	Consequences
Public transportation				
Subway	M	M-98,000		Decongestion
Bus & tramway	147,000	256,000		Δ surplus
Total public transportation	M+147,000	M+158,000	+11,000[a]	
Private cars and trucks				
Maréchaux bvds	198,000	116,000		Δ surplus
Périphérique (ring road)	P	P+54,000		Congestion
Total private cars	P+198,000	P+170,000	-28,000[b]	
Grand total	P+M+345,000	P+M+328,000	-17,000	

Note: [a]8,000 formerly by car plus 3,000 formerly by bicycle and two-wheelers. [b]This difference is equal to the 8,000 passenger*km now done by tramway, plus the 10,000 passenger*km eliminated by the overall transportation policy of the municipality, plus the 10,000 passenger*km corresponding to the decline in mobility.

Section 3. Welfare gains and losses of travellers on the *IG* axis

3.1. Welfare gains of public transport users

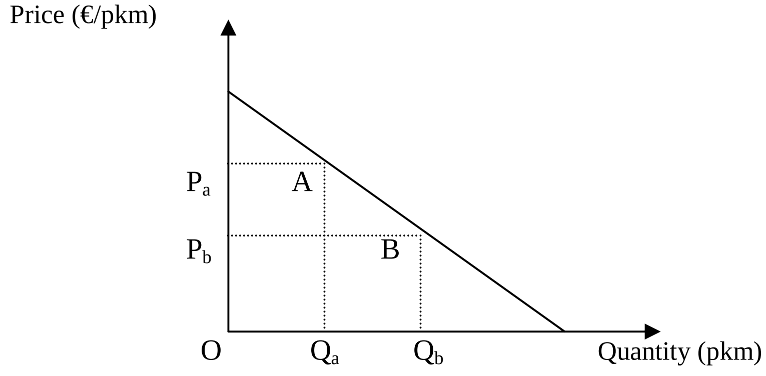
The first benefits to consider are those of tramway users, or more exactly of public transport users. They are represented in Figure 3 where AB is the public transport demand on the *IG* axis. The situation before the tramway is indicated by point A, with Q_a equal to 144,000 passenger*km, and P_a a unit price we need not know. The situation after the tramway is indicated by point B, with Q_b equal to 256,000 passenger*km and a unit price P_b. To say that the tramway is better than the bus is to recognize that $P_b < P_a$. By how much? The improvement of the public transport supply, i.e. the substitution of the bus by the tramway, has two advantages: it saves time and it improves comfort.

It is relatively easy to estimate the change in surplus generated by time savings. It is represented by the P_aABP_b area in Figure 3. Speed increased from 16 km/h (by bus) to 18 km/h (by tramway)[6] which corresponds to 0.317 minute saved per passenger*km. On the other hand, waiting times have slightly increased. There was on average a bus every 3.5 minutes; there is now a tramway every 4 minutes. For a trip of 2.56 km, the corresponding loss of time is 0.10 minute per passenger*km. On the whole, therefore the time gain is 0.217 minute per passenger*km. The official value of time is 10.2 €/hour[7]. With Q_a = 144,000 passenger*km, Q_b =256,000 passenger*km, and PaPb = 0.037 € per passenger*km, the P_aABP_b area is equal to about 7,384 € per day. By counting 365 days a year (there are about as many users on weekends as on week days), we obtain 2.69 M€ per year.

[6] 18 km/h is the number given by Cour des Comptes (2010), the authoritative Court of Accounts. It is lower than the 20 km/h originally planned.

[7] This number is updated from the Ministry of Transport *Instruction-cadre relative aux méthodes d'évaluation économique des grands projets d'infrastructures de transports*, March 25, 2004.

Figure 3 – Welfare Gains of Public Transport Users



It is much more difficult to estimate the benefits due to the better comfort of the tramway, i.e. better seats, vehicles and station's design. Technical and academic reports (TCRP 2003; Wardman 2001; Mackett and al. 2004; Litman 2007) stress the importance of qualitative features offered by public transport. They contribute to decrease the "perceived cost" of transportation by improving the "urban commute experience" (Li 2003). Taking in consideration such attributes 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 similar to the time-savings (Litman 2007)[8], while noting the very fragile character of this assumption. Comfort gains are therefore equal to our previously calculated benefit of 2.69 M€ a year.

3.2. Welfare losses of car users

The welfare loss of car users has three components: (a) the loss of time of the Q_b car users who remain on *Maréchaux* but do not drive as fast as before, which is represented by area P_bBEP_a on Figure 2; (b) the additional cost imposed upon the Q_c-Q_b car users who now drive on *Périphérique*, which is represented by area BCFE; (c) the welfare loss of the Q_a-Q_c former car users who no longer travel by car, and which is represented by area CAF. In other words, the welfare loss of car users is represented by P_bCAP_a in Figure 1. With P_b-P_a = 0.102 €/passenger*km, Qc = 178,000 passenger*km, and Qa = 188,000 passenger*km, this welfare loss is equal to 18,700 € per day, and 6.72 M € per year.

This number is an underestimate, because it ignores commercial vehicles which represent 18% of vehicles (Bilan des déplacements 2004) and have a much higher (2-3 times higher) value of time than passenger vehicles. It can be calculated that taking into account this reality would inflate the

[8] Litman (2007) offers a review of studies related to the qualitative attributes of public transports and to their valorizations. He concludes that the welfare gains associated with qualitative improvements in the public transports supply may reach the same order of magnitude as those associated with an increase in the traffic speed.

associated welfare loss by some 25%. To be on the safe side, we will not do it, but emphasize that our numbers are prudent underestimates.

3.4. Congestion externality on the périphérique

The *Périphérique* is a crowded road or rather highway. An additional vehicle slows down traffic, affecting all vehicles, and causing a marginal cost of congestion, which is an externality. As discussed above, there are good reasons to believe that the tramway project shifted an estimated 42,300 vehicle*km (or 54,000 passenger*km) from *Maréchaux* to *Périphérique*, thus creating an externality that must be estimated.

A much utilized estimate (by, for instance the European Commission, of the French Institute of the Environment.2004, p. 94) of the marginal cost of road congestion comes from INFRAS (2000). It is estimated to be 2.70 €/vehicle*km in the case of "*dense*" traffic and 3.10 €/vkm in case of "*true congestion*". *Périphérique* is a least an example of "*dense*" traffic. Applying the corresponding value to the 42,300 additional vehicle*km, produces an externality of 114,210 €/day, or 43.62 M€ a year. However, this INFRAS estimate is probably somewhat exaggerated. In addition, it uses one single marginal cost, whereas this cost varies greatly as a function of traffic conditions. We prefer to use the methodology developed to assess congestion costs on *Périphérique* by Prud'homme and Sun (2000) or Koning (2010).

For 2007, we use a set of approximately 25,000 observations relating to traffic speed and density for the relevant section of *Périphérique*. A simple regression produces an equation describing traffic speed (s) as a function of the density (q) on this particular road:

$$s(q) = \underset{(0.001)}{85.3} - \underset{(0.140)}{0.264}*q \qquad R2= 0.73$$

Driving one km has a cost in money[9] and time I(q) which is a function of density:

$$I(q) = \rho + 10{,}2*1.3/\ s(q)$$

The marginal cost of road congestion caused by one vehicle*km is the derivative of I(q) multiplied by the number of affected vehicles, i.e. the density :

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

9 ρ is the money cost of driving one km (this number is not utilized here) ; 10.2 is the hourly value of time ; 1.3 is the vehicle occupancy rate.

This cost is shown in Annex B. It varies considerably with density (q) and the associated speed. It is low, almost negligible, when speed is higher than 50 km/h (0.1 €/vehicle*km), but can be very high at low speeds (18 €/vehicle*km for a 7.5 km/h traffic speed).

The data used in Koning (2010) provides us with the distribution of traffic (on the relevant section of *Périphérique*) by speed classes. The preceding equation makes it possible to calculate the marginal cost of road congestion for each speed class. Let us assume that the vehicle*km shifted from *Maréchaux* to *Périphérique* are distributed between speed classes like ordinary *Périphérique* traffic. For each speed class, we multiply the marginal congestion cost by the number of shifted vehicle*km. Adding for all speed classes gives us the cost of the congestion caused by the tramway project, which is equal to 30.0 M€[10].

3.5. Loss of time for vehicles entering and leaving Paris

Most of the radials used by cars to enter and leave Paris are perpendicular to *Maréchaux*, and thus to the tramway line. These intersections are regulated by traffic lights. Unlike the previous buses it replaces, the tramway enjoys priority at these intersections. When the tramway arrives, red lights go on for cars on the radials, and they wait for the tramway to pass by. Cars and their passengers suffer a time loss.

According to EGT (2002), the number of Paris ↔ suburbs car trips was 1.63 M per day in 2001. The tramway line studied here accounts for about a quarter of the *Maréchaux*. One can estimate that about one quarter of incoming and outgoing passengers, i.e. 407,000 per day, are crossing the tramway line. We measured the average waiting time imposed by the tramway, and found it to be 20 seconds (=1/180 of hour). Given that the frequency of the tramway is 3.5 minutes (210 seconds), we can calculate that the probability of being stopped is approximately 1/10. This figure must be doubled to take into account the fact that the tramway circulates in the two directions. The slow-down thus concerns 81,400 travellers per day. The value of the associated time loss is therefore 1.83 M€ a year.

3.6. Subway decongestion externality

As indicated in Tables 1 and 3, subway usage decreased by 98,000 passenger*km as a result of the tramway. The subway is often crowded and congested. This reduction in patronage decreased congestion costs in the subway. What happens in the subway is the opposite of what happens on *périphérique*. Unfortunately, this benefit is difficult to estimate. There are a number of studies that discuss, mostly in a qualitative fashion, the impacts of public transport crowding on stress and welfare

[10] The details of calculation can be found in Annex B.

(Wener, Evans and Boately 2005; Cox, Houdmont and Griffith 2006), but very few that offer functions relating benefits (or costs, or willingness to pay) to density or congestion, making it possible to quantify the welfare impact of a reduction in congestion (Armelius 2006; Litman 2007). We nevertheless tried the following two approaches.

Litman (2007, p.11) advances a time elasticity of comfort of -0.4. When patronage (and the associated congestion) increases by 10%, comfort (measured by the willingness to pay in time) decreases by 4%. 98,000 passenger*km per day represents an approximate 0.5% decrease in subway patronage(RATP 2008). Thus, assuming that the Litman estimate is valid for the Paris subway (a somewhat heroic assumption, admittedly), this reduction of subway patronage generates an improvement in comfort equal to 0.2 % of the value of the time spent in the subway. Knowing that the time spent in the subway is approximately 280 Mh a year, the reduction of 0.5 % in subway patronage results in a comfort gain equal to 0.560 Mh, or 5.71 M€ a year.

Prud'homme *et al* (2011, forthcoming) conducted in the Paris subway a contingent analysis on a sample of about 700 passengers aimed at producing a function relating the willingness to pay for travelling in non-congested conditions to congestion levels, with a view to estimate a marginal cost (and benefit) of congestion (decongestion). The estimate of the marginal benefit of congestion arrived at is (in euros per trip): 0.68*d, with d the density measured in number of people per square meter. 98,000 passenger*km are generated by 38,000 trips. With an average density in the Paris subway of 1[11], the benefit of subway decongestion caused by the project is 9.43 M€.

Both approaches are fragile and tentative. The numbers they produce are somewhat different, but both are high, and suggest that subway decongestion benefits are an important component of the cost-benefit analysis of the project under study.

Section 4. Environmental impacts of the tramway project

The tramway project has five distinct impacts concerning CO2 emissions. Two are positive. They come from the replacement of buses by a tramway and, for a very modest amount, from the modal shift from cars to tramway. Two others are negative. They come from the lengthening of some car trips, and from the reduction in the speed of cars. The sign of the last impact, generated by the decline

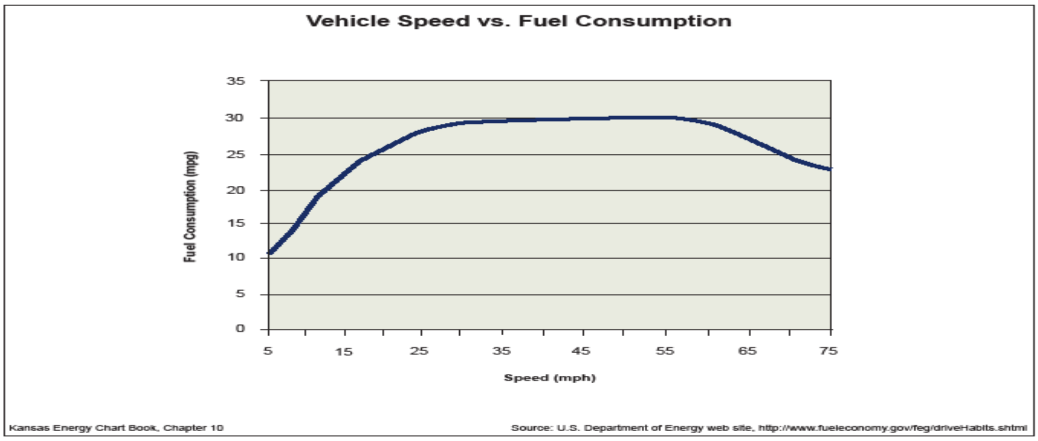
[11] This average density is obtained by dividing the number of passenger*km in the subway in 2007 (6,886 M) by the number of square meter*km offered (6,600 M) ; this number itself is obtained by dividing the « capacity offered » (26,4000 M) by 4, since this capacity is expressed on the basis of 4 passengers/square meter ; All this numbers are from RATP. 2008. *Statistiques annuelles 2007*, pp.17-18.

in mobility, is unknown. It is necessary to try to measure these effects. To do this, it is helpful to consider first the link between traffic speed and CO2 emissions.

4.1. CO2 emissions-speed function

Fuel consumption is a function of speed. 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 presented in Figure 4, which comes from the web-site of the Department of the Energy of the United-States, shows it clearly:

Figure 4 – Fuel Consumption as a Function of Traffic Speed



Source:www.fueleconomy.gov/feg/drive-Habits.shtml
Note: Fuel consumption is measured in miles per gallon. This explains the inverted form relative 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 relating fuel consumption and speed for speeds lower than 30 miles/h, i.e. 50 km/h, by considering two points: the point where the curve cuts the y-axis[12] and the point that corresponds to a speed of 30 miles/hour[13]. For speeds higher than 30 miles, fuel consumption is constant, at least in urban areas where speeds are always below 60 miles/h. Once this function is written, one multiplies it by the CO2 emissions associated with a fuel consumption of one litre (= 2.35 kg)[14] to obtain the relationship between CO2 emissions (in kg/km) and speeds (in km/h)

$$\text{For } s<50 \text{ km/h}: \quad CO2(s) = 0.624 - 0.00925*s$$

[12] At a speed of 5 miles/h (8.04 km/h) corresponds a fuel consumption of 10 miles/gallon (0.23 litre/km). The function is broadly linear between these two points.
[13] At a speed of 30 miles/h (48.27 km/h) corresponds a fuel consumption of 30 miles/gallon (0.078 litter/km)
[14] 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 fuel savings of 25%. Our estimate results in a 17% fuel saving, which is not very different.

For s>50 km/h: CO2(s) = 0.16

4.2. Impact on CO2 emissions of the elimination of buses

The frequency of the eliminated buses was 17 buses per hour at peak times. By liberally counting 18 peak hours, there were 306 buses per day, riding 2,417 bus*kilometres on the *IG* axis (of 7.9 km). According to *Statistiques Annuelles* (p.32) of RATP, buses consume 0.567 litres of diesel oil per bus*km. The buses eliminated consumed 1,370 litres of diesel oil and emitted 3.22[15] tons of CO2 per day, or 1175 tons of CO2 per year. Assuming that the tramway operates with nuclear electricity with zero CO2 emissions, a somewhat generous assumption, it saves these emissions.

4.3 Impact on CO2 emissions of modal shift

The tramway induced a modal shift of 8.000 passenger*km who shifted from car to tramway. This corresponds to 6,154 fewer vehicle*km daily driven. By postulating a traffic speed of 20 km/h[16] before the project, i.e. a CO2 emission of 0.439 kg/km, these vehicles emitted 2.87 tons of CO2 per day, or 1035 tons per year on the *Maréchaux*. They no longer do.

4.4 Impact on CO2 emissions of reduced speed for remaining vehicles on Maréchaux

The 36% reduction in the number of cars using the *Maréchaux* can only be explained by an increase in the usage cost of the *Maréchaux* caused by a decline in speed on that road - and limited, as explained in Section 2, by the cost of a detour by *Périphérique*. This cost was estimated to be 2.4 minutes per trip. Assuming a before-project speed of 20 km/h, this means an after-project speed of 16.7 km/h - a 17% decline. The equation of CO2 as a function of speed indicates that this implies an increase in CO2 emissions of 27 g/vehicle*km. The product of this difference by the number of vehicle*km remaining on *Maréchaux* (89,500 vehicle*km) yields an increase in CO2 emissions of 2.5 tons per day, or 900 tons per year. Taking into account the much higher emissions of commercial vehicles would significantly increase this number.

4.5 Impact on CO2 emissions of longer trips via the Périphérique

Vehicles that abandoned *Maréchaux* for *Périphérique* travel at least 800 meters more than before. Some certainly travel much more. As a result, they consume more fuel and emit more CO2. This concerns about 43,000 vehicle*km per day. Assuming an average trip length of 4 km, this is the case of 10,275 trips. Each is now 0.8 km longer because it uses *Périphérique*. This means an additional 8,460 vehicle*km. With per km CO2 emissions of 0.439 kg/km (corresponding to a speed of 20 km/h)

[15] The consumption of a litre of diesel oil emits 2.35 kg of CO2.

[16] The recorded speed is « 16-18 km/h » ; but this speed takes into account stops at traffic lights ; the speed used in the CO2 emissions as a function of speed is the speed at which cars drive when they move, and is higher that the speed with stops at traffic lights.

and 365 days, this means an additional CO2 emission of 1,356 tons. This is an underestimate because it ignores the more important CO2 emissions of commercial vehicles.

4.6. Impact on CO2 emissions of increased congestion on Périphérique

The main environmental impact of the tramway project comes from increased congestion on the *Périphérique* caused by cars transferred from *Maréchaux*. These additional vehicles slow down all the cars travelling on *Périphérique* and thus increase the emissions of all these vehicles. This phenomenon is merely the CO2 consequence of the congestion externality studied previously.

This consequence can be calculated with a good precision. We have:

$$CO2 = f(s) = \lambda+\mu*v \quad (\text{with } \lambda = 0.624 \text{ and } \mu = -0.00925)$$
$$s = g(q) = \alpha+\beta*q \text{ (with } \alpha = 85.3 \text{ and } \beta = -0.264)$$

This gives us:

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

The marginal emission (CO2M), which is the additional quantity of CO2 caused by one vehicle added to 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. Then, one has to multiply this marginal emission by the number of additional vehicles in the speed class and to sum it[17]. With 42,300 vehicle*km displaced each day, the reduction of speed on the *périphérique* causes a surplus in CO2 emission of 8.4 tons per day, or 3,066 tons per year.

4.7. Impact on CO2 emissions of mobility reduction

A number of people travelling on the *IG* axis by car no longer travel at all on that axis. If they were all staying home, this would reduce CO2 emissions. But it must be feared that these people have replaced their trips on the *IG* axis by other types of trips, particularly suburb-to-suburb trips, and that these new trips are longer, and therefore more CO2 producing, than the trips initially undertaken. We will therefore ignore this impact.

[17] These calculations are presented in Annex B.

Table 4 – Impacts of the Project on CO2 Emissions

	(in tons of CO2 per year)		
	Before	After	Variation
Elimination of buses	1175	Zero	-1,175
Modal shift	1,035	Zero	-1,035
Decrease in speed on the *Maréchaux*	14,144	15,046	+900[a]
Longer car trips via *Périphérique*	Zero	1,356	+1,356[a]
Increase congestion on *Périphérique*			+3,066[a]
Total			+ 3,112

Source: authors' calculations
Note: [a] These numbers are underestimate because they do not take into account the greater emissions of commercial vehicles

Table 4 shows the various envirnomental impacts of the project. Nonetheless engines are greener in 2007, let us assume all other things equal that the tramway contributes to an increase in CO2 emissions by more than 3,000 tons per year. By retaining a conventional value of 25 € per ton, one obtains a cost of less than 0.1 M€ per year. This amount is rather negligible when compared with the other profits and costs of the project.

Section 5. Socio-Economic Evaluation of the Project

5.1. Investment and operational costs of the project

Available information on the monetary costs associated with the project is scarce. One has only the *ex ante* costs envisioned in the official preliminary Public Enquiry: 341.8 M€ for the initial investment and 43.9 M€ for the exploitation of the tramway. Experience suggests that *ex post* costs are likely to be appreciably higher (Flyvbjerg et al. 2002). However, let us suppose that this project was an exception, and that the effective cost is what had been anticipated. The project is entirely financed with budgetary funds, and it is appropriate in the framework of a costs-benefits analysis to multiply this expenditure by the opportunity cost of the public funds officially fixed at 1.3 in France (Commissariat Géneral du Plan 2005). There is thus an initial investment of 443.3 M€.

For the operating costs, we are only interested in the difference between the cost of the buses and the cost of the tramway, since the marginal cost (of operation) of a subway trips is close to zero. The operating costs of buses are not published. *Statistiques Annuelles* of the RATP give an average operating cost by trip, for all trips (including subway and bus trips): 1.07 €/trip. The removed buses accounted for 55,000 trips per day. This would suggest that operating costs for the bus line were approximately equal to 17.78 M€ per year. If this same unit cost were applied to the tramway, its operational costs would be 74% higher (a sur-cost of 13 M€). But there are good reasons to believe that unit tram costs are lower than unit bus costs. We will assume that the operating cost of the tramway is equal that of the buses, in spite of its increased patronage, and consider that there is no operating cost burden.

Users' payments are hardly affected by the introduction of the tramway. In fact, the large majority of tramway users paid already the same amount before, in the form of bus or subway tickets. However, it was seen that the tramway attracted 4,300 new trips per day. If they all paid the average user payment of 0.64 €/trip[18], that would increase the receipts of the RATP by 1.00 M€ per year. Actually, many of these users benefit from a transport pass and take the tramway at a zero marginal price. To be on the safe side, we will nevertheless assume that they all pay the full price, but it should be clear that this is a serious over estimate (on a relatively small amount).

5.2. Economic appraisal of the project

Table 5 presents the various components of our economic appraisal. They relate to the changes induced by the project with reference to the *ex ante* situation (defined by the bus line and the *ex ante* road system). Some of these estimates are more uncertain than others. Three in particular must be considered fragile: the comfort gains generated by the tramway, the subway decongestion benefits, and the time lost by vehicles entering or leaving Paris. In these cases, available data does not make it possible to produce very solid figures. We could have refrained from giving the estimates arrived at, but considered that imperfect estimates were better than no estimates: we are dealing with very real impacts that it is necessary to identify, discuss, and try to measure.

From a socio-economic point of view, the project appears to fare badly. Not only did it require a major investment, but its yearly costs are greater than its yearly benefits. 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 negative yearly cash-flows. Let us repeat for non-specialists that this is not a matter of financial flows, but of social, economic and environmental resources. The Net Present Value of the project, calculated with the official rate of 4% over 30 years (Commissariat Général du Plan, 2005) is **-** 868 M€ (with the lower estimate of the subway decongestion benefits) or -806 M€ (with the higher estimate). These are estimates of the resources wasted by the project.

Another way to present our findings is to "annualize" the investment cost, and to add it to the yearly costs and benefits. The annual cost of the investment is equal to the opportunity cost of the capital utilized plus its amortization. With an opportunity cost of capital of 4% and an amortization period of 30 years, one obtains an annualized cost of capital of -32.58 M€. Added to the annual costs and

[18] This number is obtained by dividing total user payments for the entire RATP (including suburban buses and express trains (RER)) by total number of passengers. Data is for 2007, from RATP. *Statistiques Annuelles 2008*, pp. 22 & 38.

benefits of -26.56 M €, one obtains a total annual cost and benefit of -59.07; added to the annual costs and benefits of -22,84 (with the high estimate of subway decongestion benefits), the total annual cost and benefit of the projects remains negative, at -55.42 M€.

Table 5 – Costs and Benefits of the Project

	Initial (M€)	Yearly (M€)
Initial investment	-444.34	
Operating costs		pm
Variation operator surplus (additional income)		+1.00
Variation public transport users surplus:		
Time savings		+2.69
Comfort gains		+2.69
Decongestion of the subway		+5.71 to +9.43
Variation car users surplus		
Welfare loss of car users		-6.72
Time loses of the vehicles entering Paris		-1.83
Externalities		
Additional congestion on the *Périphérique*		-30.00
Over-emissions of CO2		-0.10
Totals	-444.34	-26.56 to -22.84

Sources: authors' calculations.

It is important to note that many of the costs (the negative variation in car user surplus, the congestion externality, etc) are more a consequence of road space narrowing than of the tramway itself. Tramways by themselves are not necessarily as bad as this analysis make them appear. However, two points can be made.

The first point is that the project was presented as a coherent package, and it was explained that road narrowing was a necessary and integral part of this tramway project – which is why we assess it as an integrated package. The second point is that the benefits generated by the tramway itself (if we assume that the costs borne by car users should be entirely allocated to the road narrowing component of the project) are not sufficient to justify the heavy investment made. These benefits amount to 12.09 to 15.81 M€, and cannot justify an investment of 444 M€. The net present value of the flow of costs and benefits over a 30 years period with a social rate of return of 4% is still negative, at -226 M€ and -164 M€ respectively.

This analysis is based on data for 2007 only. We did not attempt to forecast possible changes in the structure of trips in the next thirty years. First, it is difficult to imagine that tramway usage could greatly increase in the future. Mobility does not increase in Paris; as a matter of fact, it has begun to decline. If it were to increase much, the supply of tramway would have to increase, at a high cost; or else congestion in the subway would develop, and with it congestion costs. Second, could the planned completion of the tramway line along the 33 km of *Maréchaux* create some "network effects"? They would be limited by the fact that such network effects did exist with the bus line replaced (or to be replaced) by the subway, which serviced the entire *Maréchaux*. Moreover, the time to complete a trip from *Pont de Garigliano* to *Porte de la Chapelle* (see Figure 1) will take 1h15 by tramway whilst 45 minutes by car through the *Périphérique*.

Section 6. Conclusion

This research does not claim to be the last word on the appraisal of the Paris tramway. We noted a number of theoretical and factual gaps. Bridging them would make it possible to improve, and correct, our estimates. They nevertheless appear sufficiently robust to allow some conclusions.

The tramway line, opened on the *Maréchaux* boulevards in December 2006, is an apparent success. It attracted the users of the bus line that it replaced, as well as a surprisingly large number of subway users. These travellers benefit from the project: they move slightly 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, some 12-16 M€ per year. It is interesting to note that the most important benefit, subway decongestion, had not been planned and not even envisaged.

In spite of that, the tramway did not induce any significant modal shift. Only about 3% of tramway users were formerly travelling by car. This experience throws an interesting light on the limits of modal shift policies.

At the same time, the tramway was accompanied by an important reduction of road space on *Maréchaux*. This increased road congestion on *Maréchaux* and reduced traffic by approximately 40%. Despite the improvement in the supply of public transport and this worsening of driving conditions, car users did not give up their car for the tramway. Where did they go? Some are discouraged and do not travel any more on the axis considered. Most of them are now on roadways parallel to the *Maréchaux,* particularly on the nearby *Périphérique*. Here is the rub. By doing so, they use longer routes and they waste time compared to the former situation. But the worst consequence of the project is most probably increased congestion on *Périphérique*. An additional vehicle on this major artery slows down its whole traffic and generates an important congestion externality, estimated at about 30 M€ per year.

The project cannot be saved by environmental benefits. The substitution of diesel oil buses by an electric tramway does reduce CO2 emissions. So does the reduction of car traffic on Maréchaux. So does the minute modal shift. But lower speeds and longer car trips do increase CO2 emissions. The most important CO2 impact takes place on the *Périphérique*. The cars that shifted to *Périphérique* slow down the massive flow of vehicles on that artery, and increase the per vehicle*km CO2 emissions of all cars travelling on *Périphérique*. At the end of the day, after-project CO2 emissions are greater than before-project CO2 emissions.

Tramways are fashionable. But "*fashion*, said Jean Cocteau, *is what gets out of fashion*". In terms of political economy, the project, however, is probably interesting for the municipality of Paris. Benefits are mostly for the tramway users, who are predominantly (57%) Parisians, i.e. voters. Costs are mostly for the car users, who are predominantly suburban commuters who do not vote in Paris. The investment cost was borne mostly (85%) by the region and the central government. The remainder was paid out of municipal taxes which are mostly paid by enterprises, and relatively painless for Paris municipality voters. The environmental balance is negative, but not very visible. Fewer cars on *Maréchaux* are more noticeable than more congestion on *Périphérique*. Tramways are "blind commitments" according to Hensher (1999). This blindness explains why the tramway project had, and keeps, the favour of Parisian elected officials. The current prolongation of the tramway on the remainder of *Maréchaux*' at an estimated cost of one billion euros raises little opposition and will be completed at the end of 2012.

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Annex A – Estimation of the Number of Vehicle*km Eliminated by the Project

The estimation of the number of car trips, or more precisely of vehicle*km, eliminated by the project refers to Figure 2 above. It is equal to Q_a-Q_c, or FA, or Δq. Let us call ε the point elasticity of the demand curve D in A. We have:

$$\varepsilon=(\Delta q/q)/(\Delta p/p)$$

$$\Delta q=\varepsilon * q * \Delta p/p$$

$$FA=e * Qa * (P_b-P_a)/P_a$$

We already know Qa =152,300 vehicle*km per day.

To estimate P_a, we need a value of time, the number of people per car, the speed on *Maréchaux* before the project, and the fixed cost of driving one km. The official value of time for the Paris region is, for 2007, fixed at 10.2 €/h (Ministère des Transports 2004). The occupancy rate of cars is 1.3. Travel speeds on *Maréchaux* can be estimated at 20 km/h. The fixed marginal cost of driving one km, which is basically the cost of the fuel needed, is estimated to be 0.12 €. We therefore have:

$$P_a \text{ (in €/v*km)} = 0.12 + (10.2*1.3)/20 = 0.783$$

Pb-Pa is the sur-cost generated by the detour via *Périphérique*. This detour lengthens the trip by two times 400 meters, or 0.8 km. At a speed of 20 km/h, this causes a cost of 10.2€*1.3*0.8/20, of 0.530 €. Assuming a trip of 4 km, this is equal to 0.133 €/vehicle*km.

For the demand elasticity, Litman (2009) or Goodwin (1992) propose values ranging between -0.6 and -0.8. These elasticities, however, were calculated for whole trips. They are not appropriate for the analysis of the movements on *Maréchaux*, which often constitute only a segment of much longer trips (approximately two or three times longer). The demand on *Maréchaux* is consequently more inelastic, relative to the price of driving that segement. It is thus advisable to retain a demand elasticity significantly lower that the Litman or Goodwin estimates. We retained an elasticity of -0.3.

We obtain: FA = Q_a-A_c = 7,760 vehicle*km, or (by multiplying by the occupancy rate) 10,000 passenger*km. These are the passenger*km which have been eliminated. They represent about 16% of the “missing” car passenger*km. The remaining 84% are undertaken by people who continue to use their cars but on *Périphérique* or parallel streets.

One can note that this result is not very sensitive to the elasticity retained. With an elasticity of -0.2, the share of passenger*km eliminated would be 11%. With -0.4, it would be 22%.

Annex B - Additional Road congestion and Environmental Costs on *Périphérique*

Classes	Speed	Distrib.	Density	uMCC	Shifted	MCC	uCO2	CO2
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

Classes: speed classes (in km/h)
Speed: average speed of each speed class (km/h)
Distrib.: distribution, in % and for each speed-class, of the observed vehicle*km on the southern part of *Périphérique*
Density: (veh/km), calculated trough the speed-density relation q=(85.3 – s)/0.264
uMCc: unit marginal cost of congestion (€/vkm), calculated with $Cm(q)=3.5*q/(85.3 + 0.264*q)^2$
Shifted: number of vehicle*km per day shifted to *Périphérique*, allocated to each class prorata Distrib
MCC: marginal cost of congestion (€), product of Shifted by uMCC
uCO2: unit marginal CO2 emissions (kg/vehicle*km), calculated with CO2M= 0.0024*q if speed < 50 km/h, CO2M=0 otherwise
CO2: CO2 emissions (kg), product of Shifted by uCO2