Optimal Social Speed in a Highway:
Suitability of the 120 km/h (75 mph) Speed Limit

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ABSTRACT

Speed limits in Spain are the most commonly ignored driving rules. A common joke holds that if one keeps the speed limits (currently 120 km/h or 75 mph in highways) he or she risks having an accident … for going too slow. This paper presents a methodology used to determine the “optimal” speed in a highway that has a physical layout to permit high driving speeds. “Optimal” speed is defined as the speed presenting the least social costs.

To determine the optimal speed, it has first been necessary to perform a socio-economic analysis of factors which vary according to speed. The factors studied are: time savings; comfort – driver preference; accident rate and environmental impact.

The numerical application has been done in A-7 highway in Catalonia, Northeast of Spain, in a segment of highway one hour’s drive north of Barcelona. The model yields a result of 124 km/h (77.5 mph) as the optimal social speed. The conclusion is that in the analyzed stretch of the A-7 highway, speed limits could be increased to 140 km/h (87.5 mph) if these new speed limits are really enforced.

Key words: Highway, speed limits, social costs

1. INTRODUCTION

This article is intended as a small contribution in the study of the thorny problem of road safety, scientifically questioning the existing maximum speed limit on highways where the road layout, vehicle power, physical environment and driver ability permit high driving speeds.

Speed limits in Spain (currently 120 km/h or 75 mph in highways) are the most commonly ignored driving rules. All kind of drivers are “guilty” for this: both young and old. A common joke holds that if one keeps the speed limits he or she risks having an accident … for going too slow. When a rule is not respected by almost anyone, its enforcement is difficult since it would mean giving tickets to everyone. In a mature society, that fact points out that perhaps the people do not perceive the rule as “valid”.

The question which arises is: if 120 km/h (75 mph) is not the “right” speed limit as perceived by people, what should it be? This paper presents a methodology used to determine the “optimal” speed in a highway that has a physical layout to permit high driving speeds. “Optimal” speed is defined as the speed presenting the least social costs.

To determine the optimal speed, it has first been necessary to perform a socio-economic analysis of factors which vary according to speed. The factors studied are: time savings; comfort – driver preference; accident rate
and environmental impact. The numerical application has been done in stretch of A-7 highway in Catalonia, Northeast of Spain, one hour North of Barcelona.

2. METHODOLOGY

The study of the appropriate speed limit for a given section of highway is based on the analysis of the optimal speed for the same section. Optimal speed is defined in this paper as the speed which entails the least social costs.

It is necessary to assign a socio-economic value to those aspects which vary according to the driving speed. The following aspects have been studied: time savings; comfort – driver preference; accident rate and environmental impact.

In order to assign the socio-economic value mentioned above, a specific stretch of highway was selected for study of the selected variables. The stretch of highway selected for study was chosen according to criteria of fluid circulation, but also to be representative of the majority of the highways in Catalonia. The “representative” quality holds both for conditions of physical layout and traffic conditions.

Highways in the metropolitan area of Barcelona were excluded due to the excess of interchanges, above average traffic volumes, and intermittent stoppages due to congestion during many hours of the day. For these reasons, the stretch of highway upon which the socio-economic analysis is based is located in highway A-7, between the links to North Girona and South Figueres, two cities of the Northeast of Spain (Catalonia region) approximately one hour’s drive north of Barcelona.

In order to profile the characteristics of the drivers frequenting this section of highway, and primarily to gain information on driver preferences, a survey was designed and performed.

The methodology proposed for the study of the appropriate speed limit is presented in the diagram below:

![Figure 1. Diagram of methodology of speed limit study](image)
3. VARIABLES MODELING AND COST ANALYSIS

In order to assign a social cost to each of the study variables, which depend on the average driving speed, it has first been necessary to establish a direct relationship between these variables and the average highway speed. The costs studied are public or social costs. They reflect the cost of the transport system for society as a whole.

3.1 Time Savings

One intrinsic consequence of overcoming distance is spending time. Because time is a scarce good, time savings has an economic value. Given fluid traffic conditions and a highway layout, the time invested in completing a stretch of the highway depends exclusively on the driving speed.

The value of travel time savings has been estimated by applying the same method used by the first author (F. Robusté, 2000) in a recent study on the social transportation costs of the year 1998 in the metropolitan area of Barcelona, Spain. The value of time is assigned according to the following expression:

$$\bar{\alpha} = \sum_{m=1}^{n} P_m \cdot f_m \cdot R$$

where $P_m$ is the percentage of passengers who travel for trip purpose $m$; $f_m$ is the factor which multiplies the hourly income of the group studied and $\bar{\alpha}$ is the average hourly income of the group; and $R$ is the factor which multiplies the hourly income to obtain the value of time which one travels for purpose $m$. Applying the percentages of each travel purpose found in the survey performed to the average salary income in Catalonia in 1999, we obtain an estimated social value of time of 1,423 PTA/vehicle hour (7.50 $/h at 1$=190 PTA current exchange rate), bearing in mind that the average vehicle passenger load is 2.1 persons.

3.2 Preference – User Satisfaction

Driver preference has been included in this study by weighting the various driving speeds according to the number of drivers who prefer to travel at each of those speeds. Therefore it was necessary to gather data on the speed at which each individual wishes to travel.

Surveys were designed to gather information on real and preferred travel speeds, as well as the characteristics of the persons interviewed, the nature of the trips taken, and other details which make it possible to estimate what each driver’s behavior would be in the case of a change in highway speed limit.

An example of the survey and the survey results obtained are found in the graduating thesis of M. Vélez (2001) from which the present article derives.

The preference – speed curve obtained through the surveys is shown in Figure 2. Costs have been assigned based on the assumption that each driver would prefer to travel at the speed most useful to him. This perceived “usefulness” would be determined by the balance between the levels of rapidity, comfort and safety desired.

In the same way, the speed at which vehicles currently circulate is the result of the balance between those three factors and the drivers’ concern regarding possible economic sanctions (speeding fines) and/or his psychological stress related to the possibility of disobeying a legally established norm.

The benefit obtained by a driver who travels on a highway at the speed at which he currently travels is greater than or equal to the cost of the trip.

In order to place an economic value on the comfort a user derives from being able to travel at one given speed or another, it has been assumed that the benefit derived from travelling at a given speed will be, at a minimum, the cost of the toll plus whatever the drivers are willing to pay for the absence of a speed limit.
Both the average cost which drivers would be willing to pay for having no speed limit and the distribution of the total cost between speed, comfort, and safety are taken from the survey data referred to above. In calculating the average perceived toll cost, the authors have kept in mind that some drivers do not “perceive” the costs of the tolls because that cost is paid for by their companies.

The result of this analysis shows a perceived benefit of 3.5 PTA/veh-km (3 cents/car-mile). By applying this value to the curve which relates preference – comfort and speed, one obtains the relation between perceived usefulness in pta/veh·km and the average travel speed.

### 3.3 Accident Rate

Of all transportation modes, private vehicle use on the highway presents the highest accident rate. Various studies show relationships between average road speed and accident rate, but none of them is easily extrapolable from highway to highway. Therefore a specific study was conducted for the highways in Catalonia.

Data used are from the highways known as A-2 and A-7. The accident data series corresponds to 1994-2000 years. The speed data corresponds to the year 1997, taken from the Speed map of the Spanish Ministry of Public Works.

Observation of the average of the results obtained (per group, in intervals of 5 km/h), reveals a steady tendency to increase, both in the accident rate and in the number of victims. As is usual, the accident and victim rates have been calculated as the number of accidents and victims respectively for each 100 million vehicle-kilometers.

The results obtained are show in the two Figures 4 and 5 below.
The relationships shown are considered local; it is not possible to extrapolate them to lesser speeds, given that lesser speeds would imply paths with less favorable geometric characteristics or increased traffic densities, inhibiting fluid circulation.

The accident costs assigned are based on a publication of the Spanish Institute of Transportation Studies (1995) *Socioeconomic cost of the road accidents. COST 313, Ministery of Public Works, Transportation and Environment*. The values adopted for estimating the costs associated to accident victims are: 38,044,381 PTA for a fatality ($200,234 per death), 2,120,579 PTA for injury ($11,161); and the costs for material damage to a vehicle have been estimated at 222,670 PTA ($1,172).

The formula used for calculating the cost of the accident rate is:

\[
Cost_{\text{accident rate}}(v) = n_v \cdot C_{\text{material}} \cdot I_{\text{acc}}(v) + (\alpha_{\text{death}} \cdot C_{\text{death}} + \alpha_{\text{injury}} \cdot C_{\text{injuries}}) \cdot I_{\text{vict}}(v)
\]

where \(\alpha_{\text{death}}\) and \(\alpha_{\text{injury}}\) are the percentage of casualties and injuries among the total victims, respectively, \(n_v\) is the average number of vehicles involved in an accident and \(C_{\text{injuries}}\) is the average cost per victim. The \(I_{\text{acc}}\) and \(I_{\text{vict}}\) rates are those presented previously.
3.4 Environmental Impacts

Among the environmental impacts studied are: toxic emissions, noise pollution, fuel consumption, and the carbon dioxide emissions responsible for global warming.

Toxic Emissions

The relationship between vehicles, their emissions, and speed of travel has been studied in the CORINAIR program (Eggleston, 1991) of the European Community. The results of this program have been applied in the present study.

In order to analyze the emissions factors, it has been necessary to treat each pollutant separately, and each type of vehicle according to its age and engine horsepower.

Social costs of the toxic air emissions have been calculated according to the methodology used in a recent study of the ATM (Metropolitan Transport Authority) for the Barcelona Metropolitan area (Robusté, 2000).

In 1999, the total environmental pollution cost for Spain was estimated at 492,162,000 PTA ($2,590,326). Half of this cost is attributed to highway transportation. Considering the number of vehicle-kilometers on Spanish roads in 1999, the cost breaks down to an estimated 1.22 PTA/veh-km (1 cent/car-mile) at a speed of 60 km/h (37.5 mph).

According to the CORINAIR studies, the average vehicle traveling at this speed emits a total of 6.5 g/km contaminating gases, which therefore establishes a relationship between the grams of gas emitted and the social cost they imply, with the result of 0.188 PTA/g emitted. Using this value, it is possible to establish a relationship between the average speed of a vehicle and the social cost associated to its emissions.

Noise Pollution

The noise generated by vehicles arises basically from two emissions sources: the motor and the noise produced by the contact of the tires with the pavement. The relationship between the average noise emissions and the travel speed of 1 vehicle has been obtained from the French research center CETUR.

The calculation of the cost of the different noise levels has been estimated based on the cost of installing noise shields and the minimum noise attenuation that each of them offers.

Assigning a zero cost for 0 dB(A), and given that the scale dB(A) is logarithmic with respect to the noise pressure expressed in N/m², the average associated cost for noise levels measured dB(A) must be exponential. If the cost of a noise shield is spread over the number of vehicles which will circulate through the given section of highway during the useful life of the infrastructure, the expression of the noise pollution cost is as follows:

\[ C_{\text{noise}} = 1.0068^{dB(A)} - 1 \]

Because the stretch of highway selected for this study does not pass through urban centres, and considering the lack of nearby inhabitants, the noise pollution cost has been estimated at approximately 15% of that produced in urban areas.

By applying the relationship between noise emissions produced by a flow of vehicles and the average road speed presented by CETUR, and narrowing it to the intensity of traffic on the focus stretch of highway, it is possible to establish a relationship between the average driving speed and the noise pollution cost. From this point we may extract an average per vehicle.

Fuel Consumption

Fuel consumption does not depend directly on driving speed, but rather on the efficiency of the motor at any given moment.
The highest fuel consumption takes place when the motor is started up, and then reduces as the motor continues to work in a higher gear. This holds true up to approximately 2,500 r.p.m., the number of revolutions which corresponds roughly to speeds between 80 -- 100 km/h. Beyond this level, fuel consumption increases with speed.

The relationship between fuel consumption and speed used here has been taken from the study of the CORINAIR group.

With respect to the cost of fuel, since it is impossible to calculate its true cost in relation to future diminishment of fuel supply, or costs of fuel extraction, transport, and side effects such as combustion by-products (basically CO$_2$), which intensify the greenhouse effect, for purposes of this study we treat these costs as included in the selling price of the fuel.

Keeping in mind the percentage of vehicles which use leaded gas vs. those which use unleaded gas, one may obtain a weighted price to apply to the expressions proposed by CORINAIR and thus obtain a relationship between the value of the fuel consumed and the driving speed.

Greenhouse Effect

The main by-product of gasoline combustion is carbon dioxide (CO$_2$). This gas is commonly found in the atmosphere and is not toxic to humans. However, it has a negative impact on the environment, being one of the main gases responsible for the greenhouse effect.

Carbon dioxide is a by-product of the combustion of hydrocarbons used as fuels, and therefore, a vehicle’s emissions of this gas should be proportional to its fuel consumption.

By considering the proportions of carbon and hydrogen found in gasoline (ranging between approximately 83 – 86 % and 11 – 13 %, respectively), we may estimate the emissions of CO$_2$ per liter of fuel consumed.

Assuming an average fuel density of 0.825 kg/l, we estimate 2.59 kg of CO$_2$ emissions per liter of fuel consumed.

The methodology used to estimate the costs derived from the greenhouse effect and climatic change has been taken from Robusté (2000; previously mentioned study for the Barcelona Metropolitan Transit Authority).

The costs of the greenhouse effect have been associated with the cost of the mitigation measures necessary to reduce CO$_2$ emissions. This indicates a cost of 7,661 PTA/ton of CO$_2$ ($40.32/ton).

4. APPLICATION AND RESULTS

4.1 Costs Analysis

After first establishing the relationship between the social costs and driving speed for each of the study variables, the next step has been to perform a socio-economic evaluation, in an attempt to determine the optimal driving speed for the stretch of highway analyzed. This optimal speed corresponds to the speed with the lowest social costs.

The costs associated with a driver’s choice to circulate at a preferred speed appear negative in the cost axis, because they are perceived as benefits.

It may be observed that the factors which provoke an increase in average speed are time spent in the trip and the perceived benefit of being able to travel at the desired speed.
The factors which work against high speeds are more numerous, among them the accident rate, consumption of fossil fuels, noise emissions and exhaust emissions, both the toxic ones and those contributing to global warming.

The two most heavily weighted factors are time spent in the trip and fuel consumed.

The costs analysis yields an optimal average speed of 124 km/h (77.5 mph), slightly higher than the currently existing highway speed limit, but lower than the real average speed on the studied stretch of highway according to the surveys performed (134.3 km/h or 84 mph).

4.2 Sensitivy Analysis

In society’s view, not all factors involved in the analysis have the same importance. The accident rate has a greater social impact than environmental pollution or time spent in a trip.

In the socio-economic analysis, a cost has been established for the accident rate based on various economic studies. If a factor is given more weight due to being the factor of greatest impact, rather than weighted strictly according to monetary value, the economic cost may be weighted according to different factors.

The table below shows different optimal speeds (corresponding to the least social cost), changing in relation to the different weight values applied to the accident rate.
In the case of some Scandinavian countries in which the greatest importance is given to accidents and environmental pollution, the methodology yields lower optimal speeds.

### 4.3 Considerations on the Speed Limit

In order to establish a speed limit for the optimal social speed found, a cost penalty has been associated to the minimum social speed thus obtaining both an upper and lower limit for speeds with acceptable social costs, as shown in Table 2.

<table>
<thead>
<tr>
<th>∆ Cost</th>
<th>Minimum speed</th>
<th>Maximum speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 PTA/veh·km</td>
<td>109 km/h</td>
<td>138 km/h</td>
</tr>
<tr>
<td>1.0 PTA/veh·km</td>
<td>102 km/h</td>
<td>142 km/h</td>
</tr>
<tr>
<td>1.5 PTA/veh·km</td>
<td>97 km/h</td>
<td>146 km/h</td>
</tr>
</tbody>
</table>

Table 2. Maximum and minimum speed limits according to assumed over-costs

Using only this system, the speed limits which appear to be ideal are close to 140 km/h. However, if we consider the real behavior of drivers with respect to the speed limit, we may predict that the new limits would probably not be obeyed either.

An attempt to estimate driver behavior with respect to speed limits has been made using the data taken from the surveys performed. The results obtained are shown in Table 3.

The values of Table 3 show that if current behavior with respect to highway speed limits continues, those limits should be set at approximately 100 km/h (62.5 mph): in this way the average driving speed would equal the optimal speed (least social cost)…. Implicitly accepting (as happens now) that most of the drivers would continue to be law-breakers.

If, however, we presuppose an increase in monitoring and enforcing adherence to the speed limit, the speed limit should be increased, to allow an optimal average social speed of 124 km/h (77.5 mph).

<table>
<thead>
<tr>
<th>Speed limit</th>
<th>Estimated average speed</th>
<th>∆ estimated speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 km/h</td>
<td>123.8 km/h</td>
<td>-10.5 km/h</td>
</tr>
<tr>
<td>110 km/h</td>
<td>129.1 km/h</td>
<td>-5.2 km/h</td>
</tr>
<tr>
<td>130 km/h</td>
<td>137.7 km/h</td>
<td>+3.4 km/h</td>
</tr>
<tr>
<td>140 km/h</td>
<td>139.2 km/h</td>
<td>+4.9 km/h</td>
</tr>
</tbody>
</table>

Table 3. Estimated average speeds for various speed limits

Due to a certain increase in assumed costs, the speed limit seems to lie at around 140 km/h (87.5 mph). As specified in Table 3, the average driving speed under those circumstances would increase to 139.2 km/h according to estimates based on our survey data. In that case, even if adherence to the speed limit were rigorously enforced, the average speed would continue to be close to 140 km/h, given that those drivers who would exceed the speed limit if the current levels of enforcement were maintained would begin to drive at
speeds close to the same, and those who would drive slower than 140 km/h would not change their behavior. It should be remembered that our analysis does not consider the costs of the enforcement.

The following figure shows the driver behavior estimated for a speed limit of 130 km/h and the (visual) effects of rigorous enforcement.

![Límite 130 km/h](image)

Figure 7. Distribution of speeds estimated for a speed limit of 130 km/h

If 130 km/h is taken as the speed limit, approximately 43.6% of the drivers find the traffic speed modified due to the application of significant enforcement measures.

**CONCLUSIONS**

A social cost methodology has been applied to calculate the socially optimal speed of a stretch of highway in Spain, near Barcelona. When physical layout and traffic, driver, car and environmental conditions permit it, the average social speed should be 124 km/h (77.5 mph), which exceeds the current speed limit of 120 km/h (75 mph).

For highway stretches such as the one analyzed, the speed limit could be increased to 140 km/h (87.5 mph) if it were enforced. The paper does not account for the extra speed-enforcement costs and does not consider the confusion that different speed limits in the same highway might cause drivers.

**ACKNOWLEDGEMENTS**

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**REFERENCES**


