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Estimate of social and environmental costs for the urban distribution of goods. Practical case for the city of Barcelona

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Abstract

The objective of the formulation is to allow to evaluate easily the costs of the urban distribution of goods by means of wheeled vehicles, and to formalize a methodological outline for the mentioned evaluation, which allows its updating and amplification when it was necessary. The sensitivity of the model illustrates the behaviour of the social costs in front of variations of the parameters which intervene in the model.
The social costs which are analyzed in this article are the costs of the polluting emissions of the commercial vehicles, the costs of the noise emitted by the same ones, the costs which generate these vehicles in congestion and the costs of the accidents associated to their circulation.
The costs of polluting emissions are considered with a matrix model based on an updating of the deliverable 22 of the project MEET. The costs of the noise are associated to the cost of using asphalt noise reducer in the streets with a high daily average intensity. The congestion costs are evaluated starting from the losses of time of the drivers of the commercial vehicles in Barcelona. The costs of accidents are quantified starting from the accident rate studies and mobility in the city of Barcelona.

Keywords: Urban freight distribution; social costs; transportation models; estimation

1. Introduction and state of the art

The formulation of the model requires, in advance, the definition of the urban distribution of goods (DUM), as a basic task from which a series of activities are developed and which generate the costs which

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are wanted to be estimated in this article. This way, the DUM is defined in this document as the transport of goods by means of a wheeled vehicle, and the activities related to this transport, in an urban environment, considering urban environment as any city or metropolitan area.

The unitary social cost is calculated by the unit of transport of goods. The pallet which is used currently in Europe is the European standard pallet, and therefore, the unitary costs are in €/pallet, being the mentioned euro pallet the type of chosen pallet.

One of the first studies on the urban movements of load is provided by (Ogden 1992), whose urban models have been used as a starting point for the conceptualization of the DUM. The interest for the derived impacts of the urban distribution of goods favoured a growth of its study, as exemplified in (Dablanc 2007) and in (Taniguchi, Thompson 2006). Currently, important steps in its study in Europe, U.S.A. and Japan (Dablanc 2010), are occurring, so common and political indicators of improvement can be drawn.

As for the quantification of the external costs, the article (Mayeres 1996) exposes an extensive methodology and quantification of the congestion costs, accidents, atmospheric contamination and noise, so it can be consider0ed as a basic reference for any type of study of these costs. The study (Delucchi 2000) revises methods, data, uses and limitations of several studies about environmental costs generated by the use of vehicles in the U.S.A., as well as quantification of the environmental costs during 1990-1991 in the country mentioned before. In the article (Parry, Small 2005) values are exposed for the marginal costs of the atmospheric pollution, congestion and accidents and in (Ozbay *et al*. 2007) functions of internal and external costs are presented, both the means values and the marginal values, and the quantifications of these ones, under different scenarios.

One of the most recent studies is the one presented in the article (Sen, Tiwari & Upadhyay 2010) which includes the marginal external cost of the congestion, the atmospheric contamination, the traffic accidents and noise, as well as (Perez Martínez 2010) the one which reviews the use of the energy and the historical tendency of the emissions in Spain due for the transport of goods from 1990 up to 2007, and its diagnosis is estimated to 2025, under different scenarios. Another perspective of the external costs of the distribution of goods is offered it the article (Eisele, Schrank 2010), in which the impact the congestion generates in the distribution of goods is considered.

2. Formulation of the model of social costs

The costs which affect to the citizens directly are the sanitary costs due to the noxious emissions of the vehicles, the noise costs caused by the necessity of reducing the noise in the streets with a high daily average intensity, the congestion costs which cause mainly losses of time both to the users of the roadway and to the drivers of vehicles, and the costs of lesion or death due to the accidents of the urban circulation of vehicles of goods. The costs of the climatic change affect to the environment and, in an indirect way, to the citizen. The formulation of the model of social unitary costs (CUS) is the following one:

$$CUS = D * F \quad [€/pallet] \tag{1}$$

$\mathrm{CUS} = [€/\mathrm{pallet}]$: It is the unitary social cost in Euros per transported euro pallet.

$\mathrm{F} = [[(\mathrm{vehicle} * \mathrm{kilometre\ travelled})/\mathrm{number\ of\ transported\ pallets}]$: it is the operative distance, in relation to the distance travelled by the vehicle in its distribution route (since the time it leaves a deposit until it arrives to another one) and the number of pallets which are transported in that route. This independent variable is function in the way of operating of each distributor.

D = $\left[€/_{(\text{vehicle} * \text{kilometre travelled})}\right]$: it is the cost related to the distance travelled by the commercial vehicle.

$$D = emission + noise + congestion + accidents \qquad (2)$$

$$D = CSE + CSN + CSC + CSA \qquad [[€/vehicle * kilometre]$$

3. Quantitative estimate of the social costs

3.1. Cost of emissions, CSE

The quantification of these effects are the denominated costs of emissions (CSE) which have been differed in three types of costs, which are the sanitary costs of emissions (CSES), the costs of emission of climatic change (CSEC) and the emission costs for material damages (CSEM). The costs of emissions depend on several factors, such as the typology of vehicles and the proportion of these ones in the studied population, and the emitted gases and the costs of emission of each gas. The quantity of the types of vehicles, gases and costs to consider, recommends the use of an estimate of costs with a compact outline of matrix type which allows the quick and simple calculation and the clear visualization of all the variants of costs. This matrix model will be exposed next, differing among independent variables (or data which are needed) and dependent variables (or results which are obtained).

Data: $\overline{\mathrm{P}}$ is the vector of proportions. It is a vectorial column whose component i-ésima, corresponds to the proportion, as long as for one, of the type vehicle, regarding the total of vehicles. It is an adimensional vector. $\widehat{\mathrm{G}}$ is the matrix of unitary emissions. The element gij of the matrix corresponds to the tons of the gas j which are emitted by $\text{vehicle} * \text{kilometre}$ of the vehicle type i. The dimensions of the elements of the matrix are $\text{tons}/\ (\text{vehicle} * \text{kilometre})$. $\overline{\mathrm{H}}$ is the vector of unitary costs per ton of emission. It is a vectorial line whose component j-ésima, corresponds to the cost in € for each ton of emitted gas of type j. This vector is different according to the type of the studied cost. In our case, this vector is different for the sanitary costs, the costs of climatic change and the costs for material damages, as well as for the total emission costs. The dimensions of the components of this vector are $€/ton.$ $\widehat{\mathrm{H}}$ is the matrix of unitary costs per ton. It is a diagonal matrix, where each element corresponds to the component j-ésima of the vector. This matrix is different for each type of cost of the emissions. The dimensions of the elements of this matrix are $€/ton.$

Results: the results or dependent variables are obtained for each type of emission cost, as well as for the cost of emissions, considering all the costs which compose it. $\widehat{\mathrm{C}}$ is the matrix of unitary costs. The element cij of the matrix, corresponds to the cost in € due to the tons of gas j which are emitted by $\text{vehicle} * \text{kilometre}$ of the type vehicle. The dimensions of their elements are $€/(\text{vehicle} * \text{kilometre})$. $\overline{\mathrm{Cv}}$ is the vector of unitary costs per type of vehicle. It is a vectorial column whose component i-ésima, corresponds to the $€/(\text{vehícle} * \text{kilometre})$ for all the types of gases and for the type i vehicle. $\overline{\mathrm{Cg}}$ is the vector of unitary costs per type of gas. It is a vectorial line whose component j-ésima corresponds to $€/(\text{vehicle} * \text{kilometre})$ for all the types of vehicles and for the type of gas j. C is the average unitary costs for all the types of gas j, and all the types of vehicles i. it is a scale which has dimensions of $€/(\text{vehicle} * \text{kilometre})$.

The results or independent variables are presented, in each one of the points which analyze them, in a table form. This table summarizes in a compact way the previously mentioned results.

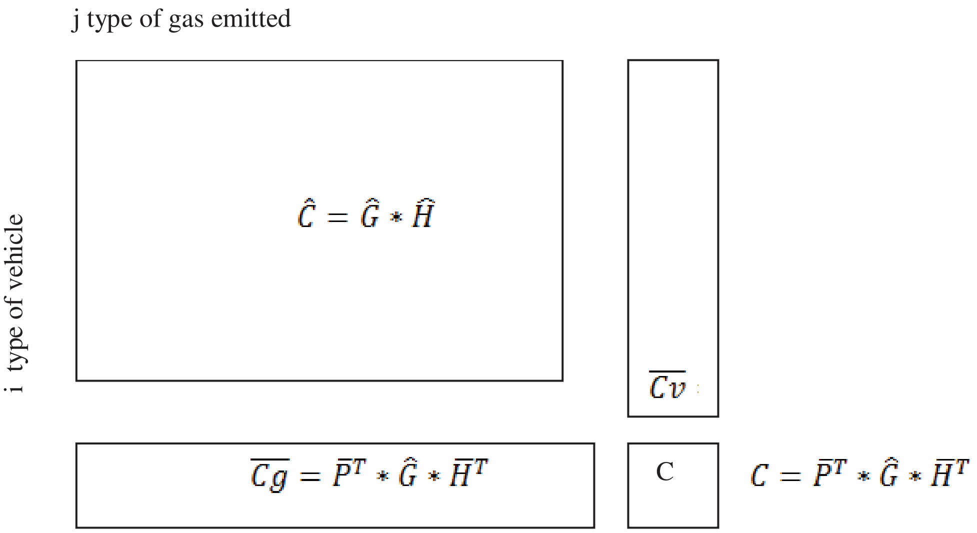

Fig. 1. Meaning of the tables of costs of emissions

Proportion of typologies of vehicles, $\overline{P}$. Because each typology of vehicle emits a quantity of gases different to the other ones, if we want to obtain an average unitary cost of emissions (CSE) for all the typologies, it is necessary that the proportions of each one were known. The typologies of vehicles according to their antiquity (Classification Euro) have been extracted from (Hickman *et al.* 1999), in which the proportions of vehicles of each typology are predicted to 2010. These proportions are of vehicles which have been extrapolated to obtain the corresponding vehicle*kilometre values starting from the knowledge of the operative characteristics of the vehicles of each type. The vehicles which have been kept in mind for the DUM are slight vehicles of less than 3,5 tons (authorized maximum weight). These typologies take most of vehicles which carry the DUM out at the present time. The proportions used in this article are shown in the Table 1.

Table 1. Proportion of vehicles in Spain in 2010, as long as for one

Type of Fuel and Vehicle	Clasification Euro, Normative	$\overline{P}$
Gasoline <3,5t	Conventional	0,02
Gasoline <3,5t	LD Euro 1 - 93/59/EEC	0,03
Gasoline <3,5t	LD Euro 2 - 96/69/EEC	0,06
Gasoline <3,5t	LD Euro 3 - 98/69/EC Stage2000	0,18
Diesel <3,5 t	Conventional	0,05
Diesel <3,5 t	LD Euro 1 - 93/59/EEC	0,11
Diesel <3,5 t	LD Euro 2 - 96/69/EEC	0,11
Diesel <3,5 t	LD Euro 3 - 98/69/EC Stage2000	0,44
TOTAL		1

Tons of Emissions per vehicle and per kilometre, $\hat{G}$. For the calculation of the costs of the emissions, the estimate of the mass of the gassy emissions is required previously, caused by the combustion of the fuel of the vehicles of the urban distribution of goods. For the estimate of the emitted gases, the calculation program (Gkatzoflias *et al*. 2007), is taken as a base, which adopts the updating of the methodology of (Hickman *et al*. 1999) for it, and that requires the following data:

Delivery speed. To define the delivery speed it is necessary to be able to calculate the tons per vehicle and per kilometre for each type of vehicle and gas. The delivery speed is different in each city and the emissions depend on it. The delivery speed is the speed the commercial vehicles of urban distribution circulate. This speed depends on the coordination of traffic lights, on the effective legislation about maximum speeds and road security, on factors related to the existent environment (existence of areas of C/D, parking rails, bus lanes, etc.) and on the flow of circulation of vehicles. According to (Robusté, Galván 2005) the speed of delivery of the urban distribution of goods can approach up to the 70% of the average speed of circulation, so the delivery speed is approximately 25 km/h in Barcelona. This value will be used to estimate the emissions in Barcelona with the program (Gkatzoflias *et al*. 2007).

The execution of the program (Gkatzoflias *et al*. 2007), provides the necessary data to obtain the matrix of the unitary emissions, shown in the Table 2.

Table 2. Tons of emissions per vehicle and per kilometre, 25 km/h

Type of Fuel and Vehicle	Clasification Euro	$\hat{G}$, Tons/(vehicle·kilometre)			
		VOC	NOx	PM 2,5	CO2
Gasoline <3,5t	Conventional	3,69E-06	2,22E-06	2,07E-08	1,00E-04
Gasoline <3,5t	LD Euro 1 - 93/59/EEC	5,85E-07	5,40E-07	2,07E-08	1,15E-04
Gasoline <3,5t	LD Euro 2 - 96/69/EEC	2,35E-07	2,16E-07	2,07E-08	1,15E-04
Gasoline <3,5t	LD Euro 3 - 98/69/EC Stage2000	1,48E-07	1,28E-07	1,88E-08	1,15E-04
Diesel <3,5 t	Conventional	1,68E-07	2,83E-06	2,78E-07	8,83E-05
Diesel <3,5 t	LD Euro 1 - 93/59/EEC	1,67E-07	1,45E-06	1,12E-07	8,03E-05
Diesel <3,5 t	LD Euro 2 - 96/69/EEC	1,67E-07	1,45E-06	1,12E-07	8,03E-05
Diesel <3,5 t	LD Euro 3 - 98/69/EC Stage2000	1,09E-07	1,20E-06	8,66E-08	8,03E-05

Unitary cost per ton of emission, $\overline{H}$. The unitary costs per ton of emission considered in this article are those referred to the sanitary emission costs (CSES), to the emission costs for climatic change (CSEC) and to the emission costs for material damages (CSEM).

$$\overline{Htotal} = \overline{Hs} + \overline{Hc} + \overline{Hm} \qquad [€/ton] \tag{3}$$

$\overline{\text{Hs}}$: The unitary costs per ton of the emission for the sanitary emission costs have been valued according to the study (Bickel *et al*. 1997). The main variation in the unitary costs of emission in the city is the factor of the increase due to the increase of the affectation of the particles PM 2,5 in urban environments. In this case a factor of 7'5 has been considered for the case of Barcelona (the urban base cost is 33.000 €/ton which should be multiplied by 7,5 for the particles PM 2,5). The damages caused by PM 2.5 are dominant regarding to the rest of emissions, coinciding with (McCubbinand, Delucchi 1999). In (Delucchi 2000) is defended the hypothesis that the functions of sanitary costs spread to overestimate the sanitary costs, so the values here presented can be overestimating the real sanitary costs.

$\overline{Hc}$: The cost of the climatic change is calculated starting from the emissions of CO2 which are spilled to the atmosphere. A certain importance is also given to the emissions of other gases which have a smaller effect in the emission of the greenhouse gases, as the case of the methane (CH4) and the Oxide of Nitrogen (N2O). To facilitate the accounting of this cost we will appeal to the study of Montreal (Gourvil, Joubert 2004) en el que se propone una correlación entre el coste de las emisiones de CO_2 y los costes de las emisiones de CH_4 y N_2O. in the one which intends a correlation among the cost of the emissions of CO2 and the costs of the emissions of CH4 and N2O. The values which are given to these emissions usually come from the derived agreements of the Kyoto Protocol. The values usually have an inferior limit to 20 €/ton which contemplate the demands to short term defined in the Kyoto Protocol, and a superior limit of 140 €/ton which takes into account in the long term the objective of reducing the emissions of the transport in 50%. In the case of defining the current congestion of Barcelona, the value which takes is equal to a value of 140 €/ton, since it is the value used in other studies of the Metropolitan Area of Barcelona. The cost of €/ton is applied to the tons of CO2 which overcome the threshold settled down by the Kyoto Protocol. This threshold is variable for each country, and variations can even exist in studies in the same country depending on the increments regarding the base year (1990) which are taken into account. In this document will be applied 24% of increase (Cañas, Garriga & Gili 2006) regarding the base year to calculate the threshold emissions in the city of Barcelona. This is equal, in the case of Catalonia and considering the emissions of all the systems of transport, that the spare tons are 27% of the total of the emissions.

$\overline{Hm}$: The gases emitted by the combustion of the vehicle cause damages on the buildings. The model (Holland *et al*. 2005) proposes costs for the case of Spain which are the ones used in this article.

Table 3. Costs per ton of emission H, in €/ton.

Emisión	$\overline{\boldsymbol{Hs}}^{T}$, Sanitary	$\overline{\boldsymbol{Hc}}^{T}$, Climatic	$\overline{\boldsymbol{Hm}}^{T}$, Material	$\overline{\boldsymbol{Htotal}}^{T}$, Total
VOC	880	0	203	1.083
NOx	4.700	0	150	4.850
PM 2,5	247.500	0	0	247.500
CO2	0	140	0	140

Sanitary costs of emissions, CSES. The Sanitary Costs of emissions (CSES) are calculated starting from the vector of proportions $\overline{P}$ (Table 1), from the matrix $\widehat{G}$ (Table 2), and from the vector of unitary cost per ton of emission for the costs of sanitary emission $\overline{Hs}^{T}$ (Table 3). The result is synthesized in the values of the Table 4 which have the meaning exposed in the Fig. 1 of this article.

$$CSES = 25{,}8 * 10^{-3} \quad €/(vehicle * kilometre) \tag{4}$$

Costs of emissions for climatic change, CSEC. The Sanitary Costs of emissions (CSES) are calculated starting from the vector of proportions $\bar{P}$ (Table 1), from the matrix $\hat{G}$ (Table 2), and from the vector of unitary cost per ton of emission for the emission costs for climatic change $\overline{Hc}^{T}$ (Table 3).

$$CSEC = 12{,}7 * 10^{-3} \quad €/(vehicle * kilometre) \tag{5}$$

Costs of emissions for material damages, CSEM. The Costs of Emissions for Material Damages (CSEM) are calculated starting from the vector of proportions $\bar{P}$ Table 1), from the matrix $\hat{G}$ (Table 2), and from the vector of unitary cost per ton of emission for the emission costs for material damages $\overline{Hm}^{T}$ (Table 3).

$$CSEM = 0{,}21 * 10^{-3} \quad €/(vehícle * kilometre) \tag{6}$$

Summary of costs of emissions, CSE. The Costs of total Emissions (CSE), sum of the sanitary costs of emissions (CSE), the costs of the emissions of climatic change (CSEC) and the costs of the emissions for material damages (CSED), are calculated starting from the vector of proportions $\overline{P}$ (Table 1), from the matrix $\widehat{G}$ (Tabla 2), (Table 2), and from the vector of unitary cost per ton of emission for the costs of total emission $\overline{H}^{T}$ (Table 3). The result is synthesized in the values of the Table 4 which have the meaning exposed in the Fig. 1 of this article.

Table 4. Costs of total emissions in €/(vehicle·kilometre).

Type of fuel and vehicle	Clasification Euro	€/(vehicle*kilometre)				
		VOC	NOx	PM2,5	CO2	TOTAL
Gasoline <3,5t	Conventional	4,00E-03	1,08E-02	5,12E-03	1,40E-02	3,39E-02
Gasoline <3,5t	LD Euro 1 - 93/59/EEC	6,34E-04	2,62E-03	5,12E-03	1,61E-02	2,45E-02
Gasoline <3,5t	LD Euro 2 - 96/69/EEC	2,55E-04	1,05E-03	5,12E-03	1,61E-02	2,25E-02
Gasoline <3,5t	LD Euro 3 - 98/69/EC Stage2000	1,60E-04	6,21E-04	4,65E-03	1,61E-02	2,15E-02
Diesel <3,5 t	Conventional	1,82E-04	1,37E-02	6,88E-02	1,24E-02	9,51E-02
Diesel <3,5 t	LD Euro 1 - 93/59/EEC	1,81E-04	7,03E-03	2,77E-02	1,12E-02	4,62E-02
Diesel <3,5 t	LD Euro 2 - 96/69/EEC	1,81E-04	7,03E-03	2,77E-02	1,12E-02	4,62E-02
Diesel <3,5 t	LD Euro 3 - 98/69/EC Stage2000	1,18E-04	5,82E-03	2,14E-02	1,12E-02	3,86E-02
TOTAL		2,44E-04	5,26E-03	2,04E-02	1,27E-02	3,85E-02

The costs of emissions, removed for each one of the types of the studied costs, are summarized in the following expression:

$$CSE = CSES + CSEC + CSEM = 25{,}8 * 10^{-3} + 12{,}66 * 10^{-3} + 0{,}21 * 10^{-3} = \\ = 38{,}63 * 10^{-3} \quad €/(vehicle * kilometre) \tag{7}$$

3.2. Cost of noise, CSN

The cost of noise is calculated starting from the flooring cost, with noise redactor pavement, in those streets with a daily average intensity superior to 10.000 vehicles/day, considering that in these streets the action to reduce the noise is obligatory, due to the high sound level which is generated in them. This methodology is different to the one used in (Mayeres 1996) and (Sen, Tiwari & Upadhyay 2010), based on the estimate of decibels and the cost by depreciation of the housing and which is the most habitual for the estimate of the cost of noise.

Following the above-mentioned, the cost of noise has been obtained starting from the study (Saurí, Almoguera & Canudas 2005), which refers to the Metropolitan Region of Barcelona, understanding the count city and the municipalities which surround it. According to this study, the cost of noise is 6,6 €/(vehícle*kilometre) for the Metropolitan Region of Barcelona. A corrective factor is applied to this value which represents the biggest affectation which the noise has in the city of Barcelona, because a bigger vehicle·kilometre proportion exists circulating in streets with a lot of intensity, in nearby places to focuses of affectation (residents).

$$CSN = 6{,}6 * 10^{-3} * f \quad €/(vehicle * kilometre) \tag{8}$$

$$f = \frac{\frac{(km\ ADT > 10000\ \ Barcelona\ city)}{(km\ ADT > 10000\ Barcelona\ province)}}{\frac{(veh * km\ \ \ Barcelona\ city)}{(veh * km\ Barcelona\ province)}} = \frac{0{,}287}{0{,}206} = 1{,}39 \tag{9}$$

$$CSN = 9{,}18 * 10^{-3} \quad €/(vehicle * kilometre) \tag{10}$$

3.3. Cost of congestion, CSC

The document has been used (Campos 2008), as a basis for the estimate of the costs of the congestion of the vehicles of goods in the city of Barcelona. Other reference articles for these costs are (Mayeres 1996, Ozbay *et al*. 2007, Sen, Tiwari & Upadhyay 2010). The congestion costs include several associate costs which are the costs of time, the costs of noise, the operational costs (fuel and maintenance) and the environmental costs. The unitary costs have been calculated keeping in mind that the number of kilometres travelled in Barcelona by the fleet of vehicles of distribution of goods during one year is 496 million kilometres. The quantification of these costs is exposed in the Table 5.

Table 5. Costs of Congestion in the city of Barcelona of vehicles of goods

COSTS		Cost (in €)	Breaking down sharing out	Total percentage	Unitary Cost
Costs of Time	Costs of users	41.064.575	44,06%	86,90%	8,28E-02
	Costs of goods	912.529	0,98%		1,84E-03
	Costs of workers	6.190.228	6,64%		1,25E-02
	Costs of the passengers of TP	32.832.735	35,22%		6,62E-02
Costs of noise	Costs of nuisance via users	503.423	0,54%	0,91%	1,01E-03
	Cost depreciation housing	347.395	0,37%		7,00E-04
Cost of fuel		1.540.847		5,74%	3,11E-03
Costs of maintenance	Lubricant cost,	788.767	0,85%	2,82%	1,59E-03
	Pneumatic costs,	516.737	0,55%		1,04E-03
	Costs of repairs,	1.325.460	1,42%		2,67E-03
Environmental costs	Costs of health	1.160.034	1,24%	3,63%	2,34E-03
	Cost of material	1.971.251	2,11%		3,97E-03
	Cost of Climatic Change	247.725	0,27%		4,99E-04
TOTAL	Cost of congestion	93.210.001	100%		1,88E-01

$$CSC = 188 * 10^{-3} \quad €/vehícle * kilometre \qquad (11)$$

3.4. Cost of accidents, CSA

The cost of accidents has been calculated starting from the data of the accidents offered by (Anonymous2009) where the number of annual accidents is quantified. The data which have been extracted correspond to the year 2008, because more up-to-date data are not available. According to this study, in Barcelona there are 31 deaths by accident a year, and 10.913 injured a year, 2,03% corresponding to the vehicles of goods. On the other hand, the study (Anonymous2003) has been used to estimate the costs for each accident. In short, 742.740 € is considered for each dead, and 13.750 € for each injured. The article (Ozbay *et al*. 2007) offers functions of stockings and marginal cost for the accidents. Starting from the obtained data, and keeping in mind that the number of kilometres travelled by the fleet of vehicles of distribution of goods during one year is 496 million kilometres, it is considered the unitary cost for accident as the sum of the cost due to the deceased (CSAM) and to those injured (CSAL):

$$CSA = CSAM + CSAL = 9{,}42 * 10^{-4} * 6{,}14 * 10^{-3} = \qquad (12)$$
$$= 7{,}08 * 10^{-3} \quad €/(vehicle * kilometre)$$

4. Value obtained for the constants of the model

The quantitative estimate of the social costs, allows us, at this point, to present the values of the constants of the model, and the values for CUS, considering $F = (50\ km.of\ route/\ 4\ pallets) = 12{,}5$, which is at the present time a habitual value in the DUM in the city of Barcelona. The results are expressed in the Table 6.

Table 6. Value of the constants of the model

Constant	Cost	Subcost	Constants €/veh·kilometre	€/pallet	Percentage
D €/(vehicle·km)		CSES	25,8*10-3		
		CSEC	12,66*10-3		
		CSEM	0,21*10-3		
	Emission CSE		38,63*10-3	0,48	15,83%
	Noise CSN		9,19*10-3	0,11	3,67%
	Accidents CSA		7,08*10-3	0,09	2,80%
	Congestion CSC		187,50*10-3	2,34	77,32%
	Total		242,40*10-3	3,03	100,00%

$$CUS = 3{,}03 \quad €/pallet \qquad (13)$$

5. Sensitivity of the model of social costs

5.1. The operative distance, F

The operative distance is an independent variable of the model which represents the effectiveness in the allotment of pallets of goods in the city, by means of smooth transport. The model depends lineally on the operative distance F. The expression of the model considering that the rest of parameters is constant, is:

$$CUS = 242 * 10^{-3} * F \quad [€/pallet] \tag{14}$$

The breakdown of F, allows evaluating other accounts. The model depends lineally on the vehicles·kilometre:

$$CUS = K_{VKM} * VKM \quad [€/pallet]; \; VKM = vehicle * kilometre, \tag{15}$$
$$K_{VKM} = 0{,}061 \quad €/(VKM * pallet)$$

The model depends hyperbolically on the number of pallets transported in each route:

$$CUS = K_P / K_{VKM} \quad [€/pallet], \qquad K_P = 12{,}12 \quad € \tag{16}$$

5.2. Relative delay, D_{VKM}

The relative delay is the quotient among the accumulated hours of delay and the kilometres travelled by the vehicles of goods, both in delay and without it. The congestion cost depends almost lineally on this parameter, in the following way:

$$CSC = K_H * D_{VKM} \quad [€/pallet], \; K_H = 9{,}91 \quad €/hour, \tag{17}$$
$$D_{VKM} = 0{,}188 \quad (delay\ hours)/kilometre$$

Therefore, the model depends lineally on D_{VKM}. The expression of the model considering that the rest of parameters are constant, is:

$$CUS = K_D^0 + K_D^1 * D_{VKM} \quad [€/pallet] \tag{18}$$
$$K_D^0 = 0{,}69 \; €/palet \;\; ; \;\; K_D^1 = 123{,}88 \quad (€ * VKM)/(hour * pallet)$$

The constant K_D^0 the cost in €/pallet without having congestion in the city.

5.3. Vehicle type, $\boldsymbol{C_{vi}}$, λ

The typology of the vehicle influences lineally in the model. ConcretelyC_{vi}, q that is the component i-ésima of the column vector $\overline{Cv}$, and therefore, the average unitary cost for the type ivehicle type i, affects lineally to the model:

$$CUS = K_{Cv}^{0} + K_{Cv}^{1} * C_{vi} \quad [€/pallet] \tag{19}$$

$$K_{Cv}^{0} = \left(\sum_{\forall j \neq i} \left(P_j * C_{vj}\right) + CSN * CSA + CSC \right) * F \quad [€/pallet]$$

$$K_{Cv}^{1} = P_i * F \quad [VKM/pallet]$$

The constants cannot be determined numerically because they vary depending on the chosen C_{vi} component. As an example for the type of diesel vehicle <3.5 T, LD Euro 3 - 98/69/EC Stage2000, the values of the constants are $\mathrm{K_{Cv}^{0}} = 0{,}0022$ €/pallet y $\mathrm{K_{Cv}^{1}} = 0{,}44$ VKM/pallet.

The CSE is lineal regarding the quotient among proportions of the same type i vehicle. This quotient is denominated $\lambda = Pi_{new}/Pi_{old}$, where Pi is the proportion as long as for one of the type vehicle i by which is wanted to vary the proportion:

$$CSE = \lambda * P_i * C_{vi} + \theta * \textstyle\sum_{\forall j \neq i}\left(P_j * C_{vj}\right) \quad [€/VKM],\ \theta = Pj_{new}/Pj_{old} \tag{20}$$

We want the sum of the proportions of all the vehicles to be similar to 1, and the variation of P_j to be the same one $\forall\, j \neq i$, so:

$$\lambda * P_i + \theta * (1 - P_i) = 1 \tag{21}$$

Keeping in mind the above-mentioned, the model depends lineally λ the following expression:

$$CUS = K_{\lambda}^{1} * \lambda + K_{\lambda}^{0} \tag{22}$$

$$K_{\lambda}^{1} = F * \left(P_i * C_{vi} - \frac{P_i}{1 - P_i} * \sum_{\forall j \neq i} \left(P_j * C_{vj}\right) \right)$$

$$K_{\lambda}^{0} = F * \left[(P_i/(1 - P_i)) * \left(\sum_{\forall j \neq i} \left(P_j * C_{vj}\right) \right) + CSN + CSA + CSC \right]$$

As an example for the type of diesel vehicle <3.5 T, LD Euro 3 - 98/69/EC Stage2000, the values of the constants are $\mathrm{K_{\lambda}^{0}} = 0{,}03848$ €/pallet y $\mathrm{K_{\lambda}^{1}} = 0{,}000056$ €/pallet .

6. Conclusion

By means of the carried out study and taken in this article, the formulation of a simple model of social costs has been achieved, and allows us to understand the reality of the operation of the urban distribution of goods, and to quantify the social costs of the DUM, so the initial objective of the study has been achieved.

The social costs can be considered social in a separate way, for example, the costs of emissions, to confront their optimization in an individualized way, or to know the weight of the individual cost in the total cost. All of it convey a knowledge, both global and specific, of the social costs of the DUM, and allows us to look for general solutions of improvement of all the costs, as a specific cost. Of the analysis of this article it is concluded:

The parameters which more affect to the social cost are those of operative distance F, the relative delay D_{VKM} , and the delivery speed V.

The good delivery speed to reduce the costs of emissions is 63 km/h.

The most important cost is that of congestion (77,3%) followed by the costs of emissions (15,8%). The cost of time supposes 87% of the congestion cost, and therefore, 67% of the total costs.

The most expensive gas in the city is the PM 2,5 with 53% of the CSE. Due to it it, the diesel vehicles are not advisable in the city due to the high emission of PM2.5, but yes outside, because they emit less tons of the other noxious gases.

References

[1] Dades Mobilitat. *2009, Ajuntament de Barcelona.* Barcelona; 2008.
[2] La seguridad del transporte en España. RACE, España; 2003.
[3] Bickel P, Schmid S, Krewitt M, Friedrich R. *External costs of transport in externe.* The European Comission; 1997.
[4] Campos JM. *La congestión del tráfico en áreas metropolitanas.* Ministerio de Fomento, Madrid; 2008.
[5] Cañas J, Garriga J, Gili I. Polítiques públiques - Post-Kyoto i les polítiques de la Generalitat de Catalunya. Departament de Medi Ambient i Habitatge, Generalitat de Catalunya, Catalunya; 2006.
[6] Dablanc L. *Transportation Research Part A: Policy and Practice* 2007; 41(3): 280-285.
[7] Dablanc L. Freight transport, a key element of the urban economy. Guidelines for practitionners. *Transportation Research Board's 89th Meeting* 2010, 0977.
[8] Delucchi MA. Environmental externalities of motor vehicles use in the US. *Journal of Transport Economics & Policy* 2000; 34(2): 135-168.
[9] Eisele WL, Schrank DL. *Transportation Research Board's 89th Meeting* 2010; 2654.
[10] Gkatzoflias D, Kouridis C, Ntziachristos L, Samaras Z. Computer programme to calculate emissions from road transport, *COPERT IV* 2007.
[11] Gourvil L, Joubert F. *Évaluation de la congestion routière dans la région de Montréal*. Ministère des Transports, Canadá; 2004.
[12] Hickman J, Hassel D, Joumard R, Samaras Z, Sorenson S. *Methodology for calculating transport emissions and energy consumption, Deliverable 22 for the project MEET.* Transport Research Laboratory, European Comissión/DG VII, England; 1999.
[13] Holland M, Pye S, Watkiss P, Droste-Franke B, Bickel P. Damages per tonne emission of PM2.5, NH3, SO2, NOx and VOCs from each EU25 Member State (excluding Cyprus) and surrounding seas. Clean Air for Europe Programme (CAFE); 2005.
[14] Mayeres I. The marginal external costs of urban transport. *Transportation Research Part D: Transport and Environment* 1996; 1(2): 111-130.
[15] McCubbinand DR, Delucchi MA. The health cost of motor vehicles related air pollution. *Journal of Transport Economics & Policy* 1999; 33(3): 287-301.
[16] Ogden K. *Urban goods movement: A guide to policy and planning.* Cambridge University Press, Ashgate; 1992.
[17] Ozbay K, Bartin B, Yanmaz-Tuzel O, Berechman J. Alternative methods for estimating full marginal costs of highway transportation. *Transportation Research Part A: Policy and Practice* 2007; 41(8): 768-786.

[18] Parry IWH, Small, KA. Does Britain or the United States have the right gasoline tax? *The American Economic Review* 2005; 95(4): 1276-1289.
[19] Perez Martínez PJ. Freight Transport, Energy Use and Emission Trends in Spain. *Transportation Research Board's 89th Meeting* 2010, 307.
[20] Robusté F, Galván D. *e-logistics*. Edicions UPC; 2005.
[21] Saurí S, Almoguera JM, Canudas J. *Costos socials i ambientals del transport a la RMB*, 2005.
[22] Sen AK, Tiwari G, Upadhyay V. Estimating marginal external costs of transport in Delhi. *Transport Policy* 2010; 17(1): 27-37.
[23] Taniguchi E, Thompson RG. *Recent advances in city logistics: Proceedings of the 4th International Conference on City Logistics.* Elsevier, Amsterdam; 2006.