ELSEVIER
Available online at www.sciencedirect.com
ScienceDirect
Procedia Social and Behavioral Sciences 2 (2010) 6165–6176
Procedia Social and Behavioral Sciences

The Sixth International Conference on City Logistics

How efficient is city logistics? Estimating ecological footprints for urban freight deliveries

Jesús Muñuzuri[a*], J.H.R. van Duin[b], Alejandro Escudero[a]

[a]*University of Seville, Camino de los Descubrimientos, s/n, Seville, 41092, Spain*
[b]*Delft University of Technology, Jaffalaan 5, Delft 2628 BX, The Netherlands*

Abstract

In medium and large cities, the delivery of goods represents a significant contribution to the problems of congestion, lack of parking, pollution and energy consumption. The characteristics of this type of transport are also very different from passenger mobility, even though they are often assimilated, due to the lack of specific tools for estimation and analysis, and also of indicators to evaluate improvements in the systems of urban goods distribution. In this work, we start by developing a systematic model to estimate the transport of goods in a city, according to the particularities of its supply and demand. This model can then be used to determine with a high level of detail the contribution of the delivery of goods to the ecological footprint of the city, thus proposed as the key indicator of the efficiency of this type of transport. The work is applied to the city of Seville, in Spain.

Keywords: City logistics; ecological footprint; modelling

1. Introduction: The Ecological Footprint

Every quantitative analysis of urban freight deliveries is somehow linked to the need to evaluate the negative effects involved in this activity sector, which is at the same time essential for the sustainability of economic activity in the city. And this macro-level evaluation, as well as the decision-making involved, is carried out by quantifying the appropriate indicators, which allow different cities to be compared, estimate the needs in terms of infrastructure or policies, and evaluate the effectiveness of the infrastructure or policies that were introduced in the past (Gahin, 2003; Rydin, 2003). To this effect, there many indicators exist that can be used to quantify urban goods transport (vehicles•km, tons transported, tons of CO2 emitted, etc.), but the most appropriate one from the point of view of sustainability, and in order to compare urban goods deliveries with other types of transport, and to compare different cities, is the ecological footprint.

The ecological footprint is a concept introduced by Rees (1992) and later developed by Wackernagel (1998) and Simmons (1998). It allows the degree of sustainability associated to very different concepts to be compared, by

* Corresponding author. Tel.: +34-95-448-7205; fax: +34-95-448-7248.
E-mail address: munuzuri@esi.us.es.

1877-0428
doi:10.1016/j.sbspro.2010.04.028

computing the land surface required to produce the resources (energy, raw materials, etc.) needed for the corresponding activity. It is therefore possible to compare the consumption of energy related to different types of urban transport, or urban with interurban transport, or with other types of human activities. Also, since the calculation procedure is standard, it is useful to compare the efficiency of different systems or procedures to perform the same activity in different places, even though Aall (2005) stresses the need to take into account local particularities when calculating ecological footprints. Finally, it is also an indicator focused on sustainability, with an activity being more sustainable if it generates a lower ecological footprint.

The relatively simple concept of ecological footprint and its easy calculation procedure on a general level have turned this indicator into a very popular one. Thus it used by many political and ecological organisations. Its calculations were initially applied to overall cities (Wackernagel, 1998), comparing this footprint with the biological capacity available for human consumption and determining ecological debts. This initial work also established the calculation procedure, identifying the types of activities that should be included, with urban transport occupying a preeminent position. Barrett (2003) and Muñiz (2005) have presented works related to the ecological footprint of urban transport, even though they are focused entirely on passenger transport. The work by Holden (2004), focused on the influence of residential land use over the ecological footprint of urban transport, could provide a basis to analyse the influence of the location of commercial activities, both shippers and receivers of goods, over the overall ecological footprint of urban goods deliveries.

The calculation procedure for estimating ecological footprints has recently been refined, detailing in more depth the contribution of different specific types of activities (Wood, 2003). However, the contribution of urban goods deliveries to the overall ecological footprint of the city has not been detailed, establishing a specific calculation procedure and differentiating it in terms of sustainability and energy consumption from public and private passenger transport.

2. Urban Freight Modelling

The calculation of the ecological footprint for urban freight deliveries depends on detailed knowledge of freight vehicle flows. This is where this ecological footprint reveals itself as a much more complex calculation than passenger transport, due to the complexity of the processes involved in urban freight deliveries (Dablanc, 2007). While passenger mobility, whether in private cars or on public transport, corresponds to a great extent to a simple daily patterns of home-work-home trips, freight vehicle flows normally have a much more complicated distribution, with multiple stops in different parts of the city, different routes for different days and multiple commercial or supply-chain-related considerations involved.

As in any complex scenario, quantitative models represent a powerful tool to define the pattern of urban logistics. The work proposed here starts with the estimation and validation of an origin-destination matrix for urban freight transport, using the available data sources and following a procedure that is sufficiently simple to make it attractive for local authorities. This process is based on entropy maximisation, which has been widely applied to the estimation of O-D matrices for passenger transport (see, for example, Van Aerde (2003)), but has not been used before to estimate freight vehicle flows in urban areas.

2.1. Delivery surveys

Using previous results which resulted in the estimation of an O-D matrix for urban freight transport during the morning peak-hour (Muñuzuri et al., 2009), and which were tested and validated in the city of Seville, the objective is to derive a demand model which allows the estimation of a similar matrix for the whole day, which will then be used to determine vehicle flows, distances travelled, average speeds and number of stops through simulation. To do so, we analysed in depth four specific areas of the city. For each one of these areas, in order to find out the flow of goods, the demand for goods and their characteristics in terms of arrival times, we completed surveys for traders and transporters, and also counted vehicle flows at different points in the streets of each surveyed area.

The first step in each area was to calculate, for each type of activity, the average travel time between stops, i.e. the time required for a vehicle, after completing a delivery, to reach its next stop on its route. This time was estimated using the data of the distance between consecutive establishments on the route of the vehicle and assuming an average velocity of 10 km/h. (this figure is used by the Municipal Urban Transport Company of Seville to estimate the average speed of the bus fleet). Adding the average load/unload time, we obtained the average delivery time, that is, the average time between the arrivals to two consecutive stops. The average delivery time provides the number of deliveries per hour. Given that the total number of daily operative hours per vehicle was known from the surveys, this in turn allowed us to calculate the daily number of deliveries per vehicle for each type of activity considered in the surveyed areas. We finally expanded the results obtained in the four surveyed areas to the rest of the city, by dividing it into zones and obtaining the number of retail stores in each zone from the Chamber of Commerce of Seville. We thus estimated the number of delivery vehicles entering and leaving each zone on a daily basis.

Figure 1 shows the modelling process, with Table 1 containing the results of one of the four surveys and Table 2 showing the final data used for calculations in the entire city.

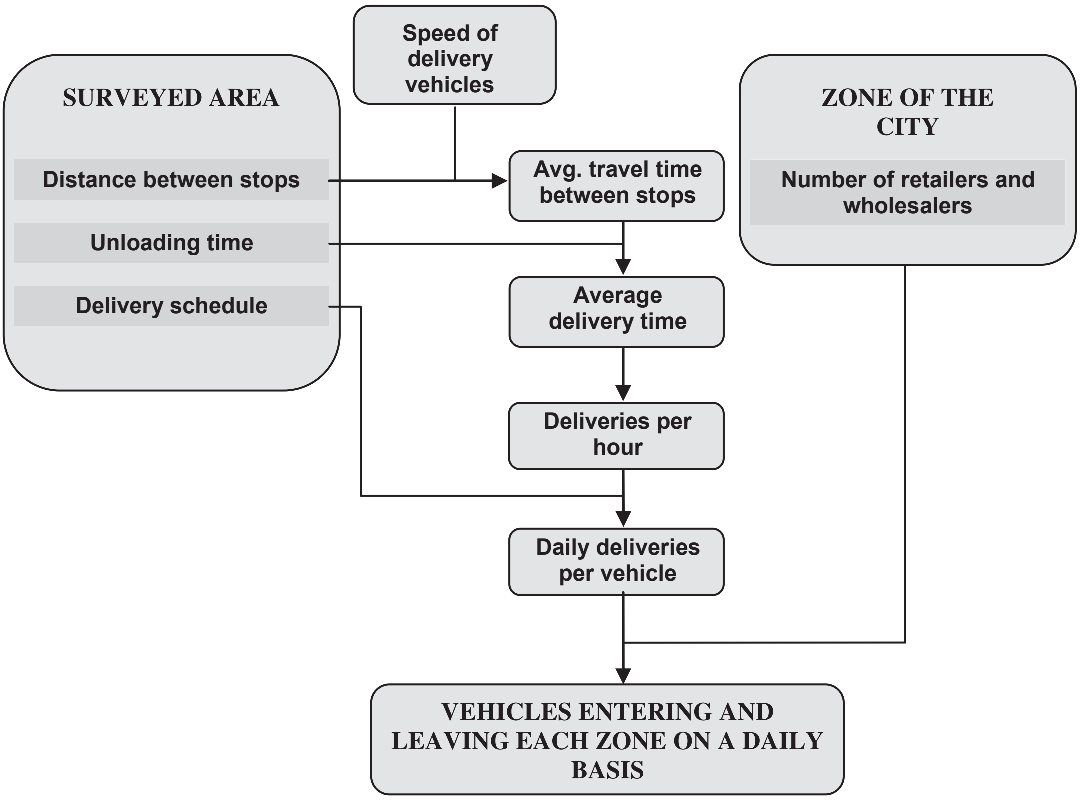

Figure 1 Structure of the data processing process

Table 1 Data collected and processed for one of the surveyed areas in Seville (Reyes Católicos)

Sector	Type of establishment	Average daily deliveries	Number of establishments	Unloading time (min)	Average displacement itme (min)	Total delivery time (min)	Delivery schedule (h)	Deliveries per hour	Type of vehicle used	Daily deliveries per vehicle
1	Pharmacies	2	3	4.0	7.0	11.0	6	5.5	Van	32.7
1	Flowers	1	1	17.5	26.0	43.5	6	1.4	Van	8.3
1	Hair dressers	0.2	1	2.5	23.0	25.5	8	2.4	Van	18.8
1	Perfumes/drugs	0.5	2	10.0	22.0	32.0	6	1.9	Van & truck	11.3
2	Home appliances	1.5	2	6.0	31.0	37.0	8	1.6	Van	13.0
2	Decoration/gifts	0.4	2	17.5	24.0	41.5	8	1.4	Van	11.6
2	Hardware	1	2	20.0	31.0	51.0	8	1.2	Van	9.4
2	Opticians	0.8	2	4.0	25.0	29.0	5	2.1	Van	10.3
2	Multiprice shops	1	1	75.0	7.0	82.0	8	0.7	Van	5.9
2	Telephone shops	1	1	4.0	14.0	18.0	5	3.3	Van	16.7
3	Banks	1	7	1.5	14.0	15.5	5	3.9	Van	19.4
3	Bars/cafeterias	3	13	10.0	3.0	13.0	8	4.6	Van & truck	36.9
3	Training centers	1.5	4	1.5	45.0	46.5	5	1.3	Van	6.5
3	Tobacco shops	0.2	3	2.5	16.0	18.5	8	3.2	Truck	25.9
3	Bakeries/ice cream	3	2	12.5	18.0	30.5	8	2.0	Van	15.7
3	Pizza/burger	0.4	3	25.0	18.0	43.0	8	1.4	Truck	11.2
4	Jewelry	1	5	2.5	36.0	38.5	8	1.6	Van	12.5
4	Toy shops	4	1	33.0	45.0	78.0	8	0.8	Van & truck	6.2
4	Newspaper stalls	4	3	2.5	9.0	11.5	5	5.2	Van	26.1
4	Furniture	0.6	3	45.0	51.0	96.0	8	0.6	Truck	5.0
4	Fur/leather	0.2	2	12.5	66.0	78.5	8	0.8	Van & truck	6.1
4	Gifts/souvenirs	0.2	2	6.0	27.0	33.0	8	1.8	Van	14.5
4	Paintings/art shops	0.6	1	6.0	54.0	60.0	5	1.0	Van & truck	5.0
4	Sports goods	1.5	3	3.5	36.0	39.5	8	1.5	Van	12.2
4	Large clothing shops	1	11	4.0	27.0	31.0	8	1.9	Van & truck	15.5
4	Small clothing shops	0.2	6	7.5	27.0	34.5	8	1.7	Van	13.9
4	Large shoe shops	1	4	5.0	39.0	44.0	8	1.4	Van	10.9
4	Small shoe shops	0.4	5	5.0	39.0	44.0	8	1.4	Van	10.9
5	Small food shops	1	2	20.0	7.0	27.0	5	2.2	van & truck	11.1

Table 2 Final numbers of daily deliveries per vehicle

Sector	Type of activity	No premises	Daily deliveries per vehicle	Sector	Type of activity	No premises	Daily deliveries per vehicle
1	Dietetics	3	13,9	4	Antiques	1	11,2
1	Pharmacies	4	10,9	4	Bathrooms	4	14,1
1	Flower shops	2	13,0	4	Babies	10	7,0
1	Herbal dietetics	1	13,0	4	Bedroom furniture	2	15,9
1	Drugstore	3	16,4	4	Tables and frames	1	7,1
1	Hairdressers	2	9,7	4	Photos	2	13,8
1	Perfumes	4	32,9	4	Eyeglasses	4	12,7
2	Electrical	2	10,3	4	Toys	1	12,4
2	Electronics	4	8,5	4	Kiosks	4	14,4
2	Decoration and Gifts	11	9,0	4	Lingerie shops	4	15,7
2	Cutlery	1	13,3	4	Bookstores	2	6,1
2	Hardware	5	7,5	4	Willow products	2	18,8
2	Machinery	4	8,1	4	Music	2	8,8
2	Mobile telephones	2	10,3	4	Stationery	2	12,4
2	Furniture	6	23,6	4	Furs and leather	2	11,2
2	Opticians	2	30,7	4	Gifts / souvenirs	2	14,5
2	Orthopedics	1	11,7	4	Watchmakers	3	9,0
2	Multiprice Stores	1	9,5	4	Couriers	1	30,0
3	Food	12	18,5	4	Textile boutiques	11	15,8
3	Banks	6	10,0	4	Textile shops	13	15,4
3	Bars / cafes	13	16,2	4	Art shops	1	5,0
3	Bingos	1	12,2	4	Dry Cleaning	1	13,3
3	Tobacco shops	3	7,0	4	Shoes	8	15,5
3	Hotels	1	23,9	5	Fresh product markets	10	11,1
3	Bakeries / ice cream	2	13,1				
3	Small food shops	3	13,3				
3	Pizza / burger	3	9,9				

2.2. O-D data estimation

We used previous data to estimate origin-destination data for freight vehicles in the city, by dividing it into zones and assuming that the number of vehicles daily entering and leaving each zone is composed of four flows, as shown in Figure 2.

Each zone of the city is both an origin and destination of trips throughout the day. The freight vehicle flows leaving a zone is subdivided into:

- A: the number of vehicles departing from that area at the beginning of the day
- B: the number of vehicles entering the zone to distribute goods and then continue their route through other zones.

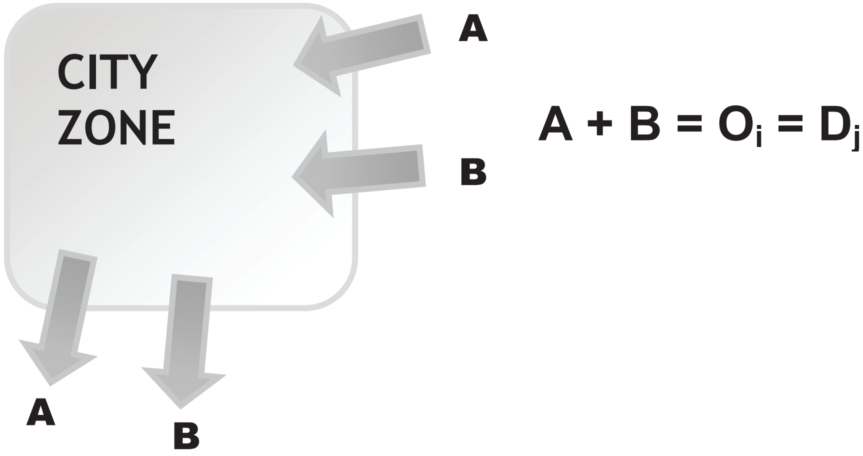

Figure 2 Freight vehicle flows entering and leaving each zone of the city

Equally, with respect to the incoming flow, it also corresponds to vehicles returning to the zone where their depot is (A) and those that enter the zone as an intermediate destination in their routes (B). As suggested by Figure 2, we assumed that the input and output stream match. This assumption is reasonably practicable, since vehicles that leave the zone in the early hours to make deliveries to other areas must return to their depot to start again the next day, while passing traffic must enter and then leave the zone. We estimated flows A and B as follows:

Flow B: the number of vehicles passing through zone *j* in their route is evaluated taking into account the number of retailers of each type *k* in the zone (t_j^k) and the number of daily deliveries per vehicle for that type of retailer (e_j^k) (see Table 2).

$$B_j^k = \sum_j \left(\frac{t_j^k}{e_j^k} \right) \tag{1}$$

Flow A: the number of vehicles departing from each zone to begin their route is estimated as the number of vehicles generated during peak hours, obtained from Muñuzuri (2009). These values were given by the expression:

$$A_i^k = \frac{O^k \, o_i^k}{\sum_i o_i^k} \tag{2}$$

Where:

A_i^k is the number of freight vehicles of sector *k* which have their origin in zone *i*.

O^k is the total number of vehicles for sector *k*.

o_i^k is the number of wholesalers of sector *k* located in zone *i*.

Finally, the number of origins and destinations in each zone is calculated by adding both flows A and B:

$$O_i^k = D_j^k = A_i^k + B_j^k = \sum_j \left(\frac{t_j^k}{e_j^k} \right) + \frac{O^k o_i^k}{\sum_i \sum_k o_i^k} \tag{3}$$

With respect to home deliveries, the average number of vehicles used is roughly one per retailer (Muñuzuri, 2009), and the number of trips with origin (O_i) and destination (D_i) in each zone i can be calculated as a weighted average depending on the population of each zone, as follows:

$$O_i = \frac{N_d R_i}{\sum_i R_i} \text{ and } D_i = \frac{N_d P_i}{\sum_i P_i} \tag{4}$$

Where:
P_i is the population in zone i.
R_i is the number of retailers doing home deliveries in zone i, that is, those dealing with home appliances (sector 2), office appliances (sector 2), doors, windows and blinds (sector 2), food shops (sector 3) and furniture retailers (sector 4).
N_d is the average number of vehicles used daily for home deliveries.

In this case, we used this data to calculate the total number of deliveries at home throughout the day across the city. This number was divided into the zones of the city in proportion to their population. We then assumed that each vehicle makes as many home deliveries per day as delivery vehicles do to the retail sector for that type of establishment.

2.3. O-D matrix calculation and macroscopic simulation

The input data for entropy maximisation uses the number of trips originating and terminating in each zone as inputs, and it calculates the elements of the matrix by maximising entropy or 'disorder', that is, by finding trips patterns that are as distributed as possible along the matrix. In the case of urban deliveries this approach is preferable to a gravity model, where interactions between close zones are favoured. In city logistics, the organisation of delivery tours is due to commercial considerations, like customer locations or time windows, rather than on proximity. The formulation of the entropy-maximisation model used here is similar to the one proposed by De la Barra (1989), without the final cost restriction introduced by these authors, which is difficult to calibrate and has less justification in the case of urban freight transport, where delivery routes are less constrained in terms of length and duration than passenger commuting.

The entropy maximisation model is then written as follows:

$$Max \qquad W^k = \frac{\left(\sum_i \sum_j T_{ij}^k\right)!}{\prod_{ij}\left(T_{ij}^k !\right)} \tag{5}$$

$$st \qquad \sum_j T_{ij}^k = O_i^k \quad \forall i,k \tag{6}$$

$$\sum_i T_{ij}^k = D_j^k \quad \forall j,k \tag{7}$$

$$T_{ij}^k \geq 0 \quad \forall i,j,k \tag{8}$$

Where the objective function may be replaced (see Muñuzuri et al., 2009) by:

$$-Min \sum_i \sum_j (T_{ij}^k \log T_{ij}^k - T_{ij}^k) \tag{9}$$

In the application to Seville, we used this approach to estimate six origin-destination matrices (one for each activity sector and an additional one for home deliveries). Once the six origin-destination matrices were estimated, the tool used for determining freight vehicle flows around the city was the commercial package EMME/2®, which performs equilibrium assignments (traffic flow calculations) using an urban network divided in zones and an origin-destination matrix. A matrix for passenger automobile traffic was already available, and the six matrices for freight vehicles were added to obtain the overall freight transportation origin-destination matrix for the city.

A joint assignment for passenger and delivery vehicles was then carried out using the software. The results obtained from the simulation were passenger automobile traffic and freight vehicle flows for all the links in the street network of the city. Figure 3 shows a detail view corresponding to the surroundings of the Historical Centre, with both private cars and estimated freight vehicle flows depicted on it.

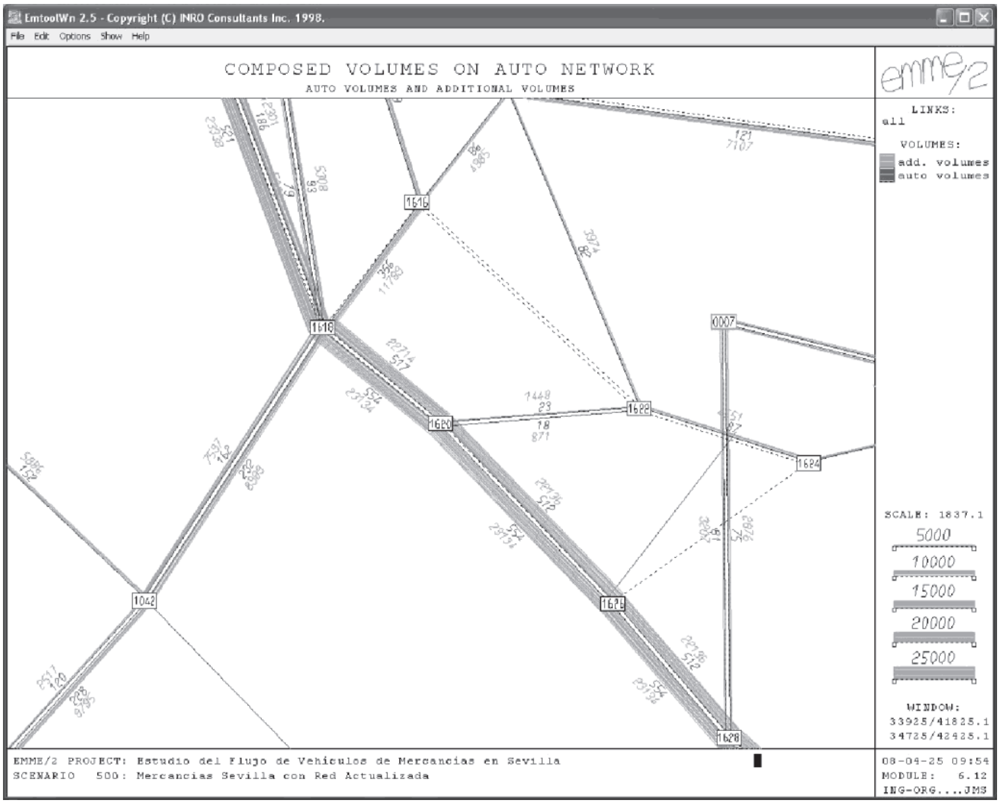

Figure 3 Estimation of private and freight vehicles for Colón St. in Seville

2.4. Validation with traffic count data

We used freight vehicle count data to validate the results obtained from the simulation. All the points that were chosen for validation correspond to first-level streets or avenues where the City Hall has traffic control cameras which allow us to record the flow of vehicles on images. The recordings were made for different 15-minute periods throughout the day, and we used them to estimate the overall daily flows.

Figure 4 shows the 15-minute counts for vans and trucks in one of the validation streets and the corresponding adjusted curves. The estimation of the total daily flow of freight vehicles along the street was then equal to the integral below the curve for the whole day, and was then compared to the results produced by the simulation (see Table 3). There is a certain underestimation in the values produced by the model, which could be due to the fact that the number of daily deliveries per vehicle is in reality lower than assumed, resulting in more vehicles circulating in the city for the same number of deliveries. We nevertheless considered acceptable all deviations below 30% between the counts and the simulation.

Table 3 Validation of the simulation results

Street	Direction	Counts	Simulation	Deviation	Validity
Torneo	Pza. de Armas	649	808	24,50%	Valid
	Barqueta	901	832	-7,66%	Valid
Paseo Colón	Los Remedios	775	554	-28,52%	Valid
	Pza de Armas	865	517	-40,23%	Non Valid
Cachorro	Sevilla	1057	789	-25,35%	Valid
	Triana	829	714	-13,87%	Valid
Luis Morales	S. Fco. Javier	686	546	-20,41%	Valid
	Kansas City	534	375	-29,78%	Valid
Juan Austria	Fuente-Estatua	661	496	-24,96%	Valid
	Estatua-Fuente	819	727	-11,23%	Valid
Macarena	Barqueta	683	485	-28,99%	Valid
	Cruz Roja	525	407	-22,48%	Valid
Kansas City	Santa Justa	677	479	-29,25%	Valid
	Airport	732	228	-68,85%	Non Valid
Bueno Monr.	Inbound	790	678	-14,18%	Valid
	Outbound	583	430	-26,24%	Valid
Ramón Cajal	Inbound	674	331	-50,89%	Non Valid
	Outbound	504	152	-69,84%	Non Valid
La Paz	Inbound	978	1001	2,35%	Valid
	Outbound	605	522	-13,72%	Valid
Las Delicias	Inbound	840	216	-74,29%	Non Valid
	Outbound	668	383	-42,66%	Non Valid
Pta Carmona	Prado S. Sebastián	577	441	-23,57%	Valid

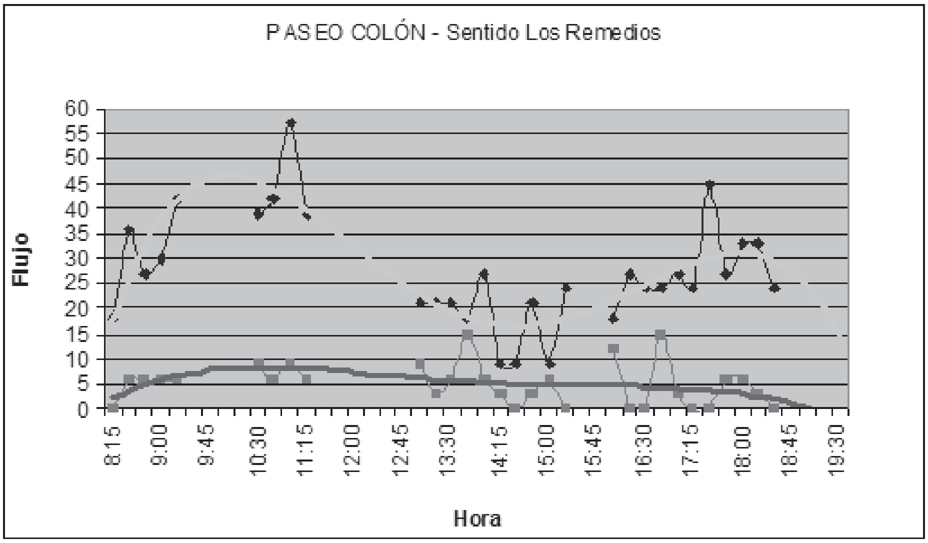

Figure 4 Traffic counts for vans (above) and trucks (below) in a street near the centre of Seville

3. Ecological Footprint Calculations

The final objective of the work was to formulate with a high level of detail the calculation of the ecological footprint related to urban logistics. This calculation stems from the previous modelling characterisation of freight transport flows, as seen in Table 4.

Table 4 Data used for the calculation of the ecological footprint for urban deliveries

Type of data	Data source
Vehicle flows	EMME/2 simulation
Vehicle speeds	EMME/2 simulation
Number of stops	Demand model
Types of vehicles	Surveys

To translate these data into ecological footprint figures, we used the results of previous research work:

- Festa and Mazzulla (2002) estimated empirically the average fuel consumption rate for different types of vehicles, including the large diesel engines of vans and trucks (see Table 5), and
- Rakha et al. (2003) determined the fuel consumption related to the cold start of vehicles, which can be assimilated to the fuel required to start the freight vehicle after each delivery (see Table 6).

Thus, from the simulation we knew the total distance travelled by freight vehicles and their average speeds in the different links of the network. We then calculated the proportion of trucks and vans, and estimated the total fuel consumption corresponding to their displacements. Finally, we were also able to determine the total number of stops for the different types of vehicles (see Table 2), which resulted in additional fuel consumptions due to cold start operations.

Table 5 Fuel consumption rates for different types of vehicles under different types of driving conditions (Festa and Mazzulla, 2002)

Vehicle categories	Displacement	Fuel cons. rate (g/km)	R^2
ECE 15-03	< 1.4 l	$277.71 \cdot V^{-0.7941}$	0.9079
	1.4-2.0 l	$351.48 \cdot V^{-0.8191}$	0.914
	>2.0 l	$539.57 \cdot V^{-0.8450}$	0.9205
ECE 15-04	< 1.4 l	$260.62 \cdot V^{-0.7761}$	0.9020
	1.4-2.0 l	$334.83 \cdot V^{-0.8040}$	0.9104
	>2.0 l	$535.65 \cdot V^{-0.8545}$	0.9213
Catalyst	< 1.4 l	$262.28 \cdot V^{-0.8036}$	0.9117
	1.4-2.0 l	$403.56 \cdot V^{-0.9977}$	0.6062
	>2.0 l	$481.53 \cdot V^{-0.8382}$	0.9199
Diesel	< 1.4 l	$184.29 \cdot V^{-0.7220}$	0.8798
	1.4-2.0 l	$\mathbf{184.29 \cdot V^{-0.7220}}$	0.8798
	>2.0 l	$\mathbf{342.26 \cdot V^{-0.8211}}$	0.9181

The figures in bold were used for estimating fuel consumption for vans and trucks respectively.

Table 6 Additional fuel consumption due to cold start operation (Rakha et al., 2003)

Vehicle Class	Fuel (litters)		Type of vehicle	Average fuel consumption (litres)
LDT1	0.0515	6.6%	Van	0.07
LDT2	0.0887	12.4%		
HE1	0.0932	15.4%	Truck	0.125
HE2	0.1581	18.1%		

The remaining calculations were simple, using the following data:

- the energy equivalent of fuel-oil is 38.6 MJ/l,
- the tonne of oil equivalent (TOE), the amount of energy released by burning one tonne of crude oil, is equal to 41.84 GJ, and
- the ecological footprint of one TOE is 1.7143 Ha.

We obtained a total ecological footprint for freight deliveries in the metropolitan area of Seville equal to 16,427 Ha. Previous research works (Calvo and Sancho, 2001) had estimated a total vehicle-related ecological footprint of 175,000 Ha for the metropolitan area, which means that, according to our calculations, the ecological footprint of urban freight transport is 9.4% of the overall transport-related ecological footprint in metropolitan Seville.

4. Conclusions

The ecological footprint is nowadays the main indicator available to monitor the sustainability of industrial activities. We have shown here that, using the information generated in a macroscopic simulation, it is possible to estimate a value for the ecological footprint of urban freight deliveries that depends on the type of vehicles used, the distances travelled by them, their average speeds and the number of stops they make. Using this formulation it is then possible to analyse urban freight policies not only in terms of their expected influence on costs, but also of their contribution to the sustainability of the urban area.

Still, some further research possibilities are nevertheless open in the future. In the first place, some further work will need to be devoted to O-D matrix estimation, in order to reduce the deviation gaps between the estimated and actual freight vehicle flows, calibrating the model to eliminate the current underestimation of flow figures. The availability of a freight vehicle census is also important, so as to distinguish between different types of vans and trucks, and to take into account their age and condition.

Finally, the importance of this type of analysis lies in the possibility to assess urban freight policies from the point of view of sustainability. This is why another research objective for the future is the comparison of the results obtained in Seville with other similar cities, which would help to validate the methodology and determine to what extent different urban configurations, access policies, routing strategies, etc., represent a significant difference in terms of overall sustainability.

Acknowledgements

The authors wish to acknowledge the financial support of this research by the Spanish Ministry of Science and Technology (Project Mevalum, DPI2008-06476).

References

Aall, C., & Norland, I. T. (2005). The use of the ecological footprint in local politics and administration: results and implications from Norway. *Local Environment*, 10(2), 159 – 172.

Barrett, J., & Scott, A. (2003). The Application of the Ecological Footprint: a case of passenger transport in Merseyside. *Local Environment*, 8(2), 167 – 183.

Calvo, M., & Sancho, F. (2001). Estimación de la huella ecológica en Andalucía y aplicación a la aglomeración urbana de Sevilla. Consejería de Obras Públicas y Transportes, Junta de Andalucía.

Dablanc, L. (2007). Goods transport in large European cities: difficult to organize, difficult to modernize. *Transportation Research A*, 41(3), 280-285.

De la Barra, T. (1989). *Integrated land use and transportation modelling*. Cambridge University Press.

Festa, D. C., & Mazzulla, G. (2002). A new simulation model of fuel consumption and pollutant emissions in urban traffic. In L. J. Sucharov, C. A. Brebbia, & F. Benitez (Eds.), *Urban transport VIII* (pp. 581-592).

Gahin, R., Veleva, V., & Hart, M. (2003). Do indicators help create sustainable communities? *Local Environment*, 8(6), 661–667.

Holden, E. (2004). Ecological footprints and sustainable urban form. *Journal of Housing and the Built Environment*, 19, 91–109.

Muñiz, I., & Galindo, A. (2005). Urban form and the ecological footprint of commuting. The case of Barcelona. *Ecological Economics*, 55, 499–514.

Muñuzuri, J., Cortés, P., Onieva, L., & Guadix, J. (2009). Modeling freight delivery flows: The missing link of urban transport analysis. *Journal of Urban Planning and Development*. In press.

Rakha, H., Ahn, K., & Trani, A. (2003). Microscopic modeling of vehicle start emissions. *TRB 2003*, Annual meeting.

Rees, W. E. (1992). Ecological footprints and appropriated carrying capacity: what urban economics leaves out. *Environment and Urbanization*, 4(2), 121–130.

Rydin, Y., Holman, N., & Wolff, E. (2003). Local sustainability indicators. *Local Environment*, 8(6), 581–591.

Simmons, C., & Chambers, N. (1998). Footprinting UK households: how big is your ecological garden? *Local Environment*, 3(3), 355–362.

Van Aerde, M., Rakha, H., & Paramahamsan, H. (2003). Estimation of origin-destination matrices: Relationship between practical and theoretical considerations. *Transportation Research Record*, 1831, 122-130.

Wackernagel, M. (1998). The ecological footprint of Santiago de Chile. *Local Environment*, 3(1), 7 – 25.

Wood, R., & Lenzen, M. (2003). An application of a modified ecological footprint method and structural path analysis in a comparative institutional study. *Local Environment*, 8(4), 365 – 386.