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PARKING POLICIES AND MODAL CHOICE: A DISAGGREGATED APPROACH APPLIED TO FRENCH CITIES

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1 Modelling modal choice in urban environments: context and issues

Given the financial and environmental constraints involved, travel problems cannot only be resolved by increasing the capacity of road infrastructure. The challenges of sustainable development have prompted the need to take all modes of transport into consideration when discussing travel policies. Although for many years, modelling travel focused largely on vehicle movements to respond to the need for fluid road traffic with a high level of throughput, current debates on the organisation of urban travel require multimodal approaches, including a consideration of parking, which is one of the major levers for rationalising the use of cars in cities (Rennes *et al.*, 1997).

For a long time, approaches to modelling modal choice were often mono-modal and relatively simplistic¹ (CETUR, 1990), and almost never considered the aspect of parking. Over the last 10 years or so in France (and for slightly longer in other countries), however, there has been a shift towards a more multi-modal approach to modelling in order to provide a much more comprehensive response to the problems of travel. These approaches to modelling generally rely on discrete choice models such as the multinomial logit model (Ben-Akiva *et al.*, 1985; CERTU, 1998).

The principle of logit² models is that they explain the behaviour of individuals based on a number of socioeconomic criteria on the one hand, and descriptive criteria relating to transport supply on the other; this is used to define a utility u_m , which depends on the mode m , the journey and the characteristics of the individual or group of individuals.

A given individual will use the mode with the highest utility for their particular needs; this utility, however, includes a random term due to a range of factors (lack of information, various constraints, etc.), which explains the differences in behaviour between “similar” individuals and results in evaluating a probable (and not strictly determined) behaviour. Overall, where the random term follows a Gumbel law, the probability p_m of using mode m for a given journey

is equal to:

$$p_m = \frac{e^{u_m}}{\sum_k e^{u_k}}$$

The advantage of this type of model is that it is able to respond to questions associated with travel policies provided these questions are expressed through the variables present in utility functions (for example, measuring the impact of the widespread introduction of paid parking in a city centre). Nonetheless, this type of model is not always easy to calibrate. Furthermore, it does not make it possible to take account of a radical change of behaviour (not observed based on the data used to calibrate the model), for example, the introduction of a new mode of transport or a sudden rise in the price of fuel.

1.1 Main lessons and difficulties encountered in logit-type models of modal choice

There are numerous examples of modelling modal choice through the application of a logit-type model, and most modelling research highlights certain difficulties or precautions to be taken into account:

- A single logit model is not sufficient to model the behaviour of all individuals within a given scope correctly
- Parking is probably one of the determinants in the choice of mode of transport, but there are real difficulties in characterising it
- Reconstructing travel time is not immediate, in particular for public transport times
- Small sample sizes can make it difficult to model modal choice

a) A single logit model is not sufficient to model the behaviour of all individuals within a given scope correctly

Given the significant differences which may exist between individuals, envisaging a single logit formulation for modal choice seems highly problematic. Ownership and access to a car within the household, for example, is an important parameter which affects the degree to which individuals are tied to public transport (PT). Depending on journey length, the choice of modes of transport available may vary: for long journeys, for example, walking cannot be the sole mode of transport used. Segmenting individuals (whether or not they are captive in relation to public transport (DREIF, 2008; IAURIF, 2008)) and/or journeys to create homogeneous groups is therefore essential to calibrate the utility functions of different modes as accurately as possible.

b) Parking is probably one of the determinants in the choice of mode of transport, but there are real difficulties in characterising it

Various studies and research projects on modal choice show that the difficulty or ease of parking has a significant impact on the final choice of mode

(Kaufmann *et al.*, 1996). Examples of logit-type modelling, however, show that it is difficult to incorporate this variable into utility functions objectively. Most of the time, parking is taken into account using “penalties” to reflect the difficulty of getting parked, and these penalties are generally pegged to “expert opinions” on the basis of highly empirical field knowledge.

In the Ile-de-France model produced by IAURIF (IAURIF, 2008), for example, the penalty for time spent searching for a parking space is calculated as a fixed amount based on a division into five zones.

Zone	Starting point	Destination
Paris	+3	+6
Inner suburbs	+2	+4
Urbanised outer suburbs	0	+1
Urban fringes + secondary urban areas	0	0
Rural	0	0

Table 1 Example of weightings applied to searching for a parking space in Ile-de-France (IAURIF, 2008)

To take another example, in the model used to analyse rail services for the Toulouse conurbation (CETE SUD-OUEST, 2002) the utility functions include a parameter for parking. The conurbation is divided into zones, with each zone classified qualitatively based on three categories according to the parking difficulties encountered (based on field knowledge). The three categories are defined as follows:

- Category 1: parking highly restricted, mostly paid
- Category 2: parking mostly free but high level of occupancy of spaces
- Category 3: few parking difficulties

In other models, the parking variable has been incorporated into models of modal choice in a more “scientific” way. This applies to the Mostra model developed by the Semaly. In the absence of objective, known data, the difficulty of parking is represented by an urban density criterion, based on a combination of population density and employment density. This combined criterion is supposed to represent both the time spent searching for a parking space and the discomfort associated with this (example taken from the multi-modal model used in the Bordeaux conurbation, 2002).

c) Reconstructing travel time is not immediate, in particular for public transport times

Reconstructing travel time for a given starting point/destination pair is neither easy nor immediate. For car journeys, the most common method is to use the results of traffic modelling. Most traffic models developed for conurbations, however, are only calibrated to peak times (the evening rush hour, for example). Matrices for journey times in off-peak periods are therefore unknown.

Reconstructing travel time poses even more problems, insofar as public transport allocation models are still not widely used in France. Sometimes, the

public transport times used are only those declared in the survey, which limits the sample significantly (CUDL, 1997).

d) Small sample sizes can make it difficult to model modal choice

Whilst segmenting demand is essential to model modal choice as accurately as possible, trying to impose too much segmentation runs the risk of being faced with samples which are too small to calibrate utility functions effectively (CUDL, 1997).

1.2 Modelling principles for modal choice developed for the Lille conurbation

Particular attention was paid to the four main points outlined above for modelling modal choice in the Lille conurbation. In part 2 below, we set out a methodology for determining objectively the level of constraint parking represents in a conurbation based on data from household travel surveys (EMD).

Then, in part 3, we present the main variables explaining modal choice in Lille based on the latest EMD, carried out in 2006. This analysis points to a segmentation of demand in respect of the choice of transport mode for individuals. Based on this segmentation, we construct a number of models of modal choice.

2 How can we describe the constraint represented by parking across a conurbation?

2.1 Methodology³

The parking constraint, which is often estimated empirically in travel models, can be approached more objectively through the household travel survey (EMD), which are an indispensable source of data for a detailed understanding of travel demand and practices.

2.1.1 Input data: the EMD

The local surveys EMD carried out in major conurbations in France since the 1970s (110 surveys in 55 urban areas) are based on a methodology standardised by CERTU (the technical department of the French Ministry of Transport). In particular, a “standard⁴” questionnaire is sent out to local transport authorities and includes various items of data describing parking difficulties in one form or another.

These relate to:

- individuals
 - the usual difficulties workers and students face parking at their place of work or study
- the journeys made by car drivers
 - time spent searching for a parking space

- walking time between the parking place and final journey destination
- type of parking at the destination: paid, prohibited or free

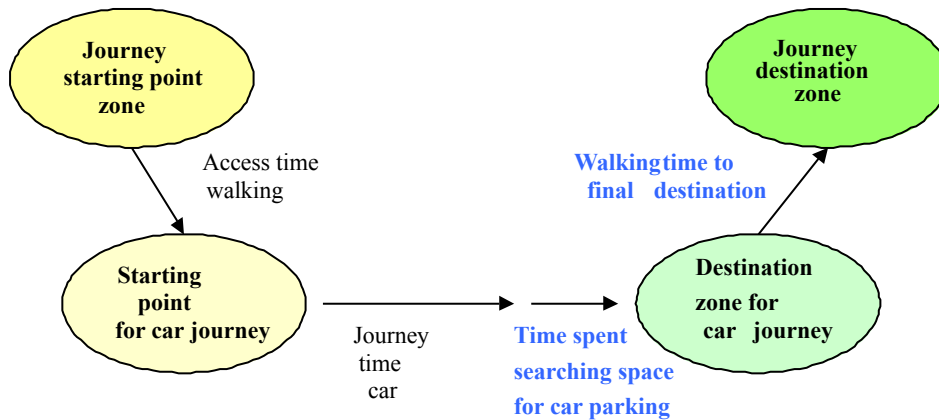


Figure 2 Diagram of journeys described in EMD

2.1.2 Choice of indicators and determining the level of constraint for each indicator

The four kinds of data listed above can be used to produce six indicators characterising the parking constraint, calculated for each zone defined in the EMD that attracts journeys made by car:

- Indicator 1: proportion of journeys whose walking time to the final destination is not null (PTMAP≠0): this indicator measures the percentage of journeys made in private cars where the person is unable to find a parking space immediately next to their final destination. Journeys made for the reason “outing or window-shopping” are excluded from this indicator and the following one because the walking time in these journeys from the arrival of the mechanised mode effectively accounts for half the time of the outing.
- Indicator 2: average walking time to final destination for people parked on the road network (MTMAP): this indicator excludes people parking in a reserved car park or garage, whose walking time to their final destination does not indicate a parking constraint. The only journey times included here are those made on foot with parking on the road network.
- Indicator 3: proportion of journeys where the time spent searching for a parking space is not null (PDRECH≠0): this refers to the percentage of journeys made in private cars where the driver does not have immediate access to a parking space.
- Indicator 4: average time spent looking for a parking space for people who park on the road network (MDRECH): as for indicator 2, journeys made by people with a garage or reserved parking space are excluded.

Only the average time spent searching for a parking space on the road network is calculated.

- Indicator 5: proportion of journeys where parking at the destination is paid or prohibited (PPAYANT): this indicator reflects another aspect of the parking constraint, which is more associated with pricing or prohibition than the difficulty of actually finding a space.
- Indicator 6: proportion of workers, school pupils and students who generally encounter parking problems at their place of work or study (PPBSTAT): this is more of a qualitative indicator and reflects the difficulty felt by workers, school pupils and students travelling to their place of work or study.

A three-level classification (low, medium, high) is produced for each indicator. In order to keep a balance between the six indicators, limits are selected in order to keep a similar proportion of zones classified in each of the three levels for all indicators (this is an iterative method based on the EMD applied in this case, namely Lille, Lyon and Montpellier). The following table gives examples of the classification limits for the four proportional indicators:

	Indic 1: PTMAP≠0		Indic 3: PDRECH≠0		Indic 5: PPAYING		Indic 6: PPBSTAT	
	Lower limit	Upper limit	Lower	Upper	Lower	Upper	Lower	Upper
Low	0%	40%	0%	15%	0%	10%	0%	20%
Medium	40%	60%	15%	30%	10%	30%	20%	40%
High	60%	100%	30%	100%	30%	100%	40%	100%

Table 3 Level classifications for proportional indicators

Using a statistical precision indicator means that certain indicators in certain areas are classified as “indeterminate” because the number of records is insufficient to ensure a statistically significant result.

2.1.3 Aggregation and final typology

The six indicators are then aggregated based on rules determined by a series of iterations (the results obtained are then compared with empirical knowledge of the parking constraints in towns and cities).

The rule used is as follows:

If	Then the overall indicator is
at least 4 indicators are “indeterminate”	Indeterminate
at least 3 indicators are “high” or 2 indicators are “high” and at least 1 indicator is “medium” or 1 indicator is “high” and at least 4 indicators are “medium”	High
2 indicators are “high” or 1 indicator is “high” and at least 1 indicator is “medium” or at least 3 indicators are “medium”	Medium
otherwise	Low

Table 4 Aggregation rules for parking constraint indicators

2.2 Results for Lille

2.2.1 Level and location of parking constraints

The two most recent surveys carried out covering Lille metropolitan area in 1998 and 2006 enable us to measure the state of parking constraints in 2006 and how these have changed compared with 1998:

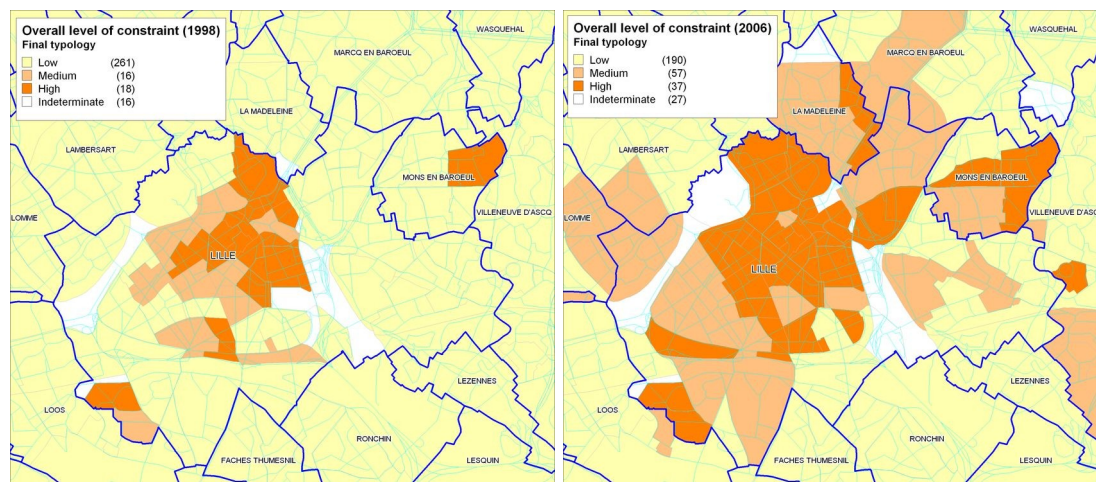


Figure 5 Map of parking constraints in Lille (1998 and 2006)

Parking constraints are largely concentrated in the densest areas of the conurbation. Constraints worsened and extended to cover a larger area between 1998 and 2006 (from 9 km² in 1998 to 53 km² in 2006, including 11 km² characterised by a high level of constraint).

The following table shows the average values for the six indicators in each type of zone in 2006:

	High level	Medium level	Low level	Combined
Indic 1: PTMAP≠0	61%	53%	28%	37%
Indic 2: MTMAP	2.0 min	1.2 min	0.6 min	0.9 min
Indic 3: PDRECH≠0	29%	21%	8%	13%
Indic 4: MDRECH	1.6 min	0.6 min	0.2 min	0.5 min
Indic 5: PPAYING	23%	7%	4%	7%
Indic 6: PPBSTAT	53%	32%	22%	31%

Table 6 Characteristics of parking constraints (Lille 2006)

There is a marked discrepancy between zones with a high and low level of constraint. For example, 61% of car drivers are unable to park in the immediate vicinity of their destination in zones with a high level of constraint, compared with 28% in zones with a low level.

The time spent searching for a parking space in zones with a high level of constraint is eight times higher, but is still under two minutes.

More than one worker in two states that they usually encounter problems parking if their workplace is in a zone with a high level of constraint, compared with only about one in five in a low-level zone.

2.2.2 Influence of parking constraints on modal choice

The effects of this constraint on the choice of mode of transport are addressed by the distinction drawn between long journeys (competition between cars and public transport) and short journeys⁵ (competition between cars, public transport and walking).

Only journeys made by people in a position of full modal choice are analysed. This therefore excludes so-called “captive” public transport users, whose access to car use is limited because they either do not have a driving licence or do not own a vehicle (cf. part 3 for further details).

Results for short journeys

The following table shows the modal share for the four main modes according to whether the journey is to a zone with a high, medium or low level of constraint in relation to parking.

		Private car (PC)	Walking	Public transport (PT)	2-wheeler
Level of constraint	High	30%	64%	2.7%	3.3%
	Medium	58%	41%	0.3%	1.2%
	Low	60%	38%	0.1%	2.1%
Combined		55%	42%	0.5%	2.1%

Table 7 Modal share of short journeys by level of parking constraint

On average, more than one journey in two of less than 2 km is made by car, but in zones with a high level of constraint, walking is used for almost two out of three journeys. In these zones there is also a limited degree of modal shift from cars to public transport and two-wheelers (3% each).

Results for long journeys

As far as long journeys are concerned, where the competition studied is between public transport and cars, different modal shares have to be measured according to the quality of the public transport offering available as an alternative.

Service levels can be measured relatively simply by assigning the highest-performing form of public transport (determined by the number of stops) to each defined zone. The various levels used are TCSP (public transport using dedicated lanes – metro or tramway), buses with a high level of service, bus with a standard level of service and TER (Regional Express Train).

The following table shows modal share based on public transport services combined with the level of parking constraint at journey destinations.

Level of constraint and public transport service		Private car (PC)	Public transport (PT)	2-wheeler	Walking
High	TCSP	77%	17%	2.0%	3.2
	Frequent bus	83%	9%	4.7%	3.4%
	<i>TER + Freq. bus</i>	76%	16%	0.0%	8.7%
	<i>TER + Bus</i>	94%	0%	0.0%	3.8%
Medium	TCSP	89%	7%	2.0%	1.7%
	<i>TER + Freq. bus</i>	100%	0%	0.0%	0.0%
	TER + Bus	96%	4%	0.0%	0.0%
	<i>Frequent bus</i>	95%	2%	2.2%	1.3%
	Buses	97%	1%	1.2%	0.9%
Low	TCSP	91%	4%	2.2%	1.7%
	<i>TER + Freq. bus</i>	92%	2%	1.8%	1.4%
	TER + Bus	95%	1%	0.6%	3.1%
	Frequent bus	94%	1%	2.1%	2.7%
	Buses	94%	0%	1.8%	3.8%
Combined		90%	5%	1.7%	2.7%

Table 8 Modal share of long journeys based on parking constraint and public transport services

The use of public transport only increases when both conditions are fulfilled, i.e. “high level of parking constraint” + “high level of public transport services”.

Unless the level of parking constraint is high, 90% of journeys to zones served by TCSP are made by car.

In zones with a high level of constraint but which are served only by a frequent bus service, the share for public transport falls below 10%.

This only increases where there is a high level of constraint combined with a TCSP service (17%).

The level of parking constraint can therefore be estimated more objectively and less empirically by using EMD. Its effects on the modal choices made by individuals are very significant. A high level of constraint results in a significantly higher level of walking for short journeys and of public transport for long journeys, provided the alternative offers a sufficiently high level of service.

3 Modelling principles for modal choice for the Lille conurbation

The methodology used to develop the modal choice⁶ model for Lille was a three-stage process:

- use of the Lille 2006 EMD to determine the main factors behind modal choice;
- segmentation of individuals to create homogeneous groups from the point of view of modal choice;
- estimation and calibration of logit-type multinomial models

3.1 The main factors behind individuals' modal choices

Statistical analyses of the EMD were used to identify three factors with a significant influence on the modal choices made by individuals: journey length, the individuals' level of captivity in relation to public transport, and at a secondary level, parking constraint.

3.1.1 Journey length

Journey length is highly discriminating in relation to modal split, primarily because of the existence of a distinct mode for short journeys, which is effectively not found at all once distances become too great.

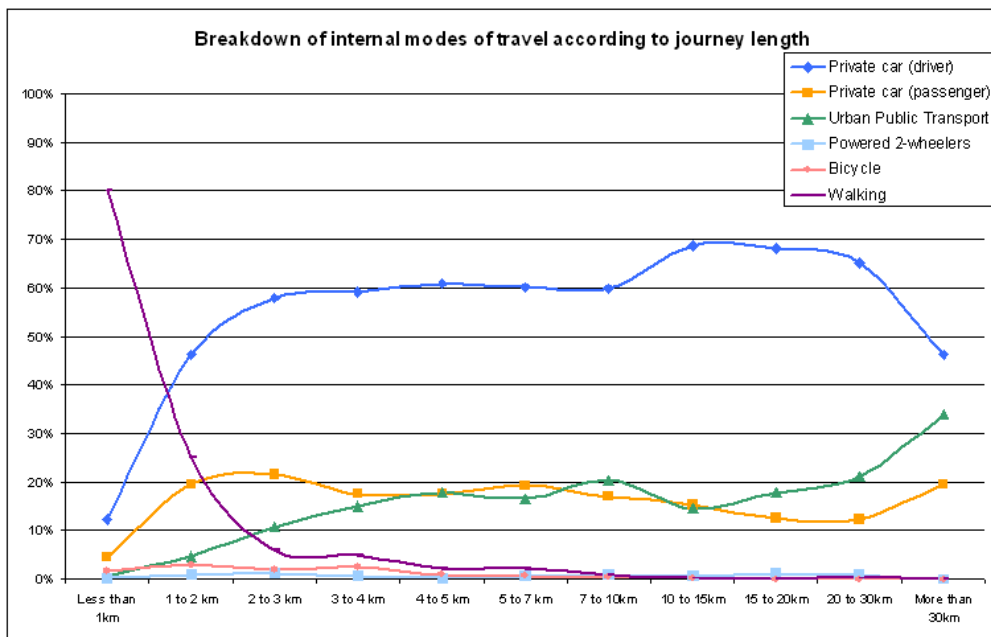


Figure 9 Breakdown of modes of travel according to journey length (Lille 2006)

Once the distance is over 3 km, almost no journeys are made on foot. Excluding walking from the modelling process for modal choice would be a major disadvantage, insofar as it would no longer be possible to assess the impact of certain public travel policies. In addition, walking and public

transport may be in direct competition for short journeys, particularly where public transport services are inadequate.

For people who are not tied to public transport, walking is also a relevant option over short distances as an alternative to the car, even more so in areas where parking is constrained.

Incorporating journey length resulted in the creation of two distinct journey samples: short journeys of less than 3 km and long journeys of more than 3 km.

Modal split	Short journeys	Long journeys	Combined
CAR DRIVER	38%	64%	47%
CAR PASSENGER	13%	16%	14%
Urban Public Transport (PT)	8%	18%	11%
WALKING	41%	1%	27%
Total	100%	100%	100%
Unadjusted numbers	17,217	9,645	26,862

Table 10 Modal share based on journey length

3.1.2 Level of captivity of individuals in relation to transport modes (public transport or private car)

The notion of captivity is defined based on a small number of variables from the EMD (number of cars in the household, position of the individual and number of people in the household, and possession of a driving licence).

	Captivity	Description
1	High Captives PT (PT++)	High captivity in relation to PT: Individual belonging to a household with no car
2	Medium Captives PT (PT+)	Medium captivity in relation to PT: Individual belonging to a household with a car but who has no driving licence
3	Medium Captives PC (PC+)	Medium captivity in relation to PC: Individual with a driving licence and whose household has a car but whose position in the household prevents them from using it as a matter of principle
4	High Captives PC (PC++)	High captivity in relation to PC: Individual with a driving licence and whose position in the household allows them to use a car as a matter of principle

The variable used to describe the captivity of individuals is also highly discriminating in relation to choice of mode of transport, as shown in the two tables below.

SHORT journeys	Private car (driver) (PCD)	Private car (passenger) (PCP)	Urban Public Transport (PT)	Walking	Total
PT++ captives	<i>Not applicable</i>	7%	22%	71%	100%
PT+ captives		40%	9%	51%	100%
PC+ captives	47%	12%	5%	36%	100%
PC++ captives	70%	4%	2%	24%	100%
Combined	38%	13%	8%	41%	100%
Raw numbers	6,518	2,264	1,360	7,075	17,217

LONG journeys	PCD	PCP	PT	Total
PT++ captives		20%	76%	100%
PT+ captives		60%	37%	100%
PC+ captives	63%	19%	17%	100%
PC++ captives	88%	6%	5%	100%
Combined	64%	16%	18%	100%
Raw numbers	6,214	1,579	1,724	9,645

Table 11 Modal share based on length of journeys and level of captivity of individuals

3.1.3 Level of parking constraint

Geographical areas where it is difficult to park a car (cf. section 2), in particular in Lille city centre, result in modal choices geared towards public transport or walking. The share of private car drivers is only 27.8% compared with over 45% in areas with fewer constraints (this remains valid whether the analysis covers the starting point of the journey or its destination).

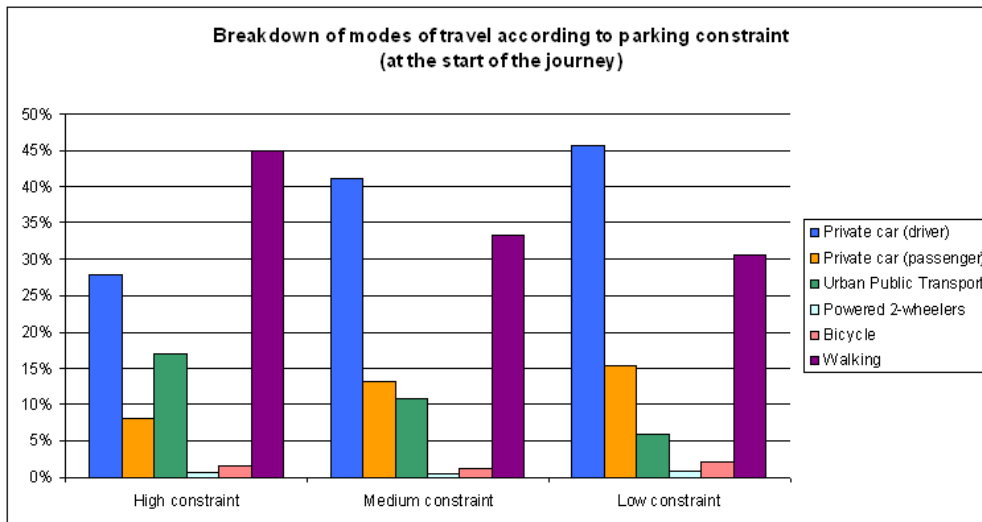


Figure 12 Modal split according to level of parking constraint

The modal share of cars is even lower, around 14%, when there is a high level of parking constraint at both the starting point of the journey and its destination.

Parking constraint by Starting Point and Destination	PCD	PCP	PT	Powered 2-wheelers	Bicycle	Walking	Combined
High ↔ High	14.4%	3.8%	10.6%	1.0%	1.8%	68.4%	100%
High ↔ Medium	34.3%	10.9%	23.6%	0.3%	1.8%	29.0%	100%
High ↔ Low	47.1%	13.5%	23.1%	0.6%	1.2%	14.7%	100%
Medium ↔ Medium	28.9%	9.4%	7.0%	0.3%	0.7%	53.7%	100%
Medium ↔ Low	56.4%	17.8%	9.8%	0.7%	1.3%	14.0%	100%
Low ↔ Low	43.3%	14.9%	3.4%	0.8%	2.2%	35.3%	100%
Combined	41.7%	13.6%	8.8%	0.7%	1.7%	33.5%	100%

Table 13 Modal share according to parking constraint at the starting point of the journey and its destination

Including parking in the utility functions can be used to assess the modal shift associated with increasing or decreasing the stringency of parking regulations: reducing or increasing supply and extending or reducing paid zones.

3.2 Segmentation of individuals prior to modelling

The principle of segmentation uses a number of statistical tools, primarily the “decision tree”⁷ method. This method is designed to split a population of individuals into the most homogeneous groups possible from the point of view of modal choice (Private Car Driver, Private Car Passenger, Public Transport and Walking) based on the variables used in the EMD⁸.

Once the statistical analysis is complete and homogeneous groups have been

created, a modal choice model is calibrated for each of them by applying the theory of discrete choice models.

For reasons associated with the size of the samples, we limited ourselves to creating eight homogeneous groups of individuals (based on a combination of journey length and the individuals' level of captivity), which resulted in estimating and calibrating eight different models.

3.3 Estimation of modal choice models using Biogeme⁹ software

The Biogeme software application, developed by Michel Bierlaire (Bierlaire, 2009) at the Ecole Polytechnique Fédérale de Lausanne, was used to estimate the various modal choice models.

Example of a modal choice model calibrated using Biogeme

The variables tested in the utility functions were those which emerged at the segmentation stage, to which time variables for public transport and private cars were then added. Finally, priority was given to variables which could "easily" be projected. Not all of the variables were therefore included.

We set out below an example of the model calibrated using Biogeme software.

Modelling long journeys by "Medium" PC Captives (PC+) users

The modal choices for PC+ captives for long journeys are cars (as driver or passenger) or public transport.

Utility functions:

$$U_{TCU} = K_{TCU} + C_{TTCU} * TTCU + C_{TCGRAT} * TCGRAT + C_{STAD2T} * STAD2 + C_{STAO2T} * STAO2$$

$$U_{VPC} = K_{VPC} + C_{TVPC} * TVP_TOT$$

$$U_{VPP} = K_{VPP} + C_{TVPP} * TVP_TOT$$

Coefficient	Description	With parking variable	Without parking variable
C_{TTCU}	TCU (Urban Public Transport) time	-0.049	-0.0665
C_{TVPC}	VPC (Private Car Driver) time	-0.169	-0.21
C_{TVPP}	VPP (Private Car Passenger) time	-0.187	-0.229
C_{STAD2T}	High level of parking constraint at destination	1.07	
C_{STAO2T}	High level of parking constraint at starting point	1.09	

Coefficient	Description	With parking variable	Without parking variable
C_{TCGRAT}	Free public transport season ticket	1.04	0.99
K_{TCU}	Alternative constant:	0.00	0.00
K_{VPC}	Alternative constant:	1.85	1.08
K_{VPP}	Alternative constant:	0.89	0.116
Adjusted Rho square		0.238	0.226

Table 14 Values of utility function variables according to models tested

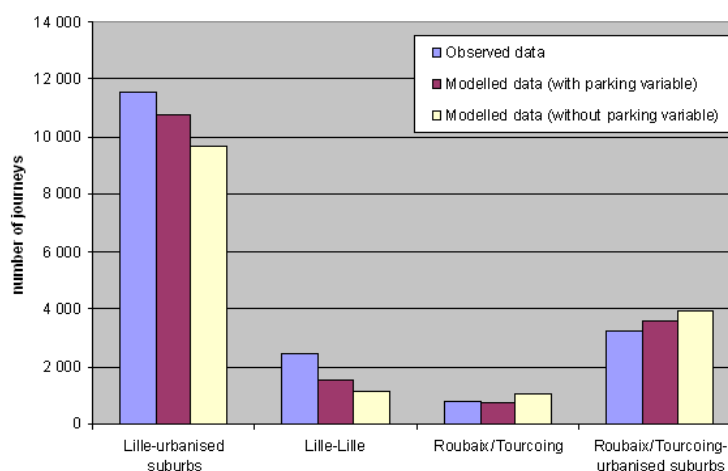


Figure 15 Comparison of observed data with modelled data

A comparison of observed data with modelled data shows that the model reflects reality reasonably accurately. In addition, the variables used to characterise the level of parking constraint can also be used to improve modal choice modelling significantly.

This type of model can then be used to test various local parking policies, as illustrated in the table below.

Present situation	Projected situation
16.3%	23.6%

Table 16 The modal share of Public Transport (Sensitivity test* for parking-related variables)

*Switch from zones with a medium level of parking constraint to a high level of constraint across the conurbation

NOTES

1. Modal share matrices (normative model) or logistic curves (S curves)
2. This section is largely based on the following publications: Modélisation des déplacements urbains de voyageurs. Guide des pratiques (CERTU, 2003) and Prévisions de la demande de transport (BONNEL, 2004)
3. See the report: Contraintes de stationnement et pratiques modales. Méthodologie et étude des cas de Lille , Lyon et Montpellier (CETE Nord-Picardie, 2009)
4. <http://www.certu.fr/>
5. The limit between the two here is set at 2 km
6. Only journeys made by car as a driver / passenger, walking and urban public transport have been included. Other modes (in particular cycling, Regional Express Transport and interurban coaches) were not included because of their low level of representation in the survey.
7. Segmentation was carried out using StatBox6 and the CART (Classification And Regression Tree) method, which systematically produces binary trees. The segmentation criterion was the GINI index. This segmentation technique has the advantage of treating a large number of variables at the same time. The software was configured not to segment a branch if one of the two secondary branches contained fewer than 30 observations (Rakotomalala, 2005).
8. Reader may wish to refer to the various publications dealing with decision tree theory (http://fr.wikipedia.org/wiki/Arbre_de_décision)
9. <http://transp-or2.epfl.ch/biogeme/>

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