# A TOPOLOGICAL ROUTE CHOICE MODEL FOR BIKE

*Felipe González[1], Louis de Grange[2], Carlos Melo[3]*

*1,2,3Universidad Diego Portales, Industrial Engineering Department, Ejercito 441, Santiago, Chile*

*Email for correspondence: felipe.gonzalezr@udp.cl*

## ABSTRACT

In this paper we analyze the performance of the bike sharing system in the municipality of Providencia, Chile and characterize their demand (users) to promote usage policies.

Additionally we study the route choice of users of the system in order to estimate the incidence of certain variables of perception of the route, such as topological variables, presence of bike paths / bikeways or parks, presence of public transport among others.

The bicycle sharing system in Providencia has 18 bicycle parking for public use, are located at strategic points of the municipality that have a high confluence of people who can make use of them for a period of time since is taken from a parking point and returned in another.

To meet the above objective, approximately 300 surveys were conducted to identify the users of the service, know the factors considered relevant when deciding whether to use the bike and finally collect information about the characteristics of the trip and the route used.

From the results it can be concluded that proximity to metro stations along with the existence of bike lanes are the main attractors of flows, so that investment in infrastructure would be justified.

*Keywords: Bike Sharing Systems, Sustainability, Route Choice.*

# 1. INTRODUCTION

The bicycle is a sustainable mode of transport which is associated with a number of advantages, such as economic, health and environment benefits. Even in some urban areas this mode can provide higher speeds than other modes of transport (Cervero and Duncan, 2003; Ortuzar et al, 2000; Olde Kalter, 2007, Pusher et al. 1999), however, the bike also has associated with some disadvantages such as physical effort for long trips, being at the mercy of the weather and be more susceptible to accidents (Heinen et al. 2010).

In the case of the city of Santiago, Chile, from 2 decades ago, urban cycling has not had a significant growth, with a percentage share of daily trips from 1.6% in 1991 (Ortuzar et al., 1993), 1.9 % in 2001 (SECTRA, 2001) and 2.7% in 2006 (SECTRA, 2008). This number is fairly low, more so when the city has favorable conditions for use: small slope, good weather throughout the year, many trips under 5 km (at least 41% of trips by private transport, SECTRA, 2008).

Perhaps, the only major drawback for mass use of this mode of transport in the city of Santiago is that has not yet developed a culture to promote use and deficient infrastructure. The city generally has large flaws in design of bike lanes, bike parking lots are scarce or nonexistent, and the connection between existing bikeways is poor.

In terms of culture to promote cycling, has been a great bench bicycles Associations (eg ciclistas furiosos, bici-cultura, among others) that have helped spread this way, educating and pressuring various municipalities to build more and better infrastructure. However, it is the belief in the authorities that the absence of demand, investment is not justified in this way, when there is the possibility that a good policy could lead to a mass use, thus justifying new investments.

For the municipality of Providencia, located in the city of Santiago, attempts have been made to promote the use of bicycles even when there is no great demand, developing a strategic plan that aims to unite all points of interest in the district with a network of cycle routes an extension of 45 km (currently built around 12 km) along with offering a bicycle hire service, in fact, was the first municipality to establish a bicycle loan system as existing in cities around the world: Paris, Barcelona, Washinton, DC (Enserink, 2007).

The aim of this paper is to analyze the functioning part of the bicycle sharing system in the municipality, characterize their demand (users) and understand topological factors affecting route choice of users of this system, with the objective of promoting use policies and determine those factors to estimate prevailing potential demand that could have this type of system to implement in other boroughs. To achieve that end, 300 surveys were conducted to system users.

## 2. PROVIDENCIA BIKE SHARING SYSTEMS

The municipality of Providencia is embedded within the city of Santiago, has an area of 14 km$^2$ and has an estimated population of 125,000, but its floating population reaches 800,000 people.

The Bike Sharing System has a total of 150 bikes at 18 stations strategically located around the town, located in places high concurrency, near metro stations, plazas, sports or cultural centers, each with a total of 20 bicycle parking lots. The service operates Monday to Saturday from 07:30 to 20:30 and costs for the municipality of approximately $ 40,000 per month. At first it was thought to provide service to residents of the town, but now anyone can join the system.

Figure 1 shows a map of the city and the location of the stations or share points. Figure 2 shows some of the stations.


Figure 1 – location of the stations in Providencia

Figure 2 – Bike Share stations

Users wishing to register can do so at any station, through the website or in the office of the licensee, and must pay a membership of $ 4.0 per month or $ 30 annually.

All the bikes are attached code, the user who wants to use should choose a bicycle and identify with the station manager. The loan of bicycles is subject to availability at each station there and can be picked up 30 minutes before closing it. The maximum usage time is 60 minutes, but can be renewed at each station for the same amount of time.

To replace the bikes are available 3 distribution trucks that go removing bicycles at stations with high stock and replenishing those bikes where the stock is low.

Regarding the demand for bicycles, until July 2012 trips have increased considerably as the user satisfaction. In December 2010, when the system began operating, there were 3,742 trips (defined as travel the journey from the user requests a bicycle until the returns) in March 2011 12,317 trips were made and in March 2012 16,508 trips. In the months of June and July the demand for bicycles decrease due to be midwinter months.

Figure 3 shows the evolution of total demand for bicycles between the months of December 2010 through July 2012.

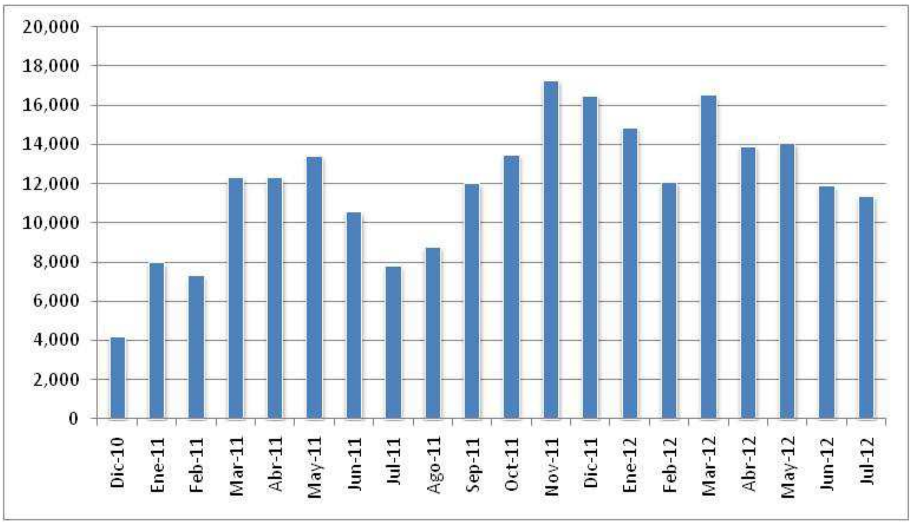


Figure 3 – Monthly demand of bike sharing system

In terms of cycling infrastructure, the municipality of Providencia is a pioneer in the city of Santiago, since 1997 has developed a plan to connect the commune and its parks with a network of bicycle routes should reach 45 km. It currently has about 12 km of cycle paths medium-high standard, with appropriate signage. However, it still lacks a proper connection between all points travel generators and attractors.

The bicycle is a sustainable mode of transport which is associated with a number of advantages, such as economic, health and environment benefits. Even in some urban areas this mode can provide higher speeds than other modes of transport (Cervero and Duncan, 2003; Ortuzar et al, 2000; Olde Kalter, 2007, Pusher et al. 1999), however, the bike also has associated with some disadvantages such as physical effort for long trips, being at the mercy of the weather and be more susceptible to accidents (Heinen et al. 2010).

In general, construction criteria were: the existence of axes without public transportation and therefore with low pedestrian flow, so that the bike path does not interfere with pedestrian movement or with the bus stops, subway stations connect enabling a intermodal exchange; equidistantly cover most of the municipal territory, to enable displacement bike from anywhere; feasibility of connecting with neighboring municipalities, among other criteria.

Figure 4 shows some of the bikeways in the municipality.

Figure 4 – some existing bikeways in Providencia

# 3. SURVEY AND MAIN RESULTS

To characterize the demand for bicycle, a total of 307 were conducted to users of the system, especially in bike stations, mainly in morning rush hour and afternoon peak (8:00 to 10:00 and 17:30 to 19:30 respectively).

The survey was divided into three parts, the first questions were asked concerning the individual, such as sex, age, occupation. The second part was about the trip: origin, destination, route taken, time travel, purpose of travel, frequency, among others. In the last part of the survey questions were asked concerning the main reasons for using the bicycle as a mode of transport, use of bicycle routes and alternatives available for the realization of the trip.

## 3.1 Characterization of users

Table 1 presents the main results of the first part of the survey. It can be seen that 63% of users surveyed are male, and mostly with ages ranging from 20 to 39 years.

Moreover, 57% of respondents living in Providencia and the rest comes mostly from neighboring municipalities, which can be explained because Providencia concentrates much of offices and universities.

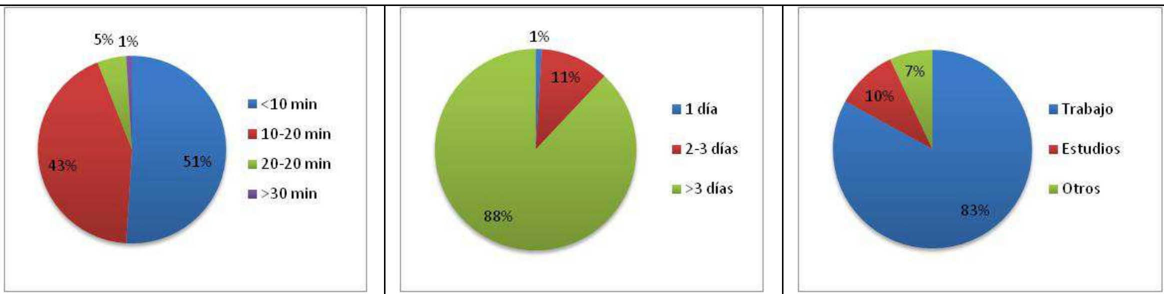
## 3.2 Characterization of trips

Figure 5 presents the main results concerning the characteristics of users surveyed trip. Of all respondents, 51% use the bike for runs under 10 minutes, and 43% between 11 and 20 minutes. 88% of respondents said to use the system more than 3 times a week and 83% used the bike for a work trip purposes.

From the information collected with the survey, we can conclude that the average distance of trips is 1.9 km and 36% comes from a bike station near to a metro station. Meanwhile, for trips originating in the other bike stations, 47% of trips has as destination a metro station, ie, many users are using the bicycle as a mode of approaching to the Metro.

Table I – Sociodemographic characteristics of users

| **Sex** | **Age** | **Not Lives in Providencia** | **Lives in Providencia** | **Total** |
|---|---|---|---|---|
| Female | <20 | 0 | 0 | **0** |
| | 20-29 | 4% | 9% | **13%** |
| | 30-39 | 5% | 13% | **18%** |
| | 40-49 | 1% | 1% | **2%** |
| | 50-59 | 1% | 3% | **4%** |
| | >=60 | 0% | 0% | **0%** |
| | **Total** | **10%** | **27%** | **37%** |
| Male | <20 | 1% | 0% | **1%** |
| | 20-29 | 10% | 9% | **19%** |
| | 30-39 | 13% | 13% | **26%** |
| | 40-49 | 7% | 5% | **12%** |
| | 50-59 | 1% | 3% | **4%** |
| | >=60 | 0% | 1% | **1%** |
| | **total** | **33%** | **30%** | **63%** |



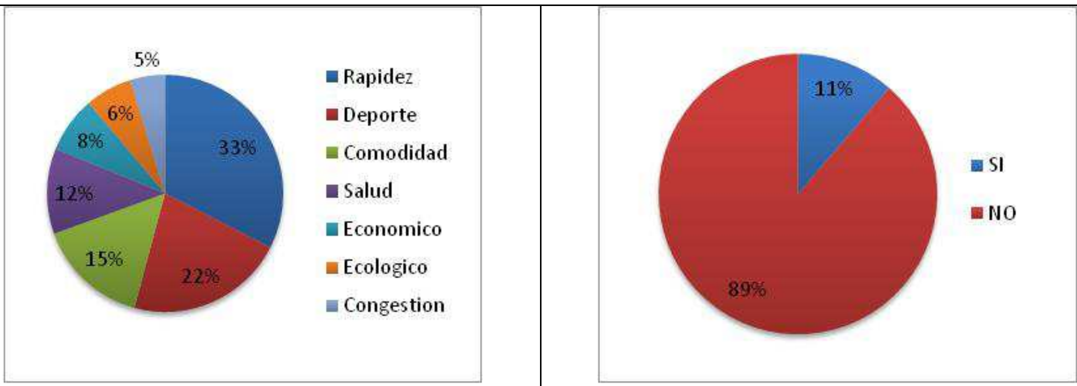

(a) Travel Time (min) | (b) Frequency of Trips | (c) Trips Purpose

Figure 5 – Characterization of trips

## 3.3 Bicycle use and alternatives available

Figure 5 presents the main results concerning the characteristics of users surveyed trip. Of all respondents, 51% use the bike for runs under 10 minutes, and 43% between 11 and 20 minutes. 88% of respondents said to use the system more than 3 times a week and 83% used the bike for a work trip purposes.

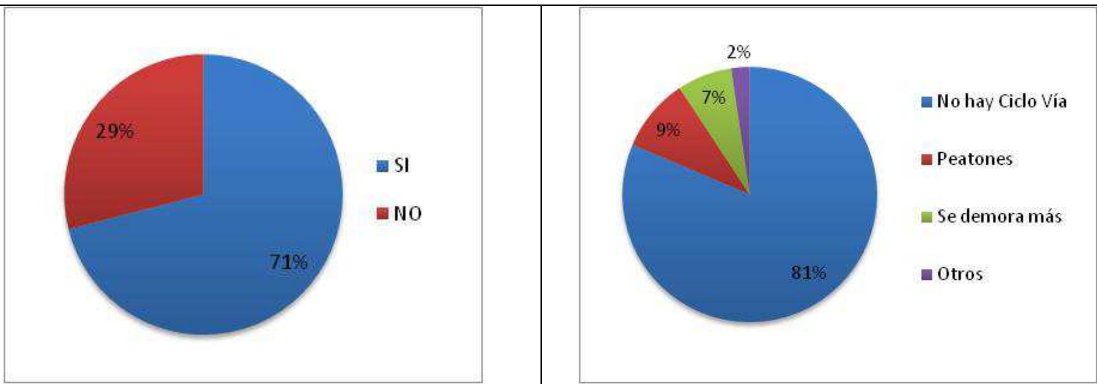
Analyzing the answers to questions about preferences for using the bicycle (Figure 6 (a)) shows that the greater quality associated with cycling over other transportation alternatives is to move quickly between different points (with a preference of 33%), the second preference is for sports with 22%. Note that 8% of respondents who used it for economic reasons, this low percentage is mainly because 95% of users do not consider relevant the amount to be paid for using the service (Figure 6 (b)).




| (a) greater quality of cycling | (b) rate relevance |
|---|---|

Figure 6 – Characterization of trips

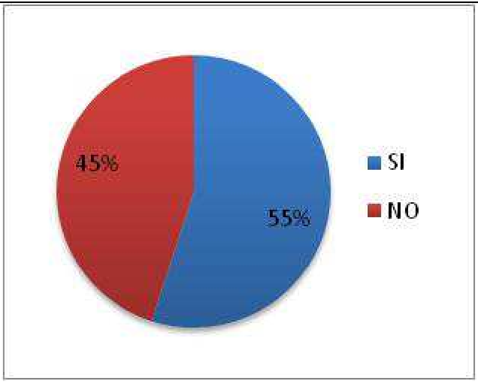
When asked if the user would use or use one of the existing bikeways on their trip, 71% said they do use the bike lanes, while users who do not use it, the main reason is the lack of this or that too many pedestrians circulating them (Figure 7).



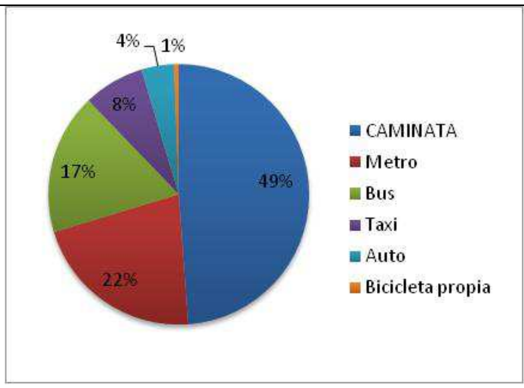

| (a) use of bike paths | (b) reason for not using bike paths |
|---|---|

Figure 7 – use of bike paths

Finally they were asked to users if car was available and what other mode of transportation would use to make the same trip (see Figure 8). 55% responded to have car, however, only 4% of respondents use the car for the same trip, the preferred alternatives were walking (49%), metro (21%) and bus (17%).




(a) car available




(b) modes available

Figure 8 – modes available

# 4. ESTIMATED MODEL

Together with the data obtained from the survey, a cadastre was conducted in order to determine the main factors influencing topological route choice of users. The variables studied are summarized in Table II:

Table II – Sociodemographic characteristics of users

| Variables | Average | Standard Deviation |
|---|---|---|
| Route length (m) | 1828.27 | 813.96 |
| % of route with bikeway | 0.31 | 0.34 |
| Number of traffic lights on the route | 5.97 | 3.15 |
| Number of priority intersections | 0.48 | 1.41 |
| Width of sidewalks on the route | 2.60 | 0.94 |
| Number of street lines | 3.10 | 0.97 |
| Level of trees in sidewalks | 1.13 | 0.41 |
| % of route with Public Transport | 0.48 | 0.35 |

With the available information we estimate a joint model of destination choice and route choice, which internally has a hierarchical structure, the associated hierarchical tree is shown in Figure 9. In this case, the user, given an origin, choose between n possible destinations, and once defined the destination, choose between available routes r. The parameters $\eta$ y $\lambda$ can be interpreted as scale factors in the random utility model (Ortúzar and Willumsen, 2001).

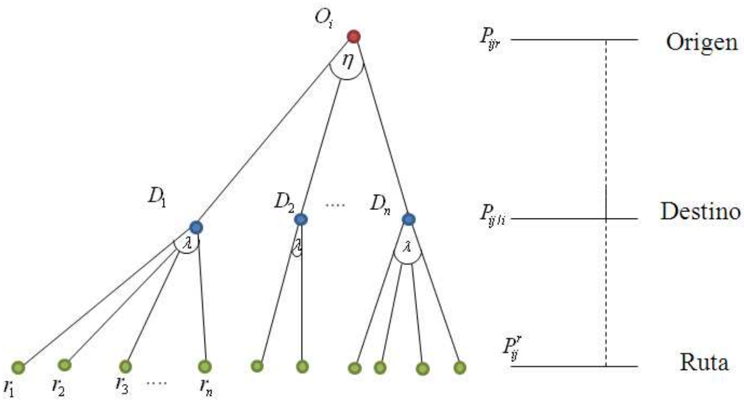



Figure 9 – hierarchical structure

In this case, the probability of choosing the route r on the Origin-Destination pair $ij$ is given by the following expression:

$$P_{ijr} = P_{ij/i} P_{ij}^{r} \quad (1)$$

In the expression (1), $P_{ij/i}$ is the probability of choosing the destination $j$ given the origin $i$ (destination choice model), while, $P_{ij}^{r}$ corresponds to the probability of choosing the route $r$ within the pair $ij$ (choice model route).

For the route choice model, we use a multinomial logit model, but incorporating an additional attribute to the utility function called Path Size Logit (LPS; Ben-Akiva and Ramming, 1998), which attempts to correct for routes which have overlaps and are therefore correlated. And also attempts to incorporate behavioral theory in Cascetta's C-Logit model. In this case $P_{ij}^{r}$ is:

$$P_{ij}^{r} = \frac{e^{V_{ij}^{r} - \psi \cdot \ln PS_{ij}^{r}}}{\sum_{r \in R^{ij}} e^{V_{ij}^{r} - \psi \cdot \ln PS_{ij}^{r}}} \quad (2)$$

The correction principle applied in this model is as follows. A route with no arcs overlapping another route needs no correction and is therefore assigned a size of 1. At the other extreme, if there are J duplicate routes (i.e., total overlap), each one has a size of 1/J. Finally, the length of routes with partial overlap is based on the sizes of the arcs, which are appropriately weighted on some criterion such as the arc's contribution to the total length of the route. Thus, $PS_{ij}^{r}$ can take the following form:

$$PS_{ij}^{r} = \sum_{a \in r} \left( \frac{l_a}{L_r} \cdot \frac{1}{\sum_{r \in R^{ij}} \delta_{ar}} \right) \tag{3}$$

Where $l_a$ is the length of arc a, $L_r$ is the length of route $r$, and $\delta_{ar}$ is equal to 1 if arc $a$ belongs to some route $r$ joining $ij$ but 0 otherwise.

$$P_{ij/i} = \frac{e^{\phi L_{ij} + Z_j}}{\sum_j e^{\phi L_{ij} + Z_j}} \tag{4}$$

With $L_{ij} = -\ln \sum_{r \in R^{ij}} e^{V_{ij}^{r} - \beta \cdot \ln PS_{ij}^{r}}$, $\phi = \eta / \lambda$ and $Z_j = \sum_m \alpha_m x_{jm}$ corresponds to a linear combination of the explanatory variables for each destination and its corresponding parameters.

Therefore, the joint model is:

$$P_{ijr} = \frac{e^{\phi L_{ij} + Z_j}}{\sum_j e^{\phi L_{ij} + Z_j}} \frac{e^{V_{ij}^{r} - \beta \cdot \ln PS_{ij}^{r}}}{\sum_{r \in R^{ij}} e^{V_{ij}^{r} - \beta \cdot \ln PS_{ij}^{r}}} \tag{5}$$

The final model considered the following explanatory variables:

- $ARB$: Level of trees in sidewalks.
- $CICLO$: % of route with bikeway.
- $SEX$ : Variable that takes the value 1 if the user is male.
- $DIST$ : length of route.
- $TPUB$: % of route with Public Transport.
- $METRO$: 1 if there is a metro station in the destination.
- $METROL1$: 1 if there is a metro station of Line 1 at destination.
- $METROL5$: 1 if there is a metro station of Line 5 at destination.

The parameters were estimated by maximum likelihood using Gauss 7.0 software. Table III summarizes the main results.

Table III – estimated model

| Parameter | Coefficient | Test-t |
|---|---|---|
| $\theta_{ARB}$ | 1,14 | 2,01 |
| $\theta_{CICLO}$ | 2,95 | 2,51 |
| $\theta_{SEXCICLO}$ | -1,53 | -1,63 |
| $\theta_{DIST}$ | -1,61 | -2,22 |
| $\theta_{TPUB}$ | -0,84 | -2,18 |
| $\theta_{PS}$ | 2,46 | 2,56 |
| $\theta_{METRO}$ | 0,37 | 3,61 |
| $\theta_{METROL1}$ | 0,46 | 4,55 |
| $\theta_{METROL5}$ | 0,16 | 5,63 |
| $\phi$ | 0,18 | 6,76 |
| $\bar{\rho}^2$ | 0.313 | |
| Log-Likelihood | -111,01 | |

From the results, it is observed that all the parameters obtained have the expected sign and most are statistically significant at 95% confidence.

From the estimated coefficients we can conclude that the bikeways are attractors of flows, so that investment in infrastructure would be justified because it largely determines the route choice of users, which was certainly expected, is also possible to conclude that women value almost twice that of men the existence of a bikeway when choosing a particular route.

Respect to parameter associated with the distance, this is negative and significant, which is intuitive and shows that users prefer shorter trips. Additionally it is important to note that other ways of making attractive a route might be to increase the number of trees in the path or, as far as possible, ensure that the layout of the new bikeways don't share intersections with public transport.

Finally, regarding the variables associated to the destination, is notorious underground influence in choosing the destination, which corroborates that the system is being used as an alternative approach to this mode of transport.

# 5. CONCLUSIONS

In this paper we analyze the performance of the bike sharing system in the municipality of Providencia and we present a joint model of destination choice and route choice, which internally has a hierarchical structure. To estimate the model we use information from a cadastre an a survey conducted to system users.

Regarding the bike share system users, most of them use the bicycle as a mode of travel closer to the Metro, using the system more than 3 times a week, usually for short trips (less trips around 20 minutes). Importantly, the system is used by individuals who do not necessarily reside in Providencia and most of them do not consider relevant payment for the system.

Respect to the variables that have the greatest influence on the choice of destination, proximity to a Metro station has great significance, especially if it belongs to Line 1 (most used line of Metro system). Regarding the factors that influence the choice of route, as expected, the existence of bikeways and trees on the route have a positive effect, not so the distance and the presence of public transport.

## REFERENCES

BEN-AKIVA,M. Y RAMMING, S. (1998). Lecture notes: Discrete choice models of traveler behavior in networks. Prepared for Advanced Methods for Planning and Management of Transportation Networks. Capri, Italy.

CASCETTA, E., NUZZOLO, A., RUSSO, F. Y VITETTA, A. (1996). A modified logit route choice model overcoming path overlapping problems. Specifications and some calibrations results for interurban network. In: Proceedings of ISTTT conference, Lyon, France.

CERVERO, R. Y DUNCAN, M. (2003). Walking, Bicycling, and Urban Landscapes: Evidence From the San Francisco Bay Area. American Journal of Public Health, Vol 93, No. 9, pp. 1478-1483.

ENSERINK, M. (2007). Vélib: de zomerhit van 2007. Fietsverkeer, 17, pp. 16–19

HEINEN, E., VAN WEE, B., MAAT, K. (2010). Commuting by Bicycle: An Overview of the Literature. Transport Reviews, 30: 1, pp. 59-96.

MIDGLEY, P. (2009). Shared Smart Bicycle Schemes in European Cities. Global Transport Knowledge Partnership (gTKP)

OLDE KALTER, MJ. (2007). Vaker op de fiets? Effecten van Overheidsmaatregelen. Den Haag: Kennisinstituut voor Mobiliteitsbeleid (KiM).

ORTUZAR, J., IACOBELLI, A., VALEZE, C. (2000). Estimating demand for a cycle-way network. Transportation Research Part A, 34 pp. 353-373.

ORTUZAR, J. DE D., IVELIC, A.M., MALBRAN, H., THOMAS, A. (1993). The 1991 Great Santiago origin-destination survey: methodological design and main results. Traffic Engineering and Control 34, pp. 362-368.

ORTUZAR, J. DE D., WILLUMSEN, L.G. (2001). Modeling Transport. John Wiley & Sons: Chichester, UK.

PUCHER J, KOMANOFF C, SCHIMEK P. (1999). Bicycling renaissance in North America? Recent trends and alternative policies to promoting bicycling. Transportation Research Part A.33, pp. 625–654.

RAVEAU, S. , MUÑOZ, J. y DE GRANGE, L. (2011). A topological route choice model for metro. Transportation Research, A (45), pp.128–147.

SECTRA (2001). Encuesta de Origen y Destino de Viajes del Gran Santiago 2001. Mideplan-Sectra

SECTRA (2008). Informe Final estudio Actualización de Encuestas Origen Destino de Viajes, III Etapa. Mideplan-Sectra.

SHAHEEN, S. GUZMAN, S. Y ZHANG, H. (2010). Bikesharing in Europe, the Americas, and Asia. Transportation Research Record No. 2143, pp. 159–167.