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Working Paper

How the inaccessibility index can improve transport planning and investment

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International Transport Forum

How the Inaccessibility Index Can Improve Transport Planning and Investment

Discussion Paper

Floridea Di Ciommo
cambiaMO, Madrid

International Transport Forum

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OECD

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The needs-based approach and the inaccessibility index

Currently, the main framework for assessing transport investment adopts the utility-based approach, including preferences, choices and travel time saving. However, when the assessment is aimed at evaluating equity in transport, the utilitarian approach is not enough. Although costs and time saving are among the variables to consider, they are not sufficient for evaluating transport projects and investments in terms of equity (Martens and Di Ciommo, 2017; Guzman et al., 2013). Other variables such as the need to carry out specific daily tasks (i.e. health, schools, food shopping, taking care of other people's mobility) have a growing impact on the evaluation of the benefits of transport projects.

Relevant studies (Currie, 2004; Currie and Sembergs, 2007; Lucas et al., 2016; Guimarães et al., 2017; Litman, 2017; Di Ciommo et al., 2017) have shown the following:

1. The transport system is perceived as essential for key human needs in terms of safety and security in health, employment and social stability, particularly among low-income households, and its excessive economic weight in the household budget may compromise other household expenditures (health, education, quality of food).
2. Failing to meet these needs may result in physical, social, geographical and economic social exclusion.
3. Observing the real needs of people is very challenging because it can be difficult for them to express what they find it necessary and important to improve their quality of life, especially in mobility.

Generally speaking, needs are associated with rights. We have the basic need to have a place to live and we have the right to housing; we have the need to be in good health and we have the right to health care; we have the need to carry out specific activities, therefore the right to mobility. The European Union has established the right to mobility as a passengers' right. The right to mobility per se for potential users who need to carry out certain essential tasks does not exist. The mobility need has not yet been defined as a universal right. This right to mobility could be expressed on different levels (national, regional, municipal) where the question of mobility directly affects people's life. The human needs associated with mobility could be differently categorised. Some examples of these needs are: existence needs (exercise, health, safety and security, multi-tasking during travel, overcoming distance barriers to maintain life-opportunities, travel independence, time and monetary saving), relatedness (togetherness, care-giving, norms and social climate), and personal growth needs (self-esteem, competitiveness, self-identity, and self-actualisation with respect to environmental sustainability and fitness) (Alderfer, 1969). This paper is oriented to operationalise the concept of the existence needs.

The notion of needs is directly related to the notion of benefits: estimating the benefits of a person or a group of people means measuring how much their needs are covered. However, current methodologies are based on the sum of benefits that are homogenised and do not always provide evidence of unmet needs. In the current literature, various approaches have been proposed to estimate population

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benefits. These benefits may be weighted differently depending on given groups of the population, their location, transport services availability, socio-economic level, age, gender, etc. (Church et al., 2000). The complexity and the variety of these factors, linked to the fact that they are referring not only to quantitative concepts, but also to qualitative characteristics, make the transport benefits assessment difficult to define through the current cost-benefit analysis (Di Ciommo and Shiftan, 2017). Consequently, several indicators which capture social benefits in transportation have been defined over the last few years. Among them, the most widely used are probably those dealing with the accessibility concept (Geurs and Van Bee, 2004; Páez et al., 2012; Farber et al., 2014; Wang et al., 2015). The advantage of accessibility indicators is that they cover several characteristics of the transport-land use system in one indicator. By doing so, they can provide a comprehensive assessment of the accessibility "service" received by the population (Martens, 2015). The disadvantage of these particular indicators is, however, that they are estimated as a sum of various elements where the diversity of people in terms of mobility needs is homogenised. Therefore, one of the main objectives of this paper is to define an inaccessibility index which can reveal the diversity of people and their unmet needs. In other words, the differences will be highlighted instead of homogenised.

Needs-based approach: A methodology based on the inaccessibility index

People's mobility needs are defined as relevant when related to a specific trip, mode, activity and time of day. Therefore, the reasons why specific needs might not be satisfied can be understood through the activity itself (i.e. work, study, daily shopping, occasional shopping, health care, and visits to family and friends, or mobility of care) and its characteristics (i.e. location, travel time) (Psarra et al., 2013). The definition of needs would indicate to planners and policy makers where to intervene to meet people's needs.

The proposed methodology includes two main steps: focusing on the unmet needs related to specific activities and exploring activity characteristics such as the travel time.

We present a simple tool of diagnosis to verify needs through the joint analysis of merged mobility and satisfaction survey data related to each user and their trip, characterised by a specific time of day, a specific mode or chain of transport, and a specific activity to carry out. The starting point is the definition of the travel time threshold of a specific activity. It represents the travel time with which users are satisfied when carrying out this activity.

Based on the initial hypothesis that in transport the need is revealed by the lowest degree of satisfaction of the travel time for each needed activity (Arentze and Timmermans, 2009), each typology of trip is characterised by the origin and destination, the purpose, the transport mode and the length. Therefore, each trip typology is associated with an estimated travel time threshold.

The proposed inaccessibility index

This section introduces the inaccessibility index based on the travel time threshold to carry out activities, with the objective of assessing the equity and social inclusion of given groups of the population living in a given region of the Eastern Metropolitan Area of Barcelona. Specifically, the paper defines an inaccessibility (IA) index, which evaluates the inaccessibility of needed activities, using the satisfaction scores of a 10-point Likert scale (which is used for evaluating the Spanish school system), ranging from

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very dissatisfied to highly satisfied with a given travel time. In this study, the satisfaction of needs refers to the satisfaction with the travel time to the destination where individuals need to carry out their activities. Considering the satisfaction of needs through the proposed inaccessibility index would ultimately result in a more equitable transport system evaluation, where the main needs of all the impacted population groups are taken into account.

In particular, the adopted index would include people's satisfaction with a specific mobility characteristic of the activity they need to carry out such as travel time. When this satisfaction is high, the individual transmits that her/his need is covered. On the contrary, when this satisfaction is low, the individual will show that the need is unmet. In this context, the analysis of the mobility survey and trip' satisfaction will reveal where public transport networks should be improved to attract potential users who still do not have access to their needed activities.

The basic idea of the proposed IA index consists in defining a time constraint that limits the set of accessible activities using the current transport system, public, private and non-motorised which includes both walking and cycling. The proposed IA index is based on the idea that inaccessibility indicators can provide a comprehensive assessment of the accessibility "service" received by the population and used to elicit the needs of people to reach their activities. Technically speaking, the proposed inaccessibility index includes two novelties compared to the previous accessibility index: travel time thresholds for each typology of trip, and the group of unsatisfied people for each typology of trip.

The starting point is the definition of the travel time thresholds, representing the travel time with which users are satisfied when carrying out an activity. Therefore, these thresholds represent the travel time beyond which an activity is considered accessible by users.

Once the time thresholds have been defined for each trip typology, the IA index can be computed in the following way:

$$IA_{o,d}^{m,p,l} = 1 - \frac{\sum_{\mathbf{d=1}}^{\mathbf{n}} \boldsymbol{TT}_{\boldsymbol{o,d}}^{\boldsymbol{m,p,l}} * \sum_{\mathbf{i=1}}^{\mathbf{j}} \boldsymbol{NU}_{\boldsymbol{o,d}}^{\boldsymbol{m,p,l}}}{\sum_{\mathbf{i=1}}^{\mathbf{g}} \boldsymbol{NU}_{\boldsymbol{o,d}}^{\boldsymbol{m,p,l}}} \quad (1)$$

where:

- *m* represents the transport mode; *p* the trip purpose; *l* the length; o the trip origin and *d* the trip destination.
- *TT* is the time threshold defined for a given trip typology; it is equal to 1 if the travel time is less or equal than the time threshold. Otherwise it is 0
- *NU* is the number of users making a given trip
- *n* is the number of the considered typologies
- *j* is the number of users which are realizing the same trip and that are satisfied
- *g* includes the number of both groups of satisfied and unsatisfied users, that are carrying out the same typology of trip.

This index allows us to differentiate between the inaccessible activities and the accessible activities. Therefore, when the IA index decreases, the accessible activities set increases: a value of the index equal to zero means that people could reach the activities they need to carry out.

Interpretation of the index: The case of Barcelona

The selected geographical area: Eastern Barcelona Metropolitan Area

The needs-based methodology has been implemented as a pilot in some municipalities in the Eastern Barcelona Metropolitan Area (BMA). The areas were selected following three main criteria: the level of income, population profile, and public and private transport level of services.

The four municipalities in the Eastern BMA, which were identified following the three main criteria are Cerdanyola Del Vallès, Sant Adrià de Besòs, Montcada i Reixac and Santa Coloma de Gramenet. The Barcelona Metropolitan Area, better known as Greater Barcelona, is a territorial entity composed of Barcelona and 36 neighbouring municipalities. It has a population of 3 239 337 in an area of 636 km^2. The identified area occupies 10% of the extension of the BMA with a population of roughly 5% of the total of the Metropolitan Area of Barcelona. The most sprawled out city is Cerdanyola del Vallès with its 30.60 km^2, and a population density of 1 883.73 ha/km^2, while Sant Adria de Besos is the most compact city (3.90 km^2 with a population density of 8 758.21 ha/km^2). Santa Coloma de Gramenet is the city with the highest population density of 17 017.46 ha/km^2 in 7.10 km^2 (IERMB, 2012). The income level in this area is between 21% and 30% lower than in the city of Barcelona, while its population includes between 35% and 43% of retired people.

These municipalities have been chosen not only because they are close to each other and differ in terms of extension, population profile, population density and income level, but also because the quality of public services that they present is different, with a reduced number of metro and regional railways stations (i.e.1-7) and a diverse number of bus lines of between ten and eighteen each.

Because equity and inequality can be better verified in lower scale areas, the proposed methodology has been implemented in lower scale areas related to the identified centroids. Fifteen specific analysis zones (AZs) have been created. Specifically, six AZs for Cerdanyola del Vallès, three for Montcada i Reixac, two for Sant Adrià de Besòs and four for Santa Coloma de Gramenet. Each AZ is indicated with the first three letters representing the name of the municipality and a number (i.e. 1-6). For example, the AZ number 2 of Sant Adrià de Besòs has been identified by BES02. Figure 1 represents the identified AZs.

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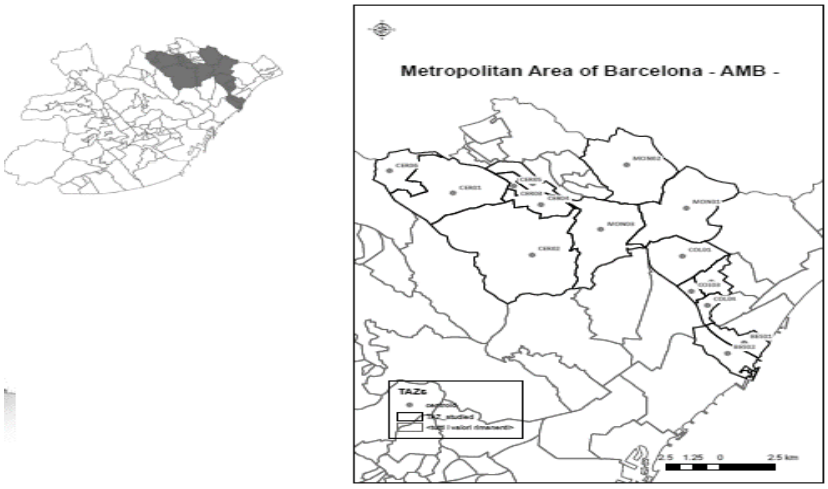
Figure 1. Eastern Barcelona Metropolitan Area



Source: Own elaboration in QGIS.

The dataset

This study implements the proposed index based on the data obtained from the mobility survey carried out by the Institute of Regional and Metropolitan Studies of Barcelona (IERMB) over the course of 2013. The objective of the survey was to identify the mobility patterns of inhabitants on weekdays (Monday to Friday) in the municipalities of Barcelona Metropolitan Area.

The questionnaire was submitted to users through a computer-assisted telephone interviewing method (CATI) and is divided in three parts: the first part concerns information related to the trips made the day before the survey (e.g. origin and destination of trips, purpose of trips, length of trips, transport mode, travel time). If any trip was made the day before, the interview then continued with an evaluation. The second part includes questions about the user's satisfaction through a 10-point Likert scale. The third part focuses on the users' socioeconomic information (i.e. age, occupation).

This research selected the mobility survey data concerning people living inside the four Eastern Municipalities of BMA and whose trip purposes include work, study, daily shopping, occasional shopping, health care and visits to family and friends. The considered transport modes are regrouped in three types: non-motorised transport (NMT) which includes walking and cycling; public transport, which includes bus, metro, tramway and train; and private transport, which includes cars and motorcycles, either as a driver or passenger.

The data preparation includes six steps:

1. Selecting the mobility survey data on people living inside a specific area (i.e. Eastern Municipalities of BMA) and whose trip purposes include work, study, daily shopping, occasional shopping, health care and visits to family and friends.

2. Making a preliminary analysis of the new sample, including inhabitants who have their origin and destination both inside and outside the considered area.
3. Regrouping the filtered data by typology of trip: people with the same trip purpose, transport mode and length of trip were included in the same typology (Di Ciommo et al., 2016).
4. Defining a given time threshold for each of the categories in the above typology, based on the users' level of satisfaction.
5. Highlighting the typologies of more problematic trips associated to less accessible activities (i.e. lower satisfaction with travel time).
6. Finding groups of population that seem to experience less satisfaction when it comes to meeting their needs.

The methodology of the needs-based approach is then developed in three phases:

- defining the trip typology and time thresholds
- estimating the inaccessibility index for identifying unmet needs
- identifying population groups with unmet needs.

Identification of trip typology and time thresholds

Following the initial hypothesis that a lower degree of satisfaction with a particular characteristic of an activity (such as travel time) means that the user's needs are not satisfied, we propose to work on identifying trip typology and time thresholds.

Time thresholds have been defined using the data from the second part of the mobility survey, where people were asked to evaluate from zero to 10 their level of travel time satisfaction with their last trip, and to indicate the duration of this trip.

Users' level of satisfaction is defined as follows:

- High satisfaction for Likert points between 10-8
- Medium satisfaction for Likert points between 7-4
- Low satisfaction for Likert points between 3-0

It has been assumed that a satisfaction level between 7 and 10 (the first two population groups) means that the user is satisfied with their travel time. Consequently, this means a higher satisfaction in terms of their needs. Table #1 includes some examples of trips typologies and associated time thresholds and their statistical average, mode, and median values of travel time.

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Table 1. Examples of identified time threshold (TT) (in minutes)

Trip typology	TT Average	TT Mode	TT Median
CER04_CER06_2_3_2	18,5	15	15
MON01_MON02_1_1_1	10,16	10	10
BES02_COL03_4_2_3	32	30	25
COL02_BES01_6_3_2	28	25	25

Legend:

Each code (i.e. CER04_CER06_2_3_2) includes: origin_destination_purpose_mode_length

1) Origin and destination use the code of identified AZs

2) Purposes refer to work=1, study=2, daily shopping=3, occasional shopping=4, medical=5, visit=6

3) Modes of transport refer to NMT=1, PUBLIC=2, PRIVAT=3

4) Length: 0-5 km=1, 6-15 km=2, 16-25 km=3, etc.

Source: Own elaboration from mobility survey, IERMB (2013)

Estimation of the inaccessibility index for identifying unsatisfied needs

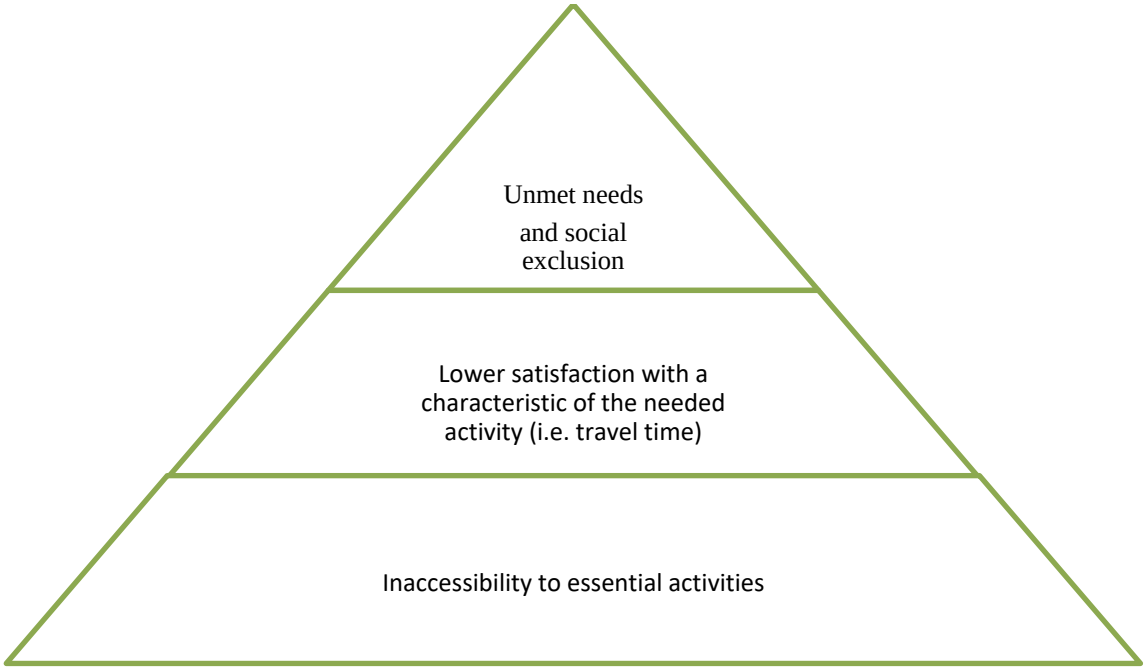
The second phase estimates the inaccessibility index. Once the time thresholds have been defined for each trip typology, the IA index is estimated for people who have shown the need to make a given trip to reach a given activity.

This index allows us to identify the inaccessible activities for specific groups of population. The IA index evaluates when people can or cannot reach the needed activity, where the need is measured by the lowest satisfaction degree with respect to the current travel time. Upcoming needs-based appraisal methods in transport indicate the satisfaction of these needs as a measure of equity (Alderfer, 1969). The pyramid below shows the needs-based approach for equity assessment where the inaccessibility index estimation is the first step to reveal the unmet needed activities for specific groups of people. Therefore the implementation of the proposed inaccessibility indicator in the analysis of Eastern BMA will open up a debate on where and for whom actions should be focused within the selected geographical area characterised by a lower level of public service, lower income and a population at risk of social exclusion (Cebollada, 2009).

Table 2. Inaccessibility index estimation

Zone	IA INDEX
MON01	0.356481481
MON02	0.358078603
MON03	0.308823529
CER01	0.475409836
CER02	0.506329114
CER03	0.344827586
CER04	0.441295547
CER05	0.512345678
CER06	0.216666667
COL01	0.376569038
COL02	0.528037383
COL03	0.531707317
COL04	0.424836601
BES01	0.310126582
BES02	0.265957447

Figure 2. Identification of needs in transport through the inaccessibility index



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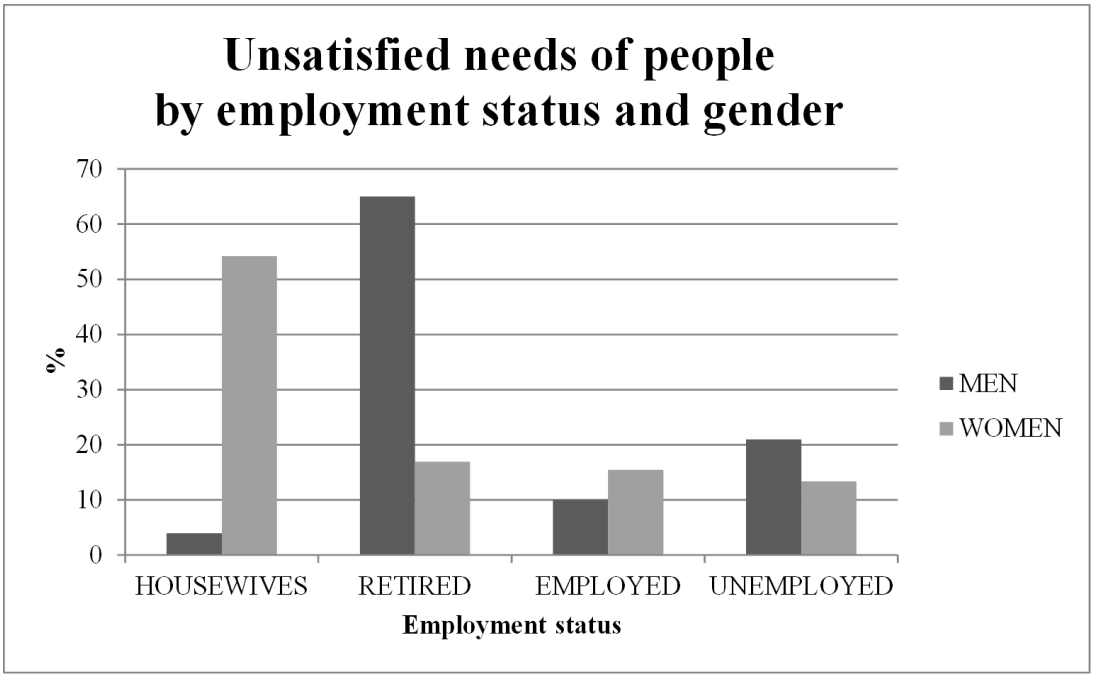
Eliciting people's needs

The third phase is aimed at identifying population groups who need to carry out essential activities. It is a simple method for eliciting the needs of people who could indirectly express what they find necessary and important to improve their quality of life. This would indicate where planners/policy makers should intervene to help those people meet their needs.

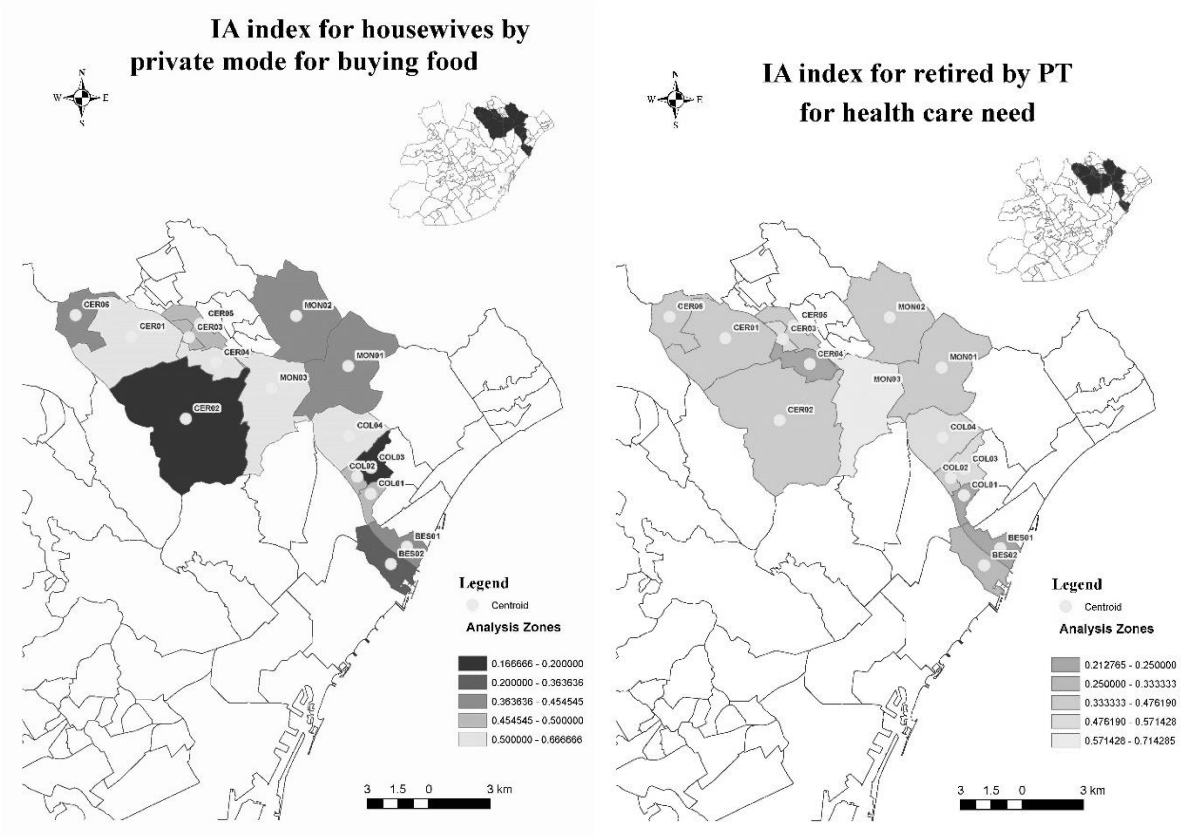
The aim of adopting the needs-based approach is to elicit the needs of people through their low level of satisfaction. Following the initial assumption that a lower degree of satisfaction with a particular characteristic of an activity, such as travel time, means that the travel need is not satisfied, we find population groups with unsatisfied needs (Di Ciommo et al., 2016). Considering the gender and employment status of users, the results show that retired men and housewives are the least satisfied among the other groups (Figure 4).

Figure 4. Least-satisfied needs of retired men and housewives



The analysis of people's satisfaction shows that in the case of retired users, their need to reach health facilities through public transport alternatives is not met (i.e. 62% of respondents assessed negatively their satisfaction), while the needs of housewives to do daily shopping through the private transport mode are not met either(i.e. 53% dissatisfied). Otherwise, 46% of respondents who answered negatively about their medical trip purpose are over 65 years old, and retired. Both population groups (the retired-elderly and housewives) cannot satisfy their own needs and thus are in a state of non-equity and at risk of social exclusion.

Figure 5. IA index for housewives and the retired-elderly



Potential incorporation into transport planning/assessment frameworks

From an equity perspective, transport policy should be mainly addressed to identify groups of population so as to increase the satisfaction of their needs to carry out a specific activity. In sum, the degree of satisfaction is how users can reveal their needs.

The natural implementation of the needs-based approach is aimed at including the inaccessibility index in the current transport assessment framework adopted by local authorities. When this framework includes the cost-benefit or multicriteria analysis of transport projects, the needs-based approach will be prone to the inclusion of the inaccessibility index in that analysis.

We are implementing the inaccessibility index related to the needs-based approach for two different transport planning initiatives:

1. The assessment of the tramway extension between Sant'Adriá de Besós and Badalona for the Transport Authority of Metropolitan Region of Barcelona.
2. The contribution to the strategic planning to decrease the inaccessibility of the poverty corridors in east Barcelona.

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According to the information gathered on actions in the field of mobility and transport projects, a typical analysis and a specific diagnosis will be carried out, which will allow us to detect the adequacy and effectiveness of the current metropolitan policy in transport according to how transport policies and projects are currently assessed. This analysis is carried out within the Metropolitan Transport Authority of Barcelona, the transport planning department.

This analysis is based on the fact that transport is mainly a derived demand related to the possibility of accessing the daily activities of the population. For this purpose, the indicator of inaccessibility for inhabitants will be estimated and oriented to identify groups of people with less access to their daily activities. An assessment of the needs of these groups will then complete the analysis.

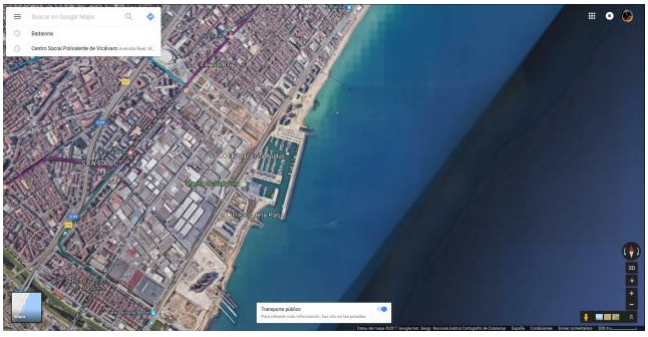
This inaccessibility indicator is estimated to be integrated into the current assessment framework of the ATM. This CBA function can be used as a pilot for assessing transport infrastructures in the Metropolitan Region of Barcelona and the corresponding transport policies. In particular, data from the mobility survey and transport projects will be used.

This project responds to the inclusion in the assessment framework of the inaccessibility index.

Ex-ante assessment of Sant-Andriá de Besós-Badalona port Tramway extension

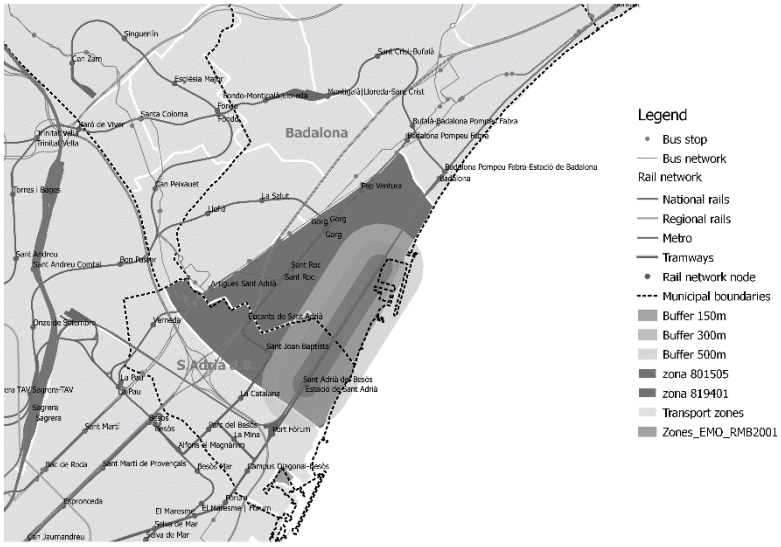
The extension of the tramway (T4) consists in 1.7 additional kilometres between Sant'Adriá de Besós and the Badalona port. This urban area includes a logistic and services zone where some space is occupied by informal housing for immigrants, a gentrified zone and a tourist port sector (Figure 6).

Figure 6. Urban area of tramway extension: Sant'Adriá-Badalona port



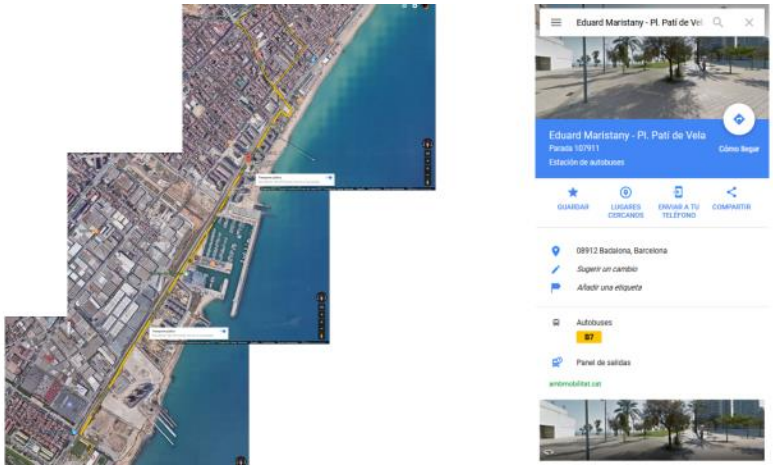
Three different buffers at 150, 300 and 500 metres have been designed around the tramway extension to define the zones including potential groups of population that could benefit from this extension in terms of their activity accessibility needs (Figure 7). After this spatial delimitation, two specific mobility zones have been identified: Zone 2 of Sant'Adriá de Besos and zone 5 of Badalona. The estimation of the inaccessibility indicator in both mobility zones shows an inaccessibility index referring to all transport modes of 0.26, which is lower than the IA index of the rest of east Barcelona where Santa Coloma de Gramenet presents an IA index value of around 0.50.

Figure 7. Buffers for eliciting tramway extension information



Source: Own elaboration in QGIS (2017).

Figure 8. Current public bus patterns within the potential tramway area



Source: Own elaboration by Google Earth (2017).

The IA index contribution to the BMA strategic plan for decreasing poverty corridors

The second implementation of the needs-based approach for the inaccessibility index refers to the assessment of certain transport planning strategies aimed at poverty corridors.

The main transport planning strategy of the Barcelona Metropolitan Area includes seven main points:

1. Limit the entry of vehicles according to the ecological tax for outbound roads (i.e. ZBE).

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2. Reduce the use of the private vehicles through a parking policy in which any parking spaces in the public area have to be regulated within the Metropolitan Urban area, and not only in Barcelona.
3. Improve the supply of rail transport mainly through measures which improve the efficiency of the existing infrastructure or through better organisation of the intermodal nodes such as the stations Torrassa, Montcada and Baricentro, in addition to the existing ones. Rodalies and Metro can increase their capacity by 40% through some investments.
4. Extend certain metro lines (L3 fins Hospital de Sant Joan de Deu) and tramway lines in strategic corridors (through the Diagonal connection, the extension from Sant Adrià to Port de Badalona, and from Laureà Miró a Esplugues).
5. Organise a competitive bus network around the poverty corridors which includes BRT corridors (C-245, C-31, B-23, C-58) and the establishment of interurban stations. This new network involves the Barcelona NXB model as well as other companies adapting solutions to needs.
6. Define a strong Park&Ride policy with centres in Castelldefels, Montgat, Barberà-Baricentro and Sant Andreu, which is attached to an extension of the Park&Ride railway station for vehicles and BitiBi models for bicycles within Barcelona Metropolitan Area.
7. Define a mobility plan around the industrial polygons focused on the urban areas of El Prat-Zona Frana; Cornellà-Hospitalet, El Pla (Sant Feliu-Molins de Rei), Badalona South andMontigalà, among others.

In the context of the strategic plan, the BMA asked for the definition of a tool to help decision making, particularly around the identified poverty corridors (Figure 9). The implementation of the needs-based approach highlights in the case of the R4 (N150) poverty corridor that there is a clear correspondence between the revealed needs of inhabitants and the lower level of services of public transport. The match between the needs that people state through the mobility survey and the lower LOS of public transport is fairly consistent (Figure 10 and 11). In this case, the transport planning task is clearly suggested by the bottom-up information: the need of inhabitants is evident, and it is, at least, related to the lack of public transport.

What is more difficult to show is the potential relation of the causality between lack of public transport and the socio-economic poverty of the considered area. We should continue with the correlation and investigate the other socio-economic factors that could be determinants of the poverty corridors. More than anywhere else, this kind of spatial area needs joint and inter-sectorial interventions in terms of education, health, land use and transport planning policies. Transport can solve a part of the problem.

Figure 9. Identified poverty corridors: A BRT proposal

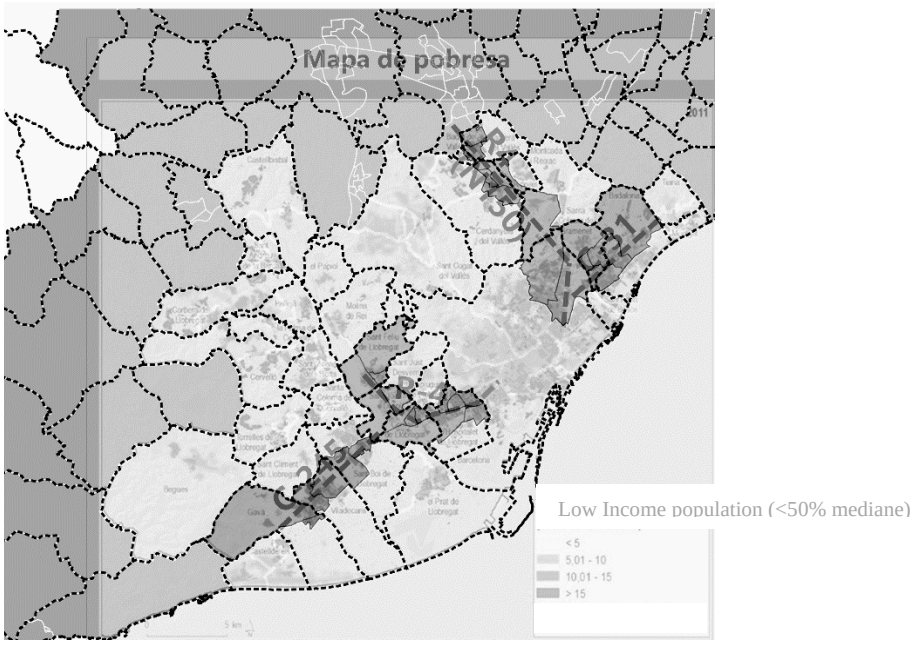

Figure 10. Estimation of the IA index for revealing people's needs

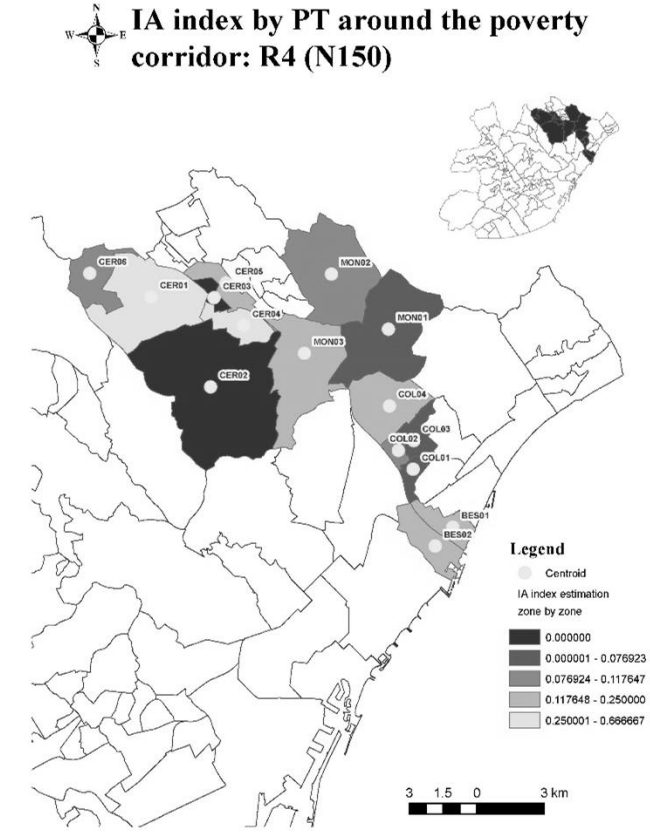

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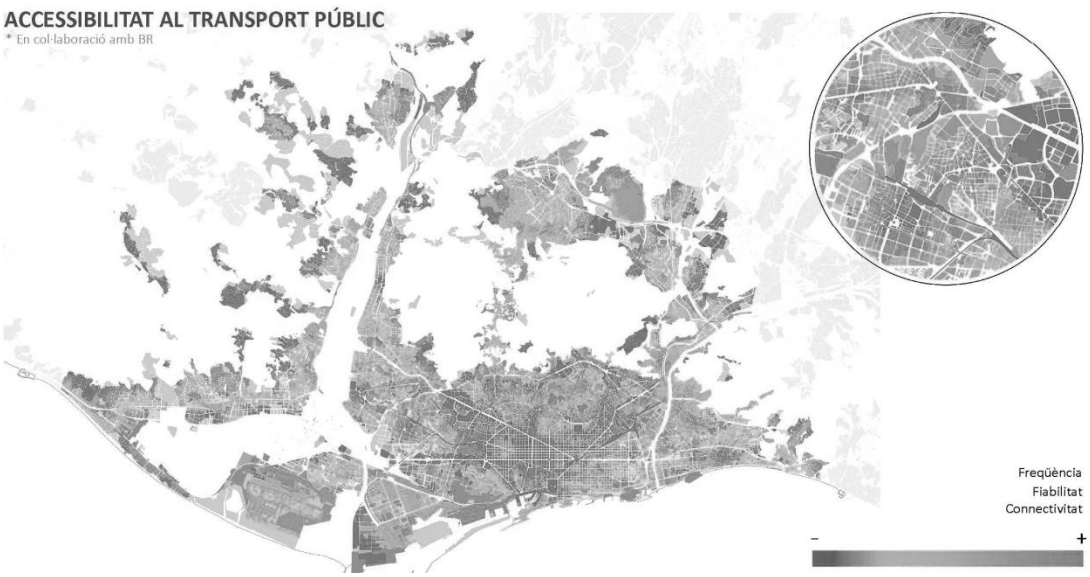
Figure 11. Public transport accessibility through the supply side: Frequency, reliability and connectivity



Source: PDU, Urbanism department of AMB (2017).

Conclusions

Following the initial hypothesis that a lower degree of satisfaction with an activity characteristic such as travel time means that the need of the user is not satisfied, we find population groups to whom transport policy should be mainly addressed so as to increase transport equity.

The opportunity of reaching activities in given areas is represented by time thresholds, transport networks location and the users' level of satisfaction regarding unmet needs. A low satisfaction level in reaching the needed activity means that the needs are not completely satisfied, and that there is some risk of lower quality of life and social exclusion.

The first results for the low-income part of Barcelona Metropolitan Area show that:

- Policy makers should invest a greater effort to win over vulnerable groups of the population, such as pensioners and housewives, who revealed their unmet needs.
- The network effect that is to the detriment of low-income social groups when they face a sparse public rail transport network should motivate planners to design a public transport bus network, able to be competitive with private vehicles. This measure would be beneficial to vulnerable groups who advocate easy access to the activities they need to carry out.
- The inclusion of the inaccessibility index in the current assessment project transport framework provides a way to consider equity in a non-paternalistic approach, and using the needs which have been revealed. This new approach has the advantage of including the micro-foundation of the stated choice preferences, considering groups of people in need. In fact, needs are a broader concept than simply preferences: all people are able to express their needs.

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How the Inaccessibility Index Can Improve Transport Planning and Investment

Within the equity in transport framework, this paper will provide an overview on the rationale of using the needs-based approach for transport planning assessment. The paper is structured into three parts. First, the presentation of the needs-based approach using the inaccessibility index. Second, the interpretation of the index through the case of Barcelona. The focus will be on how the inaccessibility index allows us to capture relevant information on the satisfied mobility needs of different population groups (particularly for vulnerable groups of the population) through different transport modes. Finally, the potential incorporation into transport planning/assessment frameworks. This section discusses the ways in which the index could be implemented in two different contexts: ex-ante infrastructure evaluation and assessment of a deprived geographic area for transport strategic planning.

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