"MOBILIDAD EN LAS ALTURAS": An analysis of space-time activity patterns and urban configuration of La Paz - Bolivia

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Abstract

A concept that provides insights into the complex relationships between individual activity patterns and the opportunities and constraints offered by the land use and transportation system is accessibility. This paper presents the results of an analysis of accessibility equity based in the analysis of space-time activity patterns and urban configuration for a group of habitants who lives in the hardest topographical zone of La Paz, Bolivia. The 2012 OD survey was used for this research. Results indicate the influence of topographical barrier in individual accessibility, showing that the most constrained travel times are were people of low income lives. Finally, a discussion about the actual urban mobility strategies of the governments of La Paz is presented.

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1. Accessibility, activities and urban configuration

Over the years hundreds of studies have been concerned with measurement and application of the accessibility concept. From different forms of view, accessibility can be considered an important issue of quality of life (Pirie, 1979; Kwan, 1998, 1999; Dijst, et al., 2002; Miller, 2007; Neutens, et al., 2007a, 2007b; Feng, et al., 2013). Many indicators are based on a definition of accessibility as the amount of effort needed to reach available services to conduct particular activities (Pooler, 1987; Kwan, et al., 2003).

People travel to engage in a range of activities at spatially distributed locations. While some of these activity engagements occur only occasionally, others are performed on a recurrent basis at fixed locations and/or times. The urban environment accommodates services, employment opportunities and other facilities where individuals may conduct desired activities (Neutens, et al., 2007a, 2007b). The relationship of cities supplying individuals with resources as well as constraints can be interpreted as the accessibility.

The measurement of accessibility has taken on different forms. The best known of such measures are distance or travel time, cumulative opportunity measures, and gravity-based measures. (Vickerman, 1974; Wachs and Kumagai, 1973; Neutens, et al., 2007a, 2007b) Another best know measurement of accessibility is the space-time accessibility from the Hägerstrand's Time Geographic framework where the focus is the measurement of the time and space consumption made by an individual during the development of his activities in an time constrained environment (Miller, 1999a, 2007; Kwan, et al., 2003; Neutens, et al., 2007a, 2007b). The concept of space-time accessibility is going to be applied because it suits better for the scope of this paper.

Spatially, accessibility by definition will not be the same to every point or zone in a city. In general, people living in suburbs and the countryside will need to travel further to central locations where most jobs and other activity destinations are located (Feng et al., 2013). It implies that equity in accessibility will not be present in urban systems. Considering equity in the discussion of accessibility is extremely important in the context of the social inclusion and the space-time autonomy of an individual, which is often centered on the requirement of equal access to a range of urban services for disadvantaged groups. Well-known early examples of equity in accessibility include Talen (1998) and Nicholls (2001). And a modern approach can include Feng, et al. (2013)

La Paz was lacking of an urban mobility planning for many years. The were focus in the implementation of infrastructure like highways, bypass, etc, leaving the service of public transportation be deficient. Those problems and the urban growth and configuration of the city have a high impact on people's quality of life, generating more constrained activity travel patterns. Actually, La Paz is in an important moment where people are demanding solutions for a deficient public transportation service and requiring for more quality of live. The national government of Bolivia and the Municipal government of La Paz are implementing respectively two projects of public transportation that are looking to attend the demand of their inhabitants.

It's by means of this context that the objective of this paper is to analyze the equity in accessibility of La Paz inhabitants. After that, Based on the results of the analysis it's made an evaluation of the projects of public transportation that are in implementation.

In the section 2 we discuss the background, data and methodology adopted for this paper. Section 3, we present the results of the analysis and the evaluation of the two projects. In the section 4, we summarize and conclude this paper.

2. Background and methodology

2.1 La Paz city

The city of La Paz or "Nuestra Señora de La Paz" (Figure 1), the seat of government and administrative capital of the country, is one of the most important cities of "El Estado Plurinacional de Bolivia". This city, located south west of the country, is characterized by rugged topography that is very unique to other cities which are often installed in places where flat plains.

The city of La Paz was initially founded in the town of Laja , on October 20, 1548 by Captain Alonso de Mendoza, which was later moved to what is now the city of La Paz, i.e. that town founded banks Choqueyapu river , which today is the center of the city, surrounded by neighborhoods located on the hillsides that make up this . Originally the city was founded by its strategic position as a resting point between the cities of Cuzco and Potosi.

Politically the city of "Nuestra Señora de La Paz" is located in the department of the same name, Murillo province and the municipality of La Paz. According to the latest census conducted by the National Institute of Statistics, the city has a population of 764,617 inhabitants, making it the third largest city with largest population of Bolivia.

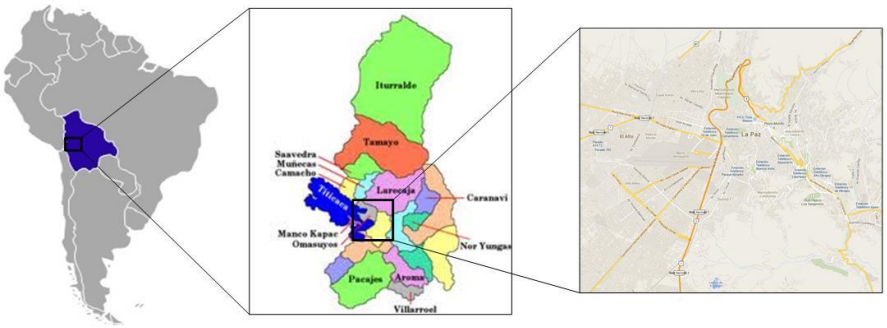


Fig. 1. La Paz city localization

2.2 The transportation problems in La Paz city

One principal problem is the public transportation service combined with the concentration of opportunities and employment in the Central Business District of La Paz. Another problem is the difficult topography of La Paz that has created urban expansions in most of the hillsides of the city. Most of the people living in the city is dependent of the transit service. The high expenses of having a car and the constrained urban configurations are reasons that explain why people are dependent of transit service.

The transit service is composed by organizations (syndicates, associations and cooperatives) and not enterprises like in other countries. This service lack of regulation because the central government had declare in past years the urban transit service as a free profession. So, the service has been imposed as an informal public transit system without planning and regulation. It's very hard to explain the whole history about the transit service in both cities. The fleet is composed by microbus and vans of 14 seats and 7 seats. Each vehicle has one only owner, so in a fleet of 2000 vans there are 2000 owners. That is one of the reasons why it is complex to make an institutional change in the organization of transit service.

As a result of these problems, there are many social and economic impacts in the population. There is a surplus of transit lines in the urban zones with

high demand, from 100% of the flow observed in an arterial street approximately 80% is of transit lines and 20 % is of individual cars. Traffic jams are because of the surplus and disorganization of transit lines. The transit fare obeys more a political decision than a technical decision. And finally one important problem is about security, especially for women and children. In the past years there were reported cases of sexual harassment, robbery and murdering in some vehicles of the transit service. About accessibility there are some impacts that could be identified: uncertainty in travel times, low reliability of the transit service at night. Because of the urban expansion on the hillsides of the city the access by walk to transit service in some urban zones takes high travel times.

2.3 Data

Data was collected from the Household OD Survey of the "Plan de Mobilidad Urbana Sustentavel 2012", made by the municipal government of La Paz City. 4728 households were interviewed for La Paz City and 1550 households for El Alto City. The city was divided in 317 traffic zones for the survey, as shown in Figure 2.

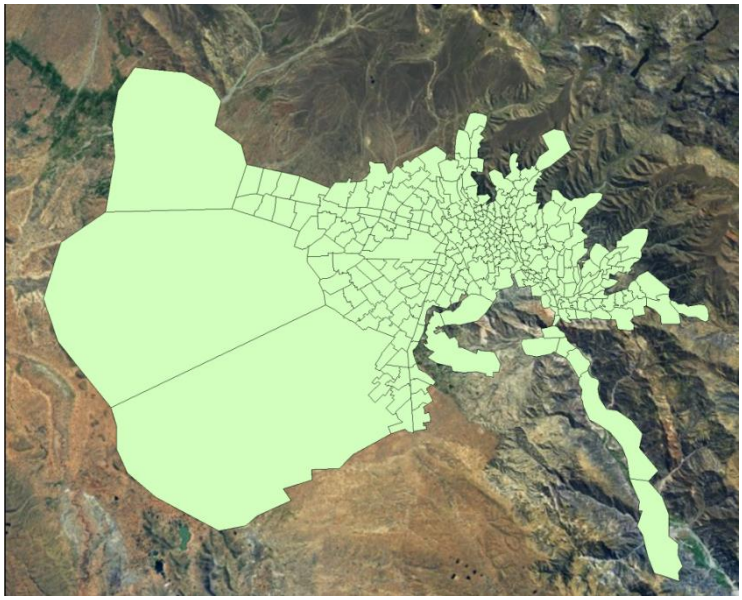


Fig. 2. Traffic zones of the cities La Paz and El Alto

The number of trips generated in the metropolitan area of La Paz and El Alto was obtained from data reported by citizens' travel in the OD Survey. This result is presented for the entire metropolitan area. The number of trips by mode of transportation is summarized in Table 1. The main information collected relates to all trips made during the day previous to the survey by members of participating households. As a standard procedure, participants are selected randomly for the survey, and then validated for representativeness. In addition to travel information, different attributes of the household and its members are asked, including the age of household members, their gender, and vehicle ownership.

Table 1. Number of trips by mode of transportation

Transportation Mode	Number of Trips (passengers/day)	Percentage (%)
Individual Transportation	129,137	4.7%
Public Transportation	1,931,969	71.0%
Walking	656,249	24.1%
Bicycle	5,639	0.2%
Total	2,722,994	100.0%

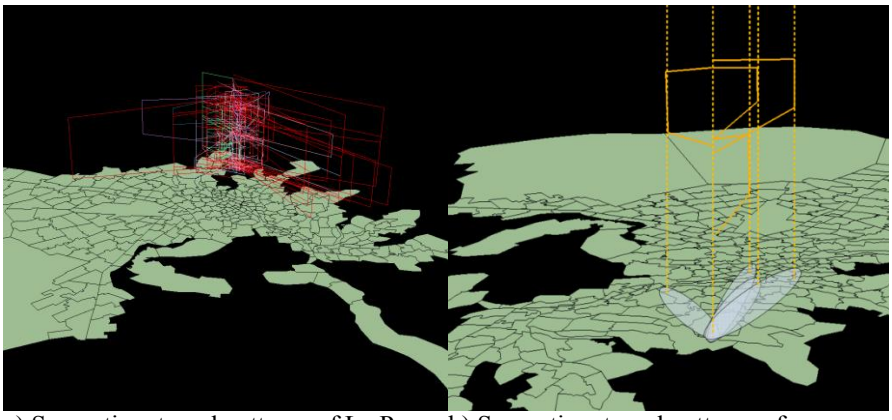
For the purposes of this research, we have extracted all activity-based travel patterns from the database, to obtain a subset of 16,563 travel patterns made by inhabitants of La Paz, and 3,571 travel patterns made by inhabitants of El Alto. Use of activity-based travel patterns means that the indicator implemented is individual accessibility at the place of residence. A different implementation could be of accessibility from the perspective of place of employment, although we do not pursue such route further in this paper. As the OD survey was conducted by the Autonomus Municipal Government of La Paz, the focus of the survey was directed on collect data from La Paz households and an representative sample of El Alto at district level. That explains the less data collected from El Alto households. A more rich data from El Alto Households can improve the results found in this paper.

2.3 Methodology

Space-time activity patterns

The activities were classified in 7 categories: Home (H), Work (W), Study (S), Leisure (L), Special errands (C), Health (M), Others (O). The category of Special errands refers to activities that involve formalities at government like taxes payment, etc. With that classification the activity travel patterns

were constructed for each individual in the survey. For the construction of the space-time activity patterns, the home-based origin and destination of each trip was geocoded with x–y coordinates using structure databases on addresses. Because of the lack of specific coordinates for the origins and destinations based in the other categories, the x-y coordinates of traffic zones centroid were geocoded for those categories. The space-time activity patterns were created for geographical illustrative purposes of the estimated consumption of space and time of each individual (Figure 3a,b).



a) Space-time travel patterns of La Paz

b) Space-time travel patterns of a specific household

Fig. 3. Space-time travel patterns of La Paz city habitants

Individual Accessibility

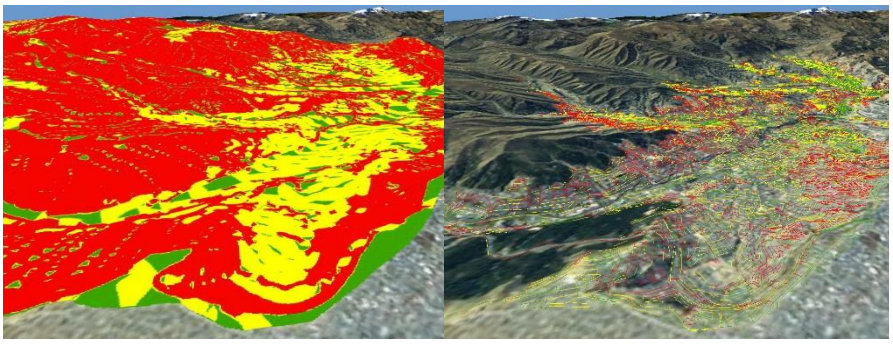
The individual accessibility was measure by travel times in minutes. The OD survey collected the travel times for each trip on the OD survey. The total travel times were calculated for each travel pattern and also the travel times of commute to work were considered for analysis. Segmentation for the inhabitants of La Paz and El Alto were made to compare the individual accessibility of both inhabitants. After that, aggregation at traffic zone level was made for a comparison of average travel time of La Paz.

The individual accessibility is proposed from the definition of space-time autonomy of an individual and the behavioral constraints that affect it (Burns, 1979; Ashiru et al., 2004). That space-time autonomy is affected by the constraints and opportunities imposed by the urban space to an individual. So, the zone with the hardest topography can be considered as the zones

where the space-time autonomy of an individual of a household is very constrained. Specifically, that individual has limited access to resources, opportunities and activities during a day.

People living in suburbs and the countryside will need to travel further to central locations where most jobs and other activity destinations are located. In addition, city dwellers experiment higher travel times to central locations, because of the hard topography that restricts the accessibility to transit service. In these cases, the geomorphology of the city can affect the space-time autonomy of an individual. An example of this type of cases is the city of La Paz where its transportation network had to be adapted to its complicated topography.

So in order to consider a real individual accessibility it is important to identified the urban morphology where the people lives. A digital elevation model (DEM) of La Paz City was constructed in order to obtain the gradients in the transport network of the city (Figure 4a). Applying a geo-processing technic the 3D network containing the gradients of the transport network of the city was obtain and linked with the travel patterns (Figure 4b)



a) La Paz digital elevation model b) 3D Transport network with gradients

Fig. 4. 3D Transport Network of La Paz

Measurement of equity

The Gini coefficient is a very popular coefficient used to measure equity. So, we decided to use this coefficient to measure equity in accessibility. For a discrete probability function, let $f(y), y_1, i-1,...,N$ denote the points (individuals, zones) with zero probabilities, indexed in increasing order $y_i < y_{i+1}$. Then, the Gini coefficient can be expressed as:

$$G = 1 - \frac{\sum_{i=1}^{N} f(y_i)(S_{i-1} + S_i)}{S_n} \quad (1)$$

Where

$$S_i = \sum_{j=1}^{N} f(y_j) y_j \quad (2)$$

And

$$S_0 = 0 \quad (3)$$

The Gini coefficient (G) is defined to be in a range from 0 to 1. A low Gini coefficient indicates a more equal distribution, while higher Gini coefficients indicate more unequal distributions, with 0 and 1 corresponding to complete equity and complete inequity, respectively. In the equity measurement of accessibility, y_i indicates the travel time between different zones. A longer value of G will thus indicate less equitable distribution of travel times. Likewise, a value closer to 0 means a more equitable distribution of travel times.

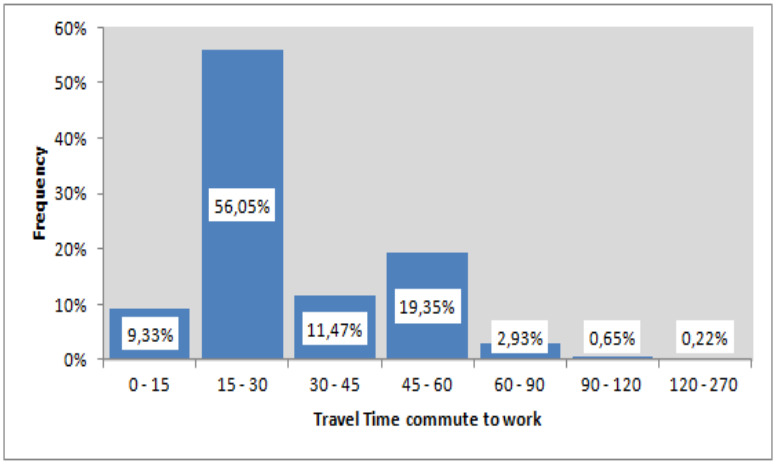
3. Results

3.1 Frequency Distribution

Figure 5 represents the frequency distribution of the travel times to work, total travel times for activity patterns and the average travel times by zone. As shown in Figure 5(a), for La Paz inhabitants, 9.33% of the travel time to work is in the range of 0 to 15 minutes, while the majority of travel times (56.05%) falls in the range between 15 to 30 minutes. 11.47% of the travel time are in the range of 30 to 45 minutes, and 19.35% falls in the range between 45 to 60 minutes. Few trips have a travel time longer than an hour.

Figure 5(b) shows the frequency of the total travel time of the activity pattern for La Paz inhabitants. About 41.66% and 22.69% of the travel times are in the range 30 to 60 minutes and 90 to 120 minutes respectively. 19.04% of travel times is in the range of 60 to 90 minutes. Few activities patterns have a total travel time longer than two hours (120 minutes).

Figure 5(c) show the frequency of the average travel time by zone of both cities. As shown in the bar chart, the highest frequencies (68.54%) for La Paz is in the range 60 to 90 minutes. In addition, only 6.18% of the average travel time is between 30 to 60 minutes.



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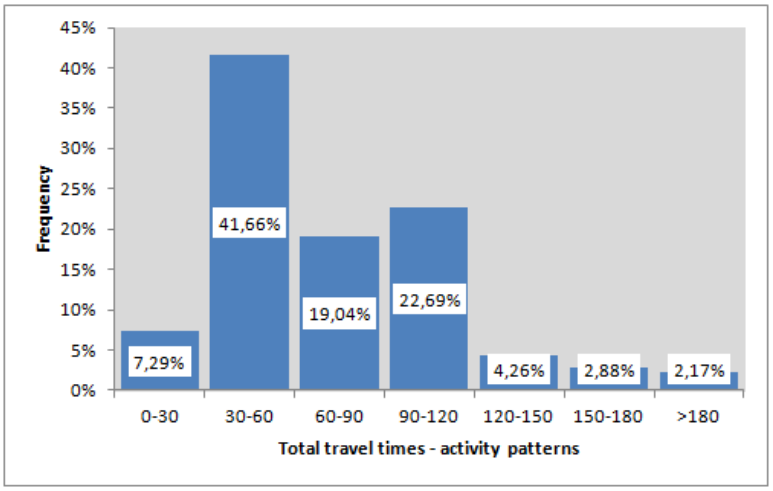

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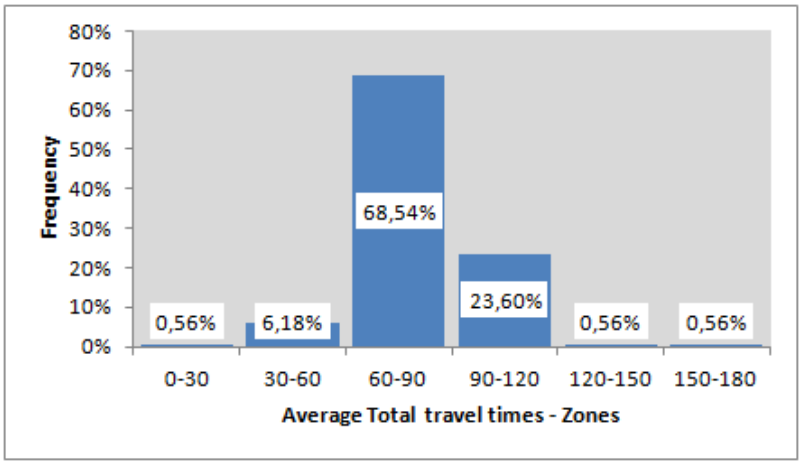


c)

Fig. 5. a) Travel times to work La Paz; b) Total travel times La Paz; c) Average Total travel times by zones La Paz

3.2 Equity of accessibility

In order to measure the equity of travel time in the aspect of spatial and horizontal dimension, Gini coefficients were calculated for all three cases. The coefficients were calculated according to the travel time across all individuals, for the travel times to work and total travel times of activity pattern respectively, and across zones for the average travel times.

In the case of individual level in La Paz (Table 2), the most equitable distribution of travel time is the travel to work (0.1342), while the most inequitable distribution is the total travel time of the activity pattern (0.2105). Analyzing the space-time activity patterns was possible to find that the majority of the patterns were concentrated in the central area of La Paz. This suggests that people are more restricted to develop activities at the central area of the city. That restriction is about the distribution of opportunities relative to home locations and the uncertainty of the transit system, because the majority of the zones are dependent of this service. Another problem is the transit service with a low reliability and no integration.

Unlike equity at individual level, equity at zone level measured low differences in a special dimension. As shown in Table 3, the most equitable distribution is obtained for the average travel time of La Paz (0.0469).

Table 2. Equity of Accessibility of La Paz

Level of analysis	Gini coefficient
Travel time to work	0.1342
Total travel time of activity pattern	0.2105
Average travel time at zone level	0.0469

3.3 Identifying the most constrained zones

In order to identify the most constrained zones was made the next steps: i) first where chosen the members of a household whose travel time to their principal activity was the maximum from the travel time of the other household members; ii) a proximity analysis applying Voroni diagrams was made between households locations considering the maximum travel time identified in the previous step as the weight factor. These zones present the household members where their travel times to their principal activity are in a threshold of 120 to 188 minutes (Figure 6).

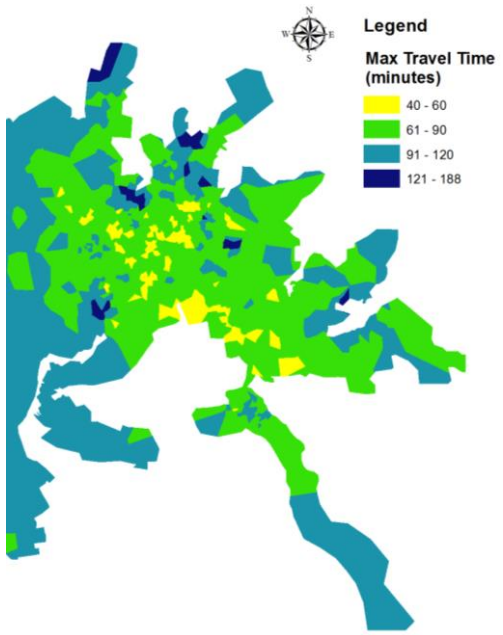


Fig. 6. Identification of constrained zones of La Paz

For a more rich analysis, applying the previous digital model of elevation and the 3D transport network in a geoprocessing method a new model of the constrained zones was obtained. These new model lend the analysis of the

constrained zones with the geomorphological characteristics of the city of La Paz. Few constrained zones where identified for La Paz. Also, these zones aren't further from the central location of La Paz compared with other zones of the city, they presented high slopes and low transportation infrastructure and service (Figure 7). In the case of La Paz, people in the constrained zones are more restricted by the hard topography and the limited transportation network and transit service.

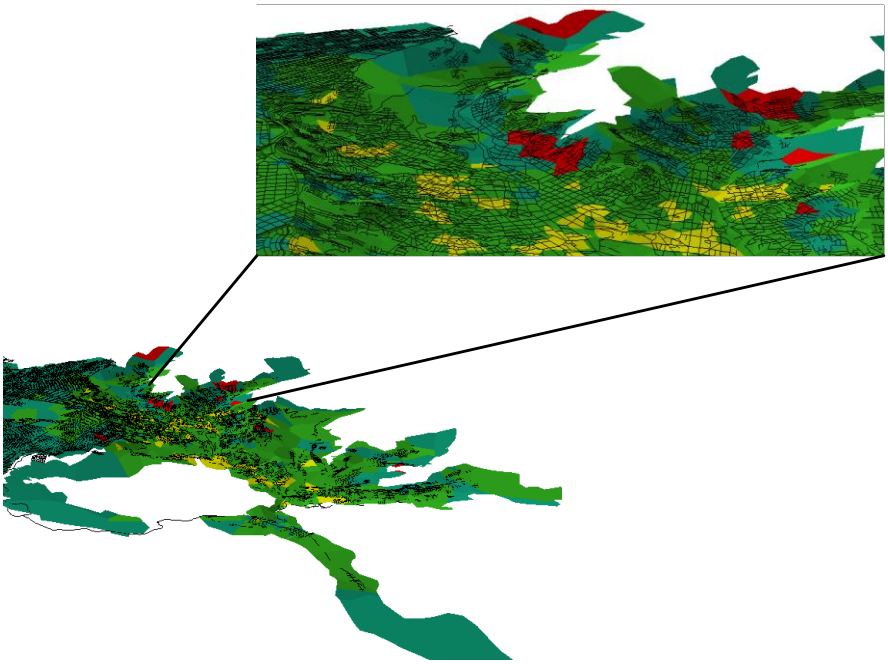


Fig. 7. Constrained zones and a comparison with the geomorphology of La Paz

3.3 "Mi Teleferico" and "El Puma Katari"

Currently the authorities of both the Central Government of Bolivia and the Autonomous Municipal Government of La Paz have focused on solving the problems of transit service and are conducting two projects with high impact on urban mobility. The first project "Mi Teleferico" implemented by the Government of the Plurinational State of Bolivia, consists of a cable car transportation system in three main lines with an investment of U.S. $ 234,680,000.00 (Figure 6). One line connects the center of El Alto to the proximity of the center of La Paz. The other line connects the south of the

center of El Alto and the south of La Paz. The cable car has a capacity of 3000 passengers per hour.

Fig. 6. *Mi Teleferico*. Source: Revista Mi Teleferico

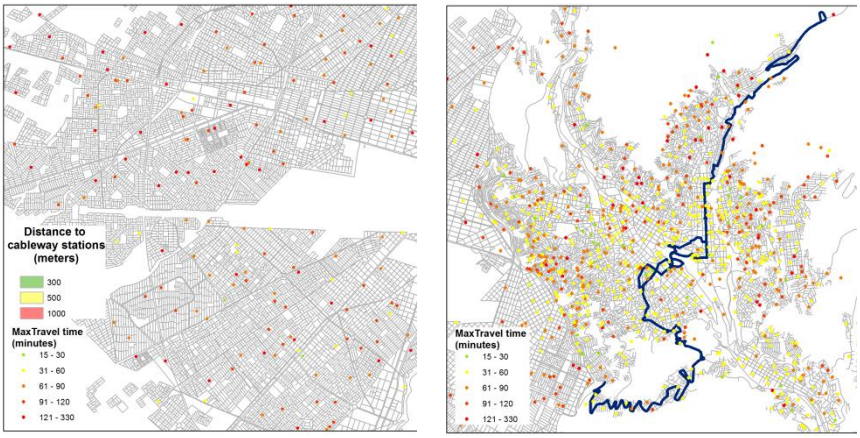
The second project "Puma Katari" implemented by the Autonomous Municipal Government of La Paz consists of a municipal transit service by bus. The first stage of the "Puma Katari" is composed by a fleet of 61 buses and two transit lines. The second step will have a fleet of 103 buses and 7 transit lines (Figure 7). The cost of the project is about U.S. $ 15,000,000.

Fig. 7. *Puma Katari*. Source: Municipal Government of La Paz

The two strategic projects in urban mobility "Mi Teleferico" and "Puma Katari" are isolated. Most importantly, there isn't a strategy of integration between to make the benefits bigger. It results a big deal for the authorities to

implement these projects considering that both would produce significant changes in travel behavior of the population and the urban configuration of the city.

"Mi Teleferico" was designed to attend the 20% of the total demand of travels between La Paz and El alto. Besides the government is prioritizing the construction of the three lines and their facilities, there are no signs of integration of this project with the actual transit system of El Alto. It doesn't have a feeder service that would bring people from the further zones, especially those identified as getho zones, to access the cable car (Figure 8a). If actually people who lives at the getho zones are traveling taking two lines of transit service, this wouldn't change with the implementation of the cable car because there isn't temporal and fare integration with the transit system. So, this project that have to improve the mobility of El Alto inhabitants, would not be successful because it didn't considered the accessibility of the population in a disaggregate level.



a) b)

Fig. 8. a) Distance to principal Cableway stations; b) Transit lines of Puma Katari

By the other hand, "Puma Katari" in comparison with "Mi Teleferico" is a little project but it brings more benefits for the population of La Paz. The two transit lines of the project attend the zones with low level of accessibility (Figure 8b). Also, there are some of the getho zones in the route of the transit lines. Another important matter of this project is the social benefit it brings for the population. It is not because it gets fast to the local of activities, but because is a 24 hour and secure transit service that brings reliability to the users. Maybe, it is not only that the space-time autonomy of an individual

has to take care of the velocity strategy to improve the constraints imposed by the urban configuration. But temporal strategies like a 24 hour reliable transit service will be more attractive especially for low-income individuals.

4. CONCLUSION AND DISCUSSION

In general, transportation planners in Latin American cities commonly adopt the aggregate average travel time or average distance to calculate measures of accessibility. However, these may fluctuate substantially due to differences in day-to-day activity patterns and the dynamics of traffic flows. Such fluctuations give rise to uncertain times. Including activity patterns in measuring individual accessibility will therefore improve the sensitivity and accuracy for urban planning and policy decision-making. This paper proposes some light on this important issue. The Household OD Survey of the "Plan de Mobilidad Urbana Sustentavel 2012" was used to extract the activity patterns and calculated the travel times to measure the individual accessibility. Furthermore, the Gini coefficient was used as a measure of equity.

Results of equity of travel times at the individual level show that the difference in travel time to work among individuals in the situation of La Paz is inequitable. In addition, the most equitable distribution of accessibility is at the zonal level based on average travel time and the most inequitable distribution is obtained at the individual level. These results show that the space-time autonomy of inhabitants of La Paz is constrained.

The proposed constrained zones identify spatially the zones where space time autonomy of individuals is more constrained. In the case of La Paz, these are more related to the limited transportation network and the hard topography of the geomorphology of La Paz city.

The importance of considering the equity of accessibility for planning and decision-making can be situated by the "Puma Katari". The social benefits that this project enhances demonstrate that it is possible to bring in practice the equity of accessibility to promote social inclusion. In the other hand, "Mi Teleferico" is a project more focused in the aggregated demand of trips. This is the reason that makes this project lack of integration to a feeder or transit system in order to improve the mobility of the population of El Alto.

Although this paper shows some interesting results in the measurement of space-time autonomy of individuals and equity of accessibility, there is still

some potential to improvement and elaboration. As the proposed method of Voroni Diagrams applied to identify the constrained zones is still ongoing now, we expect to get more data samples to validate the analysis, especially for the city of El Alto. Moreover, future emphasis could be directed at differences between socio-economic groups and temporal aspects such as time of day and day of the week, in future research.

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