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# Accessibility, Mobility, Pricing and Land Use: reflections from practitioners

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**Abstract**

In this paper we argue that mobility and accessibility are two sides of the same coin: they are mathematically related, and there is seldom a project that improves only one of the two. Next, we argue that unless two critical variables are considered, one cannot say *a priori* whether a transport project will improve accessibility or mobility. The first critical variable is land use. Current and future land-use policies must be considered meaningfully to assess whether any transport project will improve more accessibility or mobility. The second critical variable is pricing. Car owners do not pay for their externalities, particularly the delays their cars inflict on buses along the roads they share. This situation is relevant for cities in developing countries where the public transport modal share is very high, the car modal share is low, but travel times by bus are several times those by car. Therefore, accessibility to opportunities is significantly higher for the minority who travel by car and significantly lower for public transport users. We also develop an accessibility-based indicator to measure if the outcome of a transport project was met by comparing a without- against a with-project situation. An additional indicator is needed: ridership. Ridership is inherently a mobility indicator because more people can move to access opportunities. Accessibility and mobility are therefore intimately linked, like two sides of the same coin. Only by carrying out a careful analysis that meaningfully considers land use can one truly say if a project improves accessibility or mobility.



*Keywords:* Accessibility, mobility, land use, pricing, congestion.

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## 1. Introduction

Does building a metro or a bus rapid transit (BRT) line improve accessibility or mobility? Does implementing a wide avenue for mixed traffic used primarily by cars but with some important bus traffic improve mobility or accessibility? Does having a travel-time indicator to measure the success of a transport project lead inherently to solutions that favor car-based transport instead of public-based transport?

Some practitioners would say that a metro or a BRT line inherently improves access to opportunities. Accordingly, they would say that a wide avenue would inherently improve mobility. In response to the third question, some would say that thinking about travel-time savings unequivocally leads to favoring the car over public transport and therefore improving mobility.

However, these answers fail to consider the surrounding land use and subsequent land-use policies around each of the transport projects in the hypothetical questions. These answers did not consider either the relative pricing or the subsidies between cars and public transport.

In this paper, we argue that mobility and accessibility are two sides of the same coin: they are mathematically related, and there is seldom a project that improves only one of the two. When land use is considered, some projects will improve accessibility to opportunities and to a lesser extent the ability to move. Other projects will emphasize mobility but will also provide access to opportunities, but probably for a small share of the population.

Next, we argue that unless two critical variables are considered, one cannot say *a priori* whether or not a transport project will improve accessibility or mobility. The first critical variable is land use. Current and future land-use policies need to be considered meaningfully to assess if any transport project will improve accessibility or mobility. The second critical variable is pricing. Car owners do not pay for their externalities, particularly the delays their cars inflict on buses along the roads they share. Moreover, cars are net recipients of subsidies that promote their overuse and lead to congestion even at low levels of motorization. This situation is particularly relevant for cities in developing countries where the public transport modal share is very high, the car modal share is low, but travel times by bus are several times those by car. Therefore, accessibility to opportunities is significantly higher for the minority who travel by car and significantly lower for public transport users.

We define accessibility as the ability of an urban transport system to provide its users with access to opportunities in a defined length of travel time. Travel time is defined as door to door and is usually 60 minutes for large cities and 30 minutes for smaller ones. Opportunities are usually jobs, if the employment geocoded data exist, but can also be hospitals, schools, theaters, parks, etc. Therefore, accessibility is people centric: what matters is how people in the city can access opportunities. In turn, we define mobility as the capacity of a system to move vehicles. The more vehicles—buses, cars and trucks—an urban transport system can move, the higher the mobility it offers to its users. People use these vehicles to move around the city. Note that from these definitions, it should already be clear that travel time is essential to both accessibility and mobility.

This paper continues by analyzing in greater detail the definitions of accessibility and mobility, including the mathematical formulations of each. These sections show that the common thread is travel time. Therefore, accessibility and mobility are mathematically related. The paper then introduces land use: the first key variable to consider in understanding whether a project improves accessibility or mobility. This section also discusses the Urban Accessibility Tool and provides simple examples. The next section introduces the second variable: relative pricing and subsidies between public transport and cars. The following section describes how to use accessibility as an outcome indicator for a transport project. The paper closes with conclusions.

## 2. Literature review: accessibility and mobility definitions and indicators

What is Mobility? Mobility measures the ability to move from one place to another (Handy, 2002). Mobility defines transportation issues in terms of constraints on physical movement and assumes that any increase in travel mileage or speed benefits society (Victoria Transport Policy Institute, 2011). Pursuit of congestion reduction is often at the core of mobility improvement. However, congestion relief through added capacity can cause destinations to move further apart, which could be associated with more time and money spent on travel (Levine, Grengs, & Shen, 2009). Mobility is often measured in person-miles, ton-miles, and travel speeds (Victoria Transport Policy Institute, 2011). Traditional level-of-service measures used in transportation planning are in fact measures of mobility. Furthermore, mobility is sometimes also measured by either the number of trips made, or total kilometers traveled (Handy, 2002).

What is Accessibility? Accessibility, on the other hand, indicates the performance of land use and transportation systems and determines how well the systems serve their residents (El-Geneidy & Levinson, 2006). Accessibility measures the ease of reaching opportunities (Peralta Quirós & Raj Mehndiratta, 2014) and the “properties of the configuration of opportunities for spatial interaction” (Weibull, 1980).

Accessibility is often used to assess minimal service access in different areas of a city and to simulate scenarios to evaluate the impacts of new services in spatial accessibility, such as transport systems, medical services, and schools (Garrocho Rangel & Camos Alanís, 2006). Some authors have also used accessibility measurement to assess the influence of accessibility on socioeconomic variables (Jin & Pulsen, 2017) (Gulliford, 2002) (Kenyon, Lyons, & Rafferty, 2002) or to assess the influence of accessibility on the use of services (Meden, Celeste St. John-Larkin, Hermes, & Sommerschield, 2002). Accessibility promises to be a useful tool for monitoring the land use and transportation systems to assess and value the benefits of proposed changes to either land use or transport networks (El-Geneidy & Levinson, 2006).

Accessibility is important in facilitating interaction to enhance socioeconomic benefits. Jin et al. studied how job accessibility plays a role in explaining unemployment rates and household income in American cities. Increases in job accessibility for African Americans led to increases in employment. Results also showed that increased job accessibility for low-income households not only reduces unemployment but also improves household income (Jin & Pulsen, 2017). Kenyon et al. studied a transport dimension of social exclusion, suggesting a strong correlation between lack of access to adequate mobility and lack of access to opportunities, social networks, goods and services. This correlation exists as both a cause and consequence of social exclusion. However, the authors question the likelihood that increased physical mobility, by car or public transport, can by itself provide a fully viable or sustainable solution to mobility-related aspects of social exclusion (Kenyon, Lyons, & Rafferty, 2002). El-Geneidy et al. evaluated the effects of accessibility on home sales. These authors concluded that homebuyers pay a premium to live near jobs and away from competing workers (El-Geneidy & Levinson, 2006).

How to measure accessibility? The main elements in any accessibility measure are an origin and a destination, combined with potential activity at the destination and a (generalized) travel cost—travel time, for instance—to reach desired destinations (Koenig, 1980). Accessibility often multiplies each interaction by a function of the generalized travel cost (measured in terms of time, fare, or other factors). Accessibility improves as travel time decreases and worsens as the distance between opportunities increases.

There are multiple accessibility measures. The formulation depends on what is expected to be measured, the data available, and the level of disaggregation. The literature classifies accessibility measures in the following six main types: (i) Spatial Separation Measures; (ii) Cumulative Opportunity Measures; (iii) Gravity-Based Measures; (iv) Utility-Based Measures; (v) Composite Accessibility Measures; and (vi) Constraints-Based Measures (Bath, et al., 2000), (El-Geneidy & Levinson, 2006) (Garrocho Rangel & Camos Alanís, 2006).

(i) *Spatial Separation Measures:* These measures consider two variables: the spatial distance between origin and destination, and a parameter that represents the distance friction (Dupuy & Stransky, 1996) (Pooler, 1995) (Cervero, Rood, & Appleyard, 1999). Distance friction parameters can include physical or network distance, travel time, travel cost, and service quality.

*(ii)* *Cumulative Opportunity Measures or Isochoric:* This measure counts the number of opportunities that can be reached within a set travel-time threshold. The main criticism of this measure is that all the opportunities within the threshold are considered equally accessible.

*(iii)* *Gravity-Based Measures:* These accessibility measures contain two main elements: opportunities and impedance functions. There are multiple options in the definition of the impedance function, although the literature generally uses negative exponential functions. The impedance usually considers as a cost element the distance or the generalized cost. In this case, because the transport cost is a continuous function (in contrast to the cumulative opportunity measures that use a discrete threshold), the function is sensitive to changes in transport cost (Zhang, Shen, & Sussman, 1998), (Cervero, Rood, & Appleyard, 1999), (Bath, et al., 2000), (Agyemang-Duah & Hall, 1997).

*(iv)* *Utility-Based Measures:* These measures incorporate individual travel preferences: the individual utility perceived for each destination for each user. For each individual, accessibility is the value of the maximum utility between all the alternatives in destination j (among the destinations in C) (Ben-Akiva & Lermand, 1977), (Neuburger, 1971).

*(v)* *Composite Accessibility Measures:* Composite accessibility combines space–time and utility-based measures in a single measure (Miller, 1999).

(vi) *Constraints-Based Measure:* This measure uses as a central element, citizens' restrictions on accessing opportunities (for instance due to limited time in the day, legal constraints, etc.). The indicator recognizes that individuals have limited periods to perform activities (Kwan, 1998), (Miller, 1999), (Lee & McNally, 1998), (Wang, Timmermans, & Harry, 1996).

## 3. Transforming mobility indicators into accessibility indicators

Accessibility and mobility are intrinsically linked. High levels of mobility can reflect high levels of accessibility. However, low levels of mobility can also generate high levels accessibility if, for instance, the opportunities are concentrated in a short distance or time. This reflects how accessibility depends on two main variables: mobility and land use. Table 1 presents the links among accessibility, mobility and land use.

**Table 1. Links among accessibility, mobility and land use**

| | **Formulation** | **Linkage of Accessibility Measure with Mobility** | **Linkage of Accessibility Measure with Land Use** |
|---|---|---|---|
| **Common performance indicators** | **Accessibility:**<br>- Land-use accessibility<br>- Generalized cost (time, money, discomfort, risk) | **Mobility:**<br>- Travel speed (s)<br>- Person–miles<br>- Ton–miles | **Land use:**<br>- Distance (dij) |
| ***Spatial Separation Measure*** | $Ai = {\sum_j dij}/{b}$<br>$A_i$: accessibility<br>$d_{ij}$: is distance to opportunity<br>b: distance friction parameter | Depends on the definition of $d_{ij}$.<br>- If $d_{ij}$ depends only on distance, there is no direct linkage of mobility and accessibility.<br>- If dij depends on travel time or travel cost, there is a direct linkage of mobility and accessibility. | Yes. dij refers to distance (land use). |
| ***Cumulative Opportunity Measure or Isochrony*** | $Ai = \sum_{j=1}^{J} B_j a_j$<br>If $t_{ij} < t_{thre} \rightarrow$ Bj=1<br>If $t_{ij} > t_{thre} \rightarrow$ Bj=0 | Yes. Mobility (s, travel speed) is linked to Ai because of the linkage among travel speed (s), travel time ($t_{ij}$) and distance (dij) to reach opportunities. | Yes. Land use (dij, distance to opportunity) is linked to Ai because of the linkage among travel speed (s), travel time ($t_{ij}$), and distance (dij) to reach opportunities. |

| | Formulation | Linkage of Accessibility Measure with Mobility | Linkage of Accessibility Measure with Land Use |
|---|---|---|---|
| | **Bj** refers to a binary value 1/0 if opportunity aj is or is not within the threshold. **aj** refers to opportunities in j. **tij** refers to the time from origin i to opportunities j. $\mathbf{t_{thre}}$ refers to the travel-time threshold. | $t_{ij}=d_{ij}/s$, therefore, $\mathbf{Ai} = \sum_{j=1}^{J} a_j \mid dij/\mathbf{s} < t_{thre}$ | $t_{ij}=d_{ij}/s$, therefore, $\mathbf{Ai} = \sum_{j=1}^{J} a_j \mid \mathbf{d_{ij}}/s < t_{thre}$ |
| ***Gravity-Based Measure*** | $A_{im} = \sum_j Oj * f(C_{ijm})$ Oj is the opportunities at j $f(C_{ijm})$ is the impedance to travel between i and j in mode m. There are multiple formulations of the gravity-based measure of accessibility. One of the simplest ones is (Agyemang-Duah & Hall, 1997)): $Ai = \sum_{j=1}^{n} d_j e^{-t_{ij}}$ | Yes. Mobility (s, travel speed) is linked to Ai because of the linkage among travel speed (s), travel time ($t_{ij}$), and distance (dij) to reach opportunities. $t_{ij}=d_{ij}/s$, therefore, $\mathbf{Ai} = \sum_{j=1}^{n} d_j e^{-d_{ij}/\mathbf{s}}$ | Yes. Land use (dij, distance to opportunity) is linked to Ai because of the linkage among travel speed (s), travel time ($t_{ij}$), and distance (dij) to reach opportunities. $t_{ij}=d_{ij}/s$, therefore, $Ai = \sum_{j=1}^{n} d_j e^{-\mathbf{d_{ij}}/s}$ |

## 4. Operationalizing Mobility and Land Use in Accessibility Analysis and Indicators

For the purposes of this analysis, we use the Cumulative Opportunity Measure or isochoric indicator to measure accessibility. This considers the total number of opportunities that can be reached within a given time, distance or cost threshold.

To calculate accessibility in urban areas, we use the transport and transit network to calculate the travel times for each origin–destination pair in the city. We then use the estimated travel times for each origin–destination to calculate the number of opportunities that are within a given travel-time threshold. Thus, we can calculate the number of opportunities (e.g., employment opportunities) for each point in the city that are within a given travel time (e.g., 60 minutes) using a specific mode.

To do so we utilize the Urban Accessibility Tool (UAT), an open-source web-based tool (see https://analysis.conveyal.com/). This tool uses as inputs the road network (in this case OpenStreetMap) and transit attributes (specifically, a transit network GIS layer and General Transit Feed Specification). The UAT calculates travel times from each origin–destination pair in the city. The tool then combines the estimated travel times and location data for employment opportunities (or other opportunity inputs) to calculate the accessibility value for each point in the city. This flexible open-source tool provides, with ease and detailed granularity, the basis for the accessibility analysis of the city.

The UAT also allows the user to input different transport networks or land-use plans to understand not only the current accessibility levels of a city, but also how accessibility outputs will change under different scenarios.

For a more comprehensive understanding of a city's accessibility, the tool makes it possible to conduct both single-point and regional accessibility studies. For the single point, the user manually selects a location in the city to be considered as the trip origin. Travel times to all possible destinations are calculated from that origin to determine which opportunities are accessible within the allotted travel time (60 minutes).

To conduct the regional accessibility study, the city is divided in a grid (100x100m) in which each cell is a potential trip origin. The analysis calculates the travel time and employment accessibility for each single cell in the study area. The result of this is a map of the city, in which the value of each cell indicates the access percentage. The spatial representation of accessibility changes is key for transport planning. However, it only shows one key variable of land use: the spatial distribution of opportunities. The second essential input is the overlaying population: the origin/existing land-use distribution of the city is integrated into the analysis.

To summarize the regional accessibility map into a comparable and operational indicator integrating the population, the urban accessibility indicator is calculated. The urban accessibility indicator represents the population's weighted average value of accessibility, defined as:

*Percentage of jobs accessible within a 60-minute commute using non-private transport (public transportation and walking)*

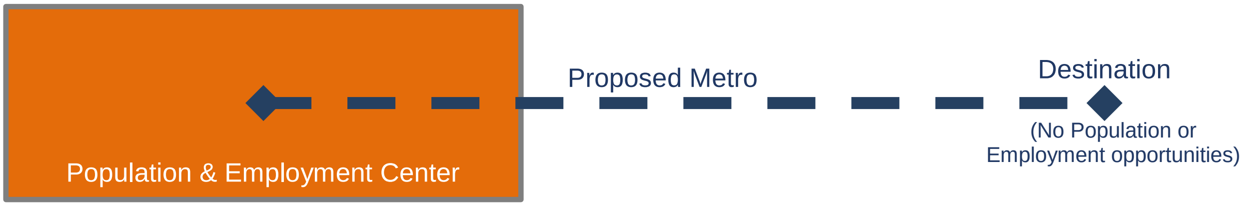
or

$$Accessibility\ Indicator = \frac{\sum(Population_i * Accesibility_i)}{\sum Population}$$

The accessibility analysis and indicator are built around two key components: mobility (travel time) and land use (spatial distribution of population and opportunities). The interplay of mobility and land use provides a very useful lens with which to understand, plan and prioritize urban and transport projects in a city.

We can imagine a scenario in which a major investment, such as a metro, would improve mobility but fail to improve access in a city. In the figure below, the proposed infrastructure exemplifies this scenario in which a metro line is built to connect the urban center, which houses all its people and employment opportunities, to a remote area outside the city. In this case, we would be able to quantify that the metro would improve mobility in this corridor, most likely by increasing travel speeds. However, without land use to support development, accessibility would remain unchanged. The enhanced mobility would not provide access to more opportunities, or access by more people to existing opportunities. More specifically, calculating the accessibility indicator would once again demonstrate that there is no change in the system, since the indicator is weighted by population.

**Figure 1. Proposed scenario: Metro investment connecting urban area to unpopulated area**



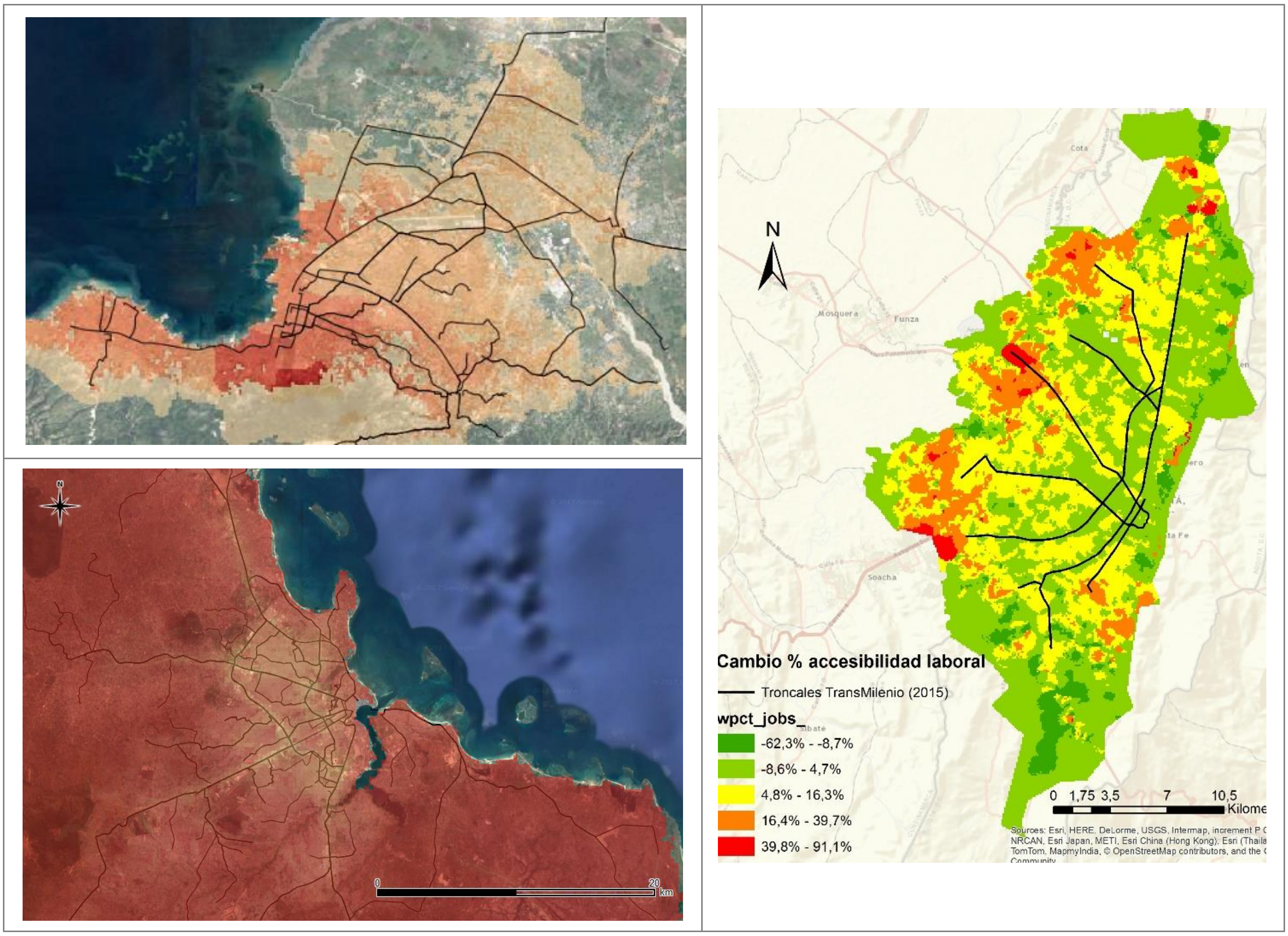

Conversely, there are also projects that change land use but fail to provide accessibility gains for its citizens. We can theoretically propose a scenario in which a new housing project, built in a peripheral unconnected region, will fail to provide accessibility gains, since the unconnected nature of housing locations provides no limited private or public transport mobility options. Although the reality of this scenario seems unlikely, this example refers to the distant, disconnected and dispersed urban development first observed in Mexico (Kim & Zangerling, 2016) and later also highlighted in the analysis of housing projects in South Africa (Picarelli, 2016), where the remote locations with limited mobility options limited the size of their accessible labor market to residents.

The UAT is useful to highlight the interplay of both factors: transport and land use. Therefore, it seems there are there two main ways of enhancing accessibility: (i) improving mobility through improvements to transportation infrastructure, or (ii) adjusting land use to incentivize more compact, dense development. However, as evidenced by the previous examples, it is not guaranteed that focusing solely on mobility or land use will automatically translate into accessibility gains. It is through a coordinated land-use and transport strategy that a city can reap the greatest accessibility benefits.

The examples provided above appear to be extreme examples of investments, yet they mirror the reality on the ground for many cities around the world. The UAT allows us to evaluate, prioritize and coordinate land use in a meaningful way to maximize the accessibility impacts of mobility projects.

This tool and methodology have now been used globally to evaluate the accessibility impacts of different transport projects. Even in the developing-country context, the growing availability of data allows us to readily identify, evaluate and prioritize transport investments. Figure 2 below exemplifies some of the projects that have been evaluated using the accessibility definition previously described. Exemplified in the figure below is the evaluation of priority lines in Port-au-Prince, Haiti (He et al. 2018); the evaluation of Bus Rapid Transit Corridors in Dar es Salaam, Tanzania (He & Peralta 2018); and the Integrated Public Transport System (*Sistema Integrado de Transporte Público*, SITP) and TransMilenio Bus Rapid Transit (BRT) in Bogota, Colombia (Rodriguez & Peralta 2017). Through the outputs of these analyses, we can more readily identify which and where these mobility improvements will have significant accessibility gains, based on the distribution of opportunities within the city.

**Figure 2. Employment accessibility changes in various transport projects: Port-au-Prince, Haiti; Bogota, Colombia; and Dar es Salaam, Tanzania**




Although the spatial representations of accessibility provide a detailed understanding of accessibility changes within a city, it does not fully capture the intersection with the existing population. It is therefore useful to complement this output with the calculation of the accessibility indicator (see Section 6 for a detailed explanation of this indicator).

Integrating the existing population distribution of the city and regional accessibility in the quantification of the accessibility indicator allows us to compare different transportation scenarios in one city; compare cities across regions in terms of the effectiveness of their transportation system; and communicate with local partners on the value added of different transportation interventions.

The table below exemplifies this result from the analysis of the UTP project in Xining, China, which included improvements to public transport infrastructure, operations, and complementary facilities along the proposed integrated public transport corridor. Calculating the indicator provides a more comprehensive understanding of the accessibility gains in the city, in coordination with the city's existing population distribution.

**Table 2. Accessibility Indicator with and without the project: Xining, China**

| PT travel time | With Project | Without |
|---|---|---|
| <=30min | 43% | 41% |
| <=45min | 66% | 64% |
| <=60min | 81% | 80% |

Not only does the accessibility framework allow us to better understand and coordinate transport investments, it allows us to optimize land-use strategies to maximize residents' access. An analysis that made modifications to the spatial layout of Nairobi found that encouraging land-use clustering can increase the share of overall opportunities which can be accessed within an hour from 20 to 42 percent (Avner & Lall, 2016). Similarly, a recent study in San Francisco found that an optimal strategy to maximize job access in the area was the densifying of job clusters, even with growing congestion and mobility concerns (Thomas, 2018).

Accessibility can help us understand cities, urban transport and the impacts. The UAT and an accessibility indicator allow us to meaningfully understand the outcome impacts of transport and land-use projects. The complementary interplay of mobility and land use highlighted in the use of accessibility allows planners to plan and prioritize new transit services and identify optimal land-use, densification and enhancement strategies that maximize access to opportunities.

## 5. Enter pricing meaningfully

The previous section explained why it is important to consider land use in a meaningful manner when analyzing whether a transport project will improve accessibility or mobility. We now turn to analyzing the role that pricing and subsidies play in this assessment. Humans respond to prices. In transport we refer to out-of-pocket costs as those that meaningfully affect user behavior. Public transport users pay a fare or tariff for using a bus or metro. Car users pay for fuel, parking fees, and registration fees. Fuels are taxed for the most part with some or all revenue earmarked for the transport system. National governments establish rules to distribute that revenue to subnational levels of government and/or to projects.

Nevertheless, parking can be free even on sidewalks, to the detriment of pedestrians, people in wheelchairs and children on baby carriages. When there is a charge for parking, then it has a structure that promotes traveling during peak hours and dissuades off-peak-hour trips. Specifically, parking fees can be flat after, for example, three hours of parking. This structure means cars parked for eight hours receive a cross subsidy from cars parked for one hour. Cars that travel during the peak hour congest streets. Buses that use those streets face more congestion and therefore longer travel times. People traveling by bus can access fewer opportunities in a fixed travel time.

Another example is car registration fees. Registration fees are low, and they usually go down with the age of the vehicle. Therefore, these fees do not capture the cost of car use or the fact that car engines pollute more as they age. Car owners end up not paying for externalities, particularly the delays their cars inflict on buses along the roads they share. Because of this, cars become net recipients of implicit subsidies that promote their overuse and lead to congestion even at low motorization levels (Ardila-Gomez & Ortegon-Sanchez, 2016).

This situation is particularly relevant for cities in developing countries where the public transport modal share is very high, the car modal share is low, but travel times by bus are several times those by car. Therefore, accessibility to opportunities is significantly higher for the minority who travel by car and significantly lower for the majority who travel by public transport. The playing field is not level but instead is biased in favor of cars due to the implicit subsidies and low charges for car use (Ardila-Gomez & Ortegon-Sanchez, 2016).

## 6. Using UAT and accessibility for Monitoring and Evaluation purposes

In Section 4 we explained the UAT and mentioned briefly the use of an indicator to assess how a transport project improves accessibility. In this section, we explain in detail how to use the UAT as an indicator to measure the impact or results of an urban transport project, whether it is a mass-transit line or an urban road.

The UAT models a single traveler who travels ubiquitously in a 60-minute period. For example, in the case of a metro project, the UAT models a single traveler to determine if this traveler can access more opportunities in 60 minutes. One problem is that once operational, the metro can move 30 or 300,000 people per day and the UAT will not distinguish the impact on access to opportunities, because the algorithm uses a single traveler. Nevertheless, the UAT can measure a project's impact on accessibility to opportunities but it needs to be complemented by another indicator: ridership.

First, to measure the impact of a transport project the approach is to run the UAT without the project. The results will show access to opportunities without the project in question. These results will be the baseline value for the indicator on accessibility. For the Quito Metro Line One Project, this value was 45.3 percent.

The next step is to run the UAT with the project. The UAT models the with-project situation by embedding a series of assumptions, such as physical and fare integration between metro and buses, bus-route reorganization, a fully built project, and land-use policies if they are part of the project. This with-project impact on accessibility becomes the target value: 50.8 percent in the case of the Quito Metro Project (World Bank, 2018). The UAT also made it possible to model the role of the feeder network in improving access, given that the metro was operational. The UAT predicted a similar impact from the feeder routes as for building the metro itself. This result matches what Tsivanidis found for the Bogota mass-transit network, TransMilenio (Tsivanidis, 2018).

Once the project is operational, evaluators first check to see if all the assumptions made initially were met. If some were not met, then the UAT will capture the reduced impact on accessibility. For example, let us assume that fare integration did not happen. Users must spend more time transferring from one mode to another and pay two fares instead of one. The UAT takes this higher transfer time and predicts lower access to opportunities in 60 minutes of travel. The project did not meet its target value for accessibility.

Note that the assumptions, such as fare integration, building all stations, and the entire alignment of the metro, usually reflect the intermediate or output indicators. Therefore, this formulation of the accessibility indicator captures whether the project was implemented as planned. If it was not, then the impact on accessibility is lower than the target value because the target value assumed that all intermediate steps would take place.

Land use can change due to the metro itself or for many other reasons. The UAT will model the without project situation with the approved land-use plan, which should reflect the existing land use. The UAT can inform planners if the project's land-use impacts will be curtailed due to rigid land-use regulations. Therefore, the analysis calls for a detailed analysis of land-use regulations, the key ones being (i) maximum floor-area ratios; (ii) minimum lot size; (iii) minimum parking requirements; and (iv) segregated land use. These regulations limit the amount of physical space that is available. Limiting the supply of land raises prices. Higher prices have a negative impact, particularly on poor people because they cannot afford to live close to opportunities. The result is low-density urbanization that can lead to distant, dispersed and disconnected cities (Kim & Zangerling, 2016), and (Lall & Wang, 2012.). Relaxing these regulations becomes a critical element to help a project achieve higher impact in terms of accessibility to opportunities. In fact, denser cities concentrate activity and place more opportunities within reach in the same travel time.

Second, although the accessibility indicator is powerful, its handicap is that the UAT models a single traveler. To fully understand whether a project has met its objective, the accessibility indicator needs to have a complementary outcome indicator on ridership that measures whether the project is carrying 30 or 300,000 people per day. In the end, the cost–benefit analysis had a ridership expectation to justify the project.

Finally, the UAT can be used to model access to opportunities by car and by public transport. Because the playing field between the two modes is not level and cars have an advantage, as explained in Section 5, the UAT usually predicts higher accessibility to opportunities when travelling by car. This conclusion should be handled with care because it reflects above all that pricing is incorrect. A second incorrect conclusion is that everyone should travel by car: congestion and travel times will increase, and accessibility will plummet.

Access to opportunities is highly unequal depending on the mode. Car owners, usually a minority in developing country cities, can access more opportunities. The majority who travel by bus can access fewer opportunities. Improvements to public transport are needed, as well as better pricing. For political reasons, improving public transport is easier to do than charging more for car use. However, improving public transport is more efficient and cheaper than expanding road capacity to accommodate future hypothetical motorization levels.

In summary, the UAT offers a way to use accessibility as an outcome indicator. The without-project situation becomes the baseline for the indicator. The with-project situation embeds critical assumptions such as fare integration or land-use policies. Once the project is operational, evaluators check to see if these assumptions were met. They will run the UAT using the assumptions that were met plus any changes in land use. If the assumptions were met, then the UAT will offer a result very similar to the target value. Land use can mean even higher values. If the assumptions were not met or if land use was severely constrained, the target accessibility value was not met. To fully capture the project's impact, the accessibility indicator needs to be complemented by a ridership indicator because the UAT is indifferent to actual ridership.

## 7. Conclusions

In this paper we strived to show first that accessibility and mobility are two sides of the same coin. A transport project can improve one more than the other, but seldom is there is a project that improves only one of them. The analysis of the different formulations for accessibility and mobility in Sections 2 and 3 shows there is a common thread: travel time. Travel time is the essence of both accessibility and of mobility. Reducing travel time is key to improving both (Sclar, Lönnroth, & Wolmar, 2016).

We also explained how only a careful analysis that meaningfully considers existing and future land-use patterns can explain how a project impacts accessibility. Using a metro as an example, critical assumptions are fare integration, physical integration, bus route restructuring, etc. Land-use changes also enter the with-project simulation. Once the project is operational, an ex-post evaluation will look at how these assumptions were met or not. The evaluators will run the UAT with the updated assumptions. The value will differ from the target value and will show if the project met its accessibility objective.

Because the algorithm in the UAT uses a single ubiquitous traveler, the modeling is indifferent to whether 30 or 300,000 passengers per day use the metro line. Therefore, a second indicator is needed: the ridership indicator. Ridership is inherently a mobility indicator because more people can move to access opportunities. This closes our argument that accessibility and mobility are intimately linked, like two sides of the same coin. Only by conducting a careful analysis that meaningfully considers land use can one truly say whether a project improves accessibility or mobility.

We also analyzed pricing: car owners do not pay the costs their cars generate. As a result, streets are congested and buses travel at slower speeds. In developing country cities, the majority who travel by bus can access fewer opportunities than the minority who travel by car. Congestion is therefore regressive and the playing field between buses and cars is stacked against public transport (Ardila-Gomez & Ortegon-Sanchez, 2016). This reality means that improving car-use pricing is essential for improving access to opportunities and improving the financing of the urban transport system.

In fact, our analysis corroborates the fact that a combination of public transport improvements, coupled with improvements in land-use regulations and car-use pricing, achieves better, more sustainable results than mobility-enhancing strategies do (Handy, 2002). Relaxing land-use regulations—minimum floor-area ratios, lot size, and parking spaces plus segregated use—increases the supply of land and built space and therefore reduces prices. Public transport users could live closer to access more opportunities per unit of travel time in reliable public transport. Pricing strategies, such as parking fees that charge more for traveling during peak hours, congestion charging, and other user fees, will reduce car use, thus allowing public transport to move faster. Users will access more opportunities and the urban labor market will work better (Bertaud, 2014) for both employers and employees (Tsivanidis, 2018).

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