Towards a New Model to Evaluate Smart Mobility in Latin America

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***Abstract*—The major metropolitan areas in Latin America are facing a fast-increasing transport crisis in terms of congestion and very long travel times, pollution, accidents, and user safety. Like cities in developed countries, many cities in the region have started smart mobility programs to address these issues. In recent years, many models have been developed to evaluate these programs but most of these models are using indicators that do not consider specific mobility problems in Latin America. This article has identified eight specific regional challenges to mobility and proposes a new model. The model includes a set of specific indicators and metrics that allow researchers to conduct a more realistic and data-driven comparative evaluation of mobility challenges and smart mobility programs Latin American cities.**

Keywords - smart mobility; mobility challenges in Latin America, mobility models.

I. Introduction

The concept of mobility has been interpreted in a variety of ways. The National Research Council in its report Key Transportation Indicators defines that "mobility refers to the time and costs required for travel" [1]. With the field of mobility, urban mobility is of key importance because the cities are the center of the economic and social activities of human beings [2]. In recent years, there have been important economic, social, and technological changes that led to new models to understand and measure urban mobility. These urban models have been implemented throughout the world considering factors, such as the increase in average distances traveled, changes in the reasons for travel and changes in the location of productive activities [3].

More recently the mobility models have evolved into the smart city model that considers a broader set of indicators. A smart city is characterized by seeking "the promotion of integrated and sustainable development, where cities become more innovative, competitive, attractive and resilient" [4]. The Smart Cities Council Readiness Guide defines a smart city as one that uses Information and Communication Technologies (ICT) to improve its habitability, work capacity and sustainability [5]. Cohen and Obediente [6] propose that smart cities, through the application of technology in their different areas, become more efficient localities in the use of their resources, saving energy, improving the services provided and promoting sustainable development. In its report Smart Cities, Ranking of European medium-sized cities, Giffinger et al. [7], reviewed the common characteristics of several European cities classified as smart and proposed a model defined by six main pillars: smart people, smart economy, smart governance, smart environment, smart living, and smart mobility.

Latin America is the world´s most urbanized developing region, characterized by high levels of economic and social inequality and fast-growing urbanization, resulting in increasing mobility problems [8]. Although some smart mobility and public transport integration projects have begun to be developed in Latin America to address these issues, smart mobility is one of the pending tasks for the region [9].

The evaluation of progress in smart mobility in Latin America is complicated since most of the smart mobility models were developed considering the mobility problems in developed countries. Consequently, there is no model that considers the specific characteristics and challenges of smart mobility in Latin American cities. The objective of this article is to identify a new smart mobility model for Latin America that can serve as the basis for a more effective comparative analysis of urban mobility in the region. To achieve this goal, this article offers a review of the literature of current mobility models and identifies the key indicators and their metrics mobility challenges in Latin America.

In Section II, the general concept of smart mobility is defined and Section III describes a series of Smart Mobility Models and their indicators proposed by different authors. Section IV details the key mobility challenges in Latin American. Section V describes the proposed smart mobility model including indicators and metrics. Conclusions are presented in Section VI.

II. Smart Mobility

According to Carballo et al. [10], the concept of smart mobility is defined as the set of actions, techniques and infrastructures that lead to the improvement of mobility and the organization of traffic in cities. The main objective of smart mobility is the use of technology and data for the integration of all actors in displacement, to achieve greater efficiency and sustainability in cities [11]. Smart mobility seeks to address some of these problems through the application of technological tools such as ICT, allowing the establishment of specific objectives. The use of technology in smart mobility allows integrating the data of the road actors to automatically attend to incidents that occur on the routes, prediction and prevention of accidents and some trends in terms of behavior, such as hours and congested routes. In the same way, it is possible to have public transport integration systems, which facilitate connections between

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one means of transport and another, while monitoring climatic and environmental conditions [12].

III. Smart Mobility Models and Indicators

Several researchers have developed smart mobility models that build on a combination of a series of underlying indicators to measure and compare the status of smart mobility in cities at global level. For this research, eleven of the most representative smart mobility models are analyzed as a starting point for the development of a suitable smart mobility model for Latin America. Cohen [13] in his research proposes a mobility index that considers three categories including efficient transport, multi-modal access, and technology infrastructure. Some of the indicators are clean-energy transport, public transport, smart cards, and access to real-time information. The model of Lupiañez, and Fauli [14], evaluates the urban smart mobility projects based on inputs, outputs, and outcomes/impact. The most relevant outcome indicators are the number of personal vehicles per capita, the travel time, transport-related victims per 100,000 inhabitants and the number of public transport services that offer real-time information to citizens.

Battarra et al. [15] compare cities through indicators and smart actions developed in them. The categories evaluated in the model are accessibility, sustainability, and ICT. Each category was eventually divided into actions and these actions were divided in parameters. Aletà et al. [16] propose a model that compare cities through the evaluation of the following factors: sustainable mobility urban plans, integrated payments in multimodal transport systems, deployment of alternative transport modes and the use of ICT in traffic control. The model also proposes measurable direct evaluation metrics. Aini and Amani [17] consider a diversity of indicators classified in the following variables: location efficiency, reliable mobility, health and safety, environmental stewardship, social equity, and robust economy.

The model of Orlowski and Romanowska [18] assesses the infrastructure of cities, their mobility methods and information management infrastructure using the following indicators including indicators on the technical infrastructure, information infrastructure, mobility methods, used vehicles and transport legislation. A complex model for European cities is proposed by Giffinger et al. [7], which evaluates local accessibility, national accessibility, availability of ICT infrastructure and a sustainable, innovative, and safe transport system. Also, the California Department of Transportation defines a series of indicators for smart mobility including location efficiency, reliable mobility, health and safety, environmental stewardship, social equity, and a robust economy [19]. Šurdonja et al. [20] presented a model that consisted of a questionnaire that allows evaluating the main aspects of the ideal model of a smart city.

Factors like those mentioned previously were evaluated in the model proposed by Martinez-Toro et al. [9]. The model proposes five key indicators to evaluate mobility and transport integration including long-term mobility policies, resistance by transport operators to system integration and digital payment, limited use of bank accounts by the population, limited infrastructure in ICT and lack of financial resources to invest in mobility programs. Finally, we can mention the model presented by Berrone and Ricart [21], that evaluates and scores cities in nine main aspects: human capital, social cohesion, economy, governance, environment, mobility and transportation, urban planning, international projection, and technology. In this model the most representative indicators are traffic index, traffic inefficiency index, exponential traffic index, CO_2 emissions, number of particles in the air (PM10 and PM 2.5) and the number of deaths from traffic accidents. The main advantage of the last two models is that it presents most of the Latin American countries, giving in advance an idea of how it would be possible to evaluate them and use the aspects they have developed.

Most of the models that we mentioned above, except for the ones proposed by Martinez-Toro et al. [9], and Berrone and Ricart [21], were developed to evaluate smart mobility in highly developed cities in developed countries and do not consider mobility problems in Latin America as presented in Section II. Therefore, this article seeks to identify a model with the most relevant indicators for the problems identified in Latin America.

IV. Mobility Challenges in Latin America

A key challenge to mobility is the advanced levels of urbanization in Latin America, at this moment the most urbanized developing region in the world. A United Nations study expresses that urbanity in Latin America has increased from 40% in 1950 to 80% in 2015 [22]. The high levels of urbanization combined with economic growth has also resulted in a fast level of motorization in the region. This is furthermore combined with a lack of road infrastructure planning in Latin America which leads to an increase in traffic congestion [23].

A further factor of concern is found in the great distances resulting in elevated travel time of citizens within the larger metropolitan areas such as Sao Paulo, Mexico City, Rio de Janeiro, and Lima, which represents great mobility problems in terms of transport time for both higher end and lower income citizens alike. These directly affect the well-being of populations as they must spend more time moving from one place to another to satisfy their social and economic needs [24].

According to a study developed by García [26], public transport allows people with limited resources to leave the precarious residential spaces where they live and the need to move to their places of work or study and to access services that these people need daily. However, the inoperative and incompleteness of the integration of transportation systems result in awfully long travel times and high cost of transport for lower income citizens that need to access work and training opportunities, as well as the services that people need daily to carry out their daily activities, despite some success stories such as the Transmilenio in Bogota, Colombia [26][27]. In many cities in the region people need to take various transport modes (bus, metro, train) that require more than two hours travel time per day. The study published by Martinez-Toro et al. [9] provides a detailed analysis of the key challenges to the development of integrated and intelligent public transport systems in eight cities in Latin American. The main challenges identified were the resistance by transport operators thus resulting in incomplete physical integration of transport systems and related digital payment options. Also, the limited ICT infrastructure and a lack of financial resources assigned by most Latin American governments to invest in smart mobility programs and policies.

In recent decades, precarious and dangerous transport conditions in Latin America are causing high levels of travel accidents. Today, traffic accidents are one of the leading causes of death in the region, mainly among people between the ages of 5 and 44 [28]. This implies that traffic accidents cause more than 100,000 deaths per year, and approximately more than 5 million people are injured [29].

Traffic congestion and a lack of regulation of the quality, maintenance and age of car vehicles comes with environmental pollution, noise pollution, deterioration in the state of the streets. Traffic congestion and pollution comes with a high level of CO_2 emission from vehicle combustion. As a result, high levels of air pollution in many Latin American cities represents the greatest environmental health risk today, and it is estimated to contribute to 7 million premature deaths each year [30]. According to the 2018 World Air Quality Report published by Greenpeace and IQAir, Lima and Santiago are among the countries with the highest level of air pollution in the world. Peru is ranked 21st in the global ranking, while Chile is ranked 26th [31]. This places Latin America as a major source of pollution, posing a serious problem for the environment and the health of the inhabitants of this continent.

Finally, we find an increasing problem caused by a lack of safety of the users of public transport. According to a study published by Jaitman [32], 50% of women in Lima and Asuncion use public transport as a daily means of travel. At least a third of these women experience unsafe transport conditions and report to have been robbed, insulted, suffered some type of verbal or even sexual assault while traveling with public transport. Another 30% of the women do not report these inconveniences because they do not believe it necessary or due to lack of time.

In summary, to develop a relevant smart mobility model for Latin American cities, a new regional model that considers key indicators from the combination of different factors is needed. In the first place it is essential to consider physical indicators of smart mobility including vehicular congestion, travel times and the presence of an adequate and inclusive ICT infrastructure. Secondly advancement in smart mobility requires sufficient planning capacity of transport authorities and access to financial resources to implement smart mobility programs. Thirdly it is important to consider environmental factors represented by air pollution levels and to consider key indicators on security which can be expressed in the level of traffic accidents and user safety.

V. PROPOSED SMART MOBILITY MODEL FOR LATIN AMERICA

To determine the models that are best suited to evaluate smart mobility challenges and conditions in Latin America, the research team has conducted a detailed analysis of the indicators used by eleven smart mobility models and their relevance for the key challenges of urban mobility in the region. The combined models proposed by Martinez-Toro et al. [9], Lupiañez et al. [14] and Berrone et al. [21] are found to be most relevant to construct a new model to evaluate smart mobility that considers specific challenges and conditions in Latin America. Table 1 presents the proposed model that demonstrates the relation between the key mobility problems in the region, the indicators and metrics that enable future measurement of each indicator.

TABLE I. PROPOSED SMART MOBILITY MODEL FOR LATIN AMERICA

Mobility Problem	Indicator	Metrics	Author
Vehicular congestion	-Traffic index -Exponential traffic index -Traffic inefficiency index	-Average one-way travel time to work in minutes [33] -Estimation of dissatisfaction due to long commute times with exponential levels of dissatisfaction with travel time to work above 25 minutes [33] -Estimation of inefficiencies in travel time caused by transport by private car compared to public transport [33]	Berrone and Ricart, 2020.
	-Number of vehicles	-Number of private vehicles per inhabitant	Lupiañez, and Fauli, 2017.
Time spent traveling	-Travel time	-Additional time needed to 30 minutes of travel distance	Lupiañez, and Fauli, 2017.
ICT infrastructure	-City-wide Internet coverage -Digital transport service platforms with real time information	-Internet penetration rate per inhabitant in the city -Percentage of transport companies with digital transport service platforms that offer real time travel information	Martinez-Toro, et al., 2019.

Transport system and payment integration	-Geographically integrated transport modes -Integrated digital payment systems among transport modes	-Percentage of transport service companies with integrated transport modes -Percentage of transport service companies with integrated digital payment systems among transport modes	Martinez-Toro, et al., 2019.
Financial resources	-Public, private, and multi-lateral investments in mobility programs	-Amount of total investment available for mobility per 100,000 inhabitants per year	Martinez-Toro, et al., 2019.
Environment al pollution	-Emission of CO_2, PM10, and PM2.5	-Emission CO_2 in grams per minute por passenger -Annual average of the number of particles PM10 in the air whose diameter is less than 10 µm. -Annual average of the number of particles PM2.5 in the air whose diameter is less than 10 µm.	Berrone and Ricart, 2020.
Traffic accidents	-Number of deaths in accidents	-Number of deaths in accidents per 100,000 inhabitants per vehicle	Berrone and Ricart, 2020.
User safety	- Public transport services that offer real-time information -Victims related to transportation	-Percentage of public transport companies that offer on-line and real-time travel information -Transport-related victims per 100,000 inhabitants	Lupiañez, and Fauli, 2017.

Source: Own Elaboration

The smart mobility model presented in Table 1 includes the interactions between key regional mobility challenges, their indicators and metrics to measure each indicator. To evaluate the eight mobility challenges, fourteen indicators were selected after the analysis of the most representative existing smart mobility models. The challenge of traffic congestion is measured by the traffic index, the exponential traffic index, the traffic inefficiency index and the number of vehicles. Excessive travel time in cities is evaluated by the additional travel time that is needed to travel in a 30-minute journey.

City-wide internet coverage and the digital transport service platforms with real time information are key indicators to evaluate urban challenges in ICT infrastructure. Problems related to a lack of transport integration can be evaluated by looking at the level of integration of the different transport modes and payment systems. The availability of public, private and multilateral investment in mobility programs represents a good indicator of the challenge of limited access to financial resources. Finally, environmental challenges are compared by the level of CO_2 emission and PM10 and PM2.5 air particles. Transport safety considers the number of fatal traffic accidents and user safety is evaluated to the extent to which travelers can dispose of public transport services that offer real-time information and the number of victims in traffic. The combined set of indicators and metrics provide a new model that considers the specific regional mobility challenges and allows to compare the smart mobility performance between Latin American cities.

VI. Conclusions And Future Work

This study on smart mobility has identified key problems that are relevant to evaluate the progress in smart mobility in urban areas in Latin America. The challenges include the traditional factors related to elevated vehicular congestion and long travel times but also problems related to a lack of integrated transport and payment systems, deficiencies in ICT infrastructure and a lack of financial resources to finance smart mobility programs. Other important factors include air pollution, traffic accidents and user safety.

The research also analyzed eleven models that evaluate smart mobility of which three models were found to be most relevant to evaluate the key smart mobility challenges in Latin America. The models developed by Martinez-Toro et al. [9], Lupiañez et al. [14] and Berrone et al. [21] together provide an accurate set of smart mobility factors and indicators that cover the aforementioned smart mobility challenges in the region.

The new model enables researchers to conduct more realistic and effective data-driven evaluations of mobility challenges and the progress in smart mobility in different Latin American cities. In addition, it allows for the development of a comparative smart-mobility index of Latin American cities. To accomplish this, we propose to set up a panel of experts with representatives of mobility professionals and researchers, government, private industry, and end users. The panel is to validate and assign individual weightings to the model´s indicators and to homogenize the values obtained to have a uniform numerical index that facilitates a more realistic evaluation of smart mobility in Latin America.

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