Design of Urban Mobility Services for an Intermediate City in a Developing Country, Based on an Intelligent Transportation System Architecture

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Abstract. Problem: Services that use ICT (Information and Communications Technologies) have been developed to improve the mobility in cities; however, especially in developing countries, these services are not often based on adequate reference architectures, such as ITS (Intelligent Transport Systems) architectures, which prevent integration and interoperability. Objective: Propose a development process for the design of mobility services in an intermediate city of a developing country, based on an ITS architecture formulated particularly considering context. Methods: The reference ITS architectures and the particular context of a Colombian intermediate city are reviewed, in order to identify which is the best process to adapt an ITS architecture to these type of cities. With the process identified, the ITS architecture for *Popayán* (Colombian intermediate city) is designed and finally, the design of the services based on it, is carried out. Results: The methodology developed for the design of the ITS architecture and the architecture designed particularly for *Popayán* are summarized. Following, the design of two mobility services ("Public transport vehicle tracking" and "Traffic measurement") for that city based on architecture is detailed. Conclusions: The particular environment of an intermediate city and its priorities allows to determine the services to select for its ITS architecture from a reference architecture. ITS architecture development of a city allows the incremental development of services that really improve their mobility in a sustainable manner.

Keywords: Intelligent Transport Systems · Urban mobility · ITS architecture Mobility services · Mobility in developing countries

1 Introduction

Traffic accidents are the most important causes of death in the world, and the main cause of death among people between 15 years and 29 years [1]. Besides, mortality rates in low-income countries are more than double compared to high-income countries [1].

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Colombia has presented in the last 10 years, considerable problems in terms of the number of traffic accidents and deceased persons, which have a marked tendency to increase [2]. In addition, there is a marked difference between the death rates of some cities in the country. In some of the intermediate cities of the country (population between 100,000 and 1,000,000 inhabitants such as *Pasto, Popayán, Ibagué, Cúcuta, Armenia, Pereira, Santa Marta, and Neiva*) the average of death rates due to traffic accidents is almost 50% more than the values of the main cities.

In cases involving deaths, disobedience to traffic rules caused the greatest number of accidents in Colombia (42%), followed by speeding (32%) and possible mechanical failures (8%) [3].

In addition to the loss of lives caused by traffic accidents and the other harmful consequences these generate related to the road safety of the city, there are other problems related to mobility in cities such as high traffic congestion.

The data of traffic congestion in cities worldwide, are measured by different international organizations, among the most recognized are: “Tom Tom Traffic Index” [4] (which does not have data of Colombian cities) and “Inrix Global Traffic Score Card” [5]. The “Inrix Global Traffic Score Card” indicates that *Bogotá*, capital city of Colombia, is ranked sixth in the ranking, with a total of 75 annual hours that travelers spend in congestion. In same report, some intermediate Colombian cities are included, with values between 45 and 27 h that travelers spend in congestion.

In search of a solution for problems of road safety and high traffic in these cities, a large number of intelligent mobility services have been developed, however, very few of these services have been developed based on an adequate reference architecture, as Intelligent Transport System (ITS) architecture is for mobility services.

Intelligent Transportation Systems (ITS) are defined as: “the application of advanced technologies in sensors, computers, communications, and management strategies to improve the safety and efficiency of the land transportation system” [6].

An architecture defines a framework within which a system can be built. An architecture defines “what” should be done, not “how” it will be done [6]. An ITS architecture is a system architecture created for the ITS domain. It consists of several descriptions of the system, each one concentrating on specific sets of characteristics [7]. Once, the ITS architecture of the city is obtained, it is necessary to discuss the technologies that will be used for the design and develop of the mobility services.

When mobility services are developed in a city, without an adequate ITS architecture, it may be that the services meet well with the specific objective that these were created, however, it´s very possible, their infrastructure and/or functionality is not adequately integrated, nor does it interoperates with other mobility services.

The main developed countries of the world (United States, European Union and Japan, among others) have taken initiative in development of ITS architectures. Many other countries (developing countries mainly), have created their own national ITS architectures based on these architectures. Although many developing countries have ITS architectures (including Colombia), the cities have not taken this architecture into account for the development of their services, very likely because the government entities do not promote their use adequately.

The purpose of this paper is to present a process for the design of mobility services in an intermediate city of a developing country, based on an ITS architecture that takes into account the particular context of the city and also using adequate enabling technology and standards of communication to provide these services. The proposal presented was applied to the city of *Popayán* (Colombian intermediate city), designing two mobility services that try to improve the identified problems of road safety and traffic management, trying to avoid the mentioned causes that generate them. The service "public transport vehicle tracking" will allow control of the speed of these vehicles and compliance with other traffic laws, in an attempt to minimize the number of accidents of these vehicles. The service "traffic measuring" will allow provide users and drivers with valuable information (speed on the route mainly) so that they can make travels more efficiently, additionally, they will be able to avoid increasing traffic at a certain crossroad, making use of said information.

In the following sections, related previous works are described; later, it is presented the process carried out to propose the methodology and the design of services; the document continues with description of results obtained, presenting a summary of the methodology designed for the development of ITS architecture, the ITS architecture of an intermediate city in particular (*Popayán*), and the design of services for this city; finally the discussion and conclusions are presented.

2 Related Works

2.1 ITS as a Solution for Problems of Road Safety and High Level of Traffic

ITS have contributed considerably in the development of solutions that improve road safety conditions and traffic worldwide. Since the 1970 s, countries such as the United States, Japan, European Union and South Korea have implemented solutions (in collaboration with vehicle manufacturers) that allow communication between vehicles and road infrastructure, or between vehicles, to try to improve traffic and safety [8].

In addition, ITS services have been developed for traffic analysis using computer vision techniques; this field on ITS allows automatic monitoring objectives such as congestion, traffic rule violation, and vehicle interaction [9].

The safety of cyclists and pedestrians on the road, who are some of the most vulnerable users, has also been an approach to developments in ITS. For this, systems have been used to allow interaction (through technology) between bicycles and vehicles, or the detection of pedestrians on the road [10].

2.2 Design of Regional ITS Architectures

Yokota and Weilland formulated a proposal to implement an ITS architecture in developing countries [11]. The authors presented four (4) criteria in the construction of architecture: affordability, regional compatibility, geopolitics and technical aspects.

The proposal was presented more than twelve years ago and versions of the architectures evaluated have been updated. In addition, although criteria are mentioned to be considered in the specification of the architecture and a basic process is proposed, a clear and detailed methodology for the design of the ITS architecture is not established. Nor is there an example of application of the criteria and the proposed process.

United States Department of Transportation presented a proposal in 2006 to "develop, use, and maintain a regional ITS architecture" [12]. In the document, six steps are established for these activities in ITS architecture. In [12], although some aspects are still valid for the development of a regional architecture, its application is limited exclusively to American architecture, excluding the possibility of incorporating other relevant aspects of other reference architectures.

FRAME architecture (European ITS architecture) is referenced for the development of a regional architecture [13]. The document proposes certain steps to get from the needs of the stakeholders to the views of the architecture. As mentioned with respect to [12], in [13] the regional ITS architecture that can be designed will be focused exclusively on the reference architecture (FRAME), additionally, the context of said reference architecture is very different from the context in this work.

With respect to the national reality, the country has an initiative called ITS Colombia national architecture [14]. The national architecture ITS is an adaptation (in 2010) of the American architecture, which unfortunately no updates have been made and no research work was found based on that architecture.

In a local project, a model for the development of ITS services for Colombian cities used the national ITS architecture and alternatives to the methodological support described in American architecture [15]. The work focused mainly on the development of a service model, however, it did not present a methodology for designing a particular ITS architecture for an intermediate city, as it is intended done in this work.

2.3 Implementation of Mobility Services Based on ITS Architectures

In a reviewed project was developed a prototype for ITS, which is useful to track a public service vehicle through GPS, receive payment of tickets, analyze crowds within said bus and finally, measure the environment inside the bus [16]. In the IoT (Internet of Things) infrastructure proposed in this project, the data collected from the sensors are sent through Internet and processed by the monitoring system to make useful decisions and send them to the visualization system. After defining the proposed system (for an intelligent bus) and its architecture, an ITS is proposed through the exploitation of the smart bus technology and the IoT infrastructure.

In [17] another development of an ITS, a system responsible for intelligent parking assistance based on IoT, is presented. Parking assistance, in the system proposed is provided by the following steps: sensors detect whether a parking space is occupied and transmit data to the central server. The smartphone app requests a parking space and guides drivers to that free space. The parking fee is paid directly through the smartphone application.

INTEL proposed the construction of another ITS, with the use of IoT [18]. The proposed architecture has three (3) main layers: sensing layer, communication layer and service layer. The sensing layer uses a "vehicle terminal" that interacts with the conductors and acts as a "gateway" for the technology inside the vehicle and the sensors. The communications layer ensures real-time, secure, and reliable transmission from a "vehicle terminal" to the service layer. The service layer supports various applications using various technologies such as "cloud computing", "data analytics", and information and data processing.

In the last documents presented [16–18], some ITS proposals based on enabling technology (mainly IoT) are presented, however, none of them is based on an ITS architecture that is taken as reference, which makes it difficult to develop related services in a sustainable way, integration and interoperability. In addition, the proposals (with the exception of [18]) are focused on solving a specific mobility problem, they do not present a proposal that can be applied to any of the smart mobility domains.

3 Methods

3.1 Development of a Methodology for the Design of an ITS Architecture

For this initial objective (ITS architecture for these cities), some activities were carried out, such as: the study of the most representative international reference ITS architectures (American, European, Asian, Colombian), the analysis of the environment of the city through the PESTLE tool (Politic, Economic, Social, Technological, Legal, and environment aspects) that is a business analysis technique [19], and the study of methodologies for the development of a regional ITS architecture.

In the design process of the ITS architecture, it was identified that it was convenient to integrate in a coherent, systemic, and orderly way, these non-articulated pieces, through a methodology for the formulation of the ITS architecture. Besides, it was determined by the authors that it was useful for similar works in other intermediate cities of the country (Colombia) or for intermediate cities in developing countries.

Therefore, the stages of the methodology were designed including: the inputs, the activities that must be developed; the techniques and tools that can be used to execute the activities of each stage; and finally, the outputs, which constitute the deliverables resulting of the execution of the activities of each stage. The use of inputs, tools and outputs, were taken as a good practice used in the description of project management methodologies of the PMI (Project Management Institute) and Scrum.

Once the aforementioned methodology was developed, its application was made for the final formulation of the ITS architecture for the city of *Popayán*.

3.2 Design of Services Based on the ITS Architecture Developed for *Popayán*

At this point, once the ITS architecture for the city has been designed, the technologies are evaluated, because the architecture was the "what" should be done, and the design and implementation are the "how".

We initially proceeded to identify the most appropriate enabling technologies for the implementation of ITS, for which the information collected in the previous related works was used. It was determined that the IoT is being considered in the proposed solutions for an "intelligent city" allowing the ITS architecture to materialize, guaranteeing that services are developed and provided to the citizen or the end user [20].

The IoT architectures of international reference were subsequently identified and different options for implementing a system using IoT technology were evaluated for the city. From the reviewed IoT architectures [21–26], it was established that the most complete architecture is that presented by the IoT- A (IoT Architecture [25]).

Once the appropriate IoT architecture was defined to implement a system in the city, we proceeded to validate whether this architecture fits well for the implementation of the ITS with the architecture determined for the city of *Popayán*. When validation was done, it was determined what mobility services would be implemented.

We determined as an adequate project scope, to design two mobility services. The following aspects (related with principal causes of traffic accidents in Colombia, reviewed before) were taken into account in the comparison and evaluation of services: improvement of road safety, relationship with traffic management, utility of the service for the end user (according to our concept), and complexity (in terms of hardware and software required, actors involved and development time).

As a result of service evaluation, selected services were: "public transport vehicle tracking" (identified with PT01) and "traffic measurement" (TM05). The design developed of the first service is presented in the following section of this report.

4 Results

4.1 Methodology for the Development of an ITS Architecture

A resume of the four stages of our methodology is presented below.

Review of the Reference ITS Architectures. In Fig. 1, the inputs, tools and outputs of the first stage are presented (as an example of what was done in each of the stages). At this stage it is necessary to carry out a systematic review of the updated versions of representative architectures at the international level, the standards, the national architecture of the assessed country and the regional (or city) architectures designed in the country. The review requires a critical comparative analysis of the service areas that each one covers, verifying that the services of interest to the city are included.

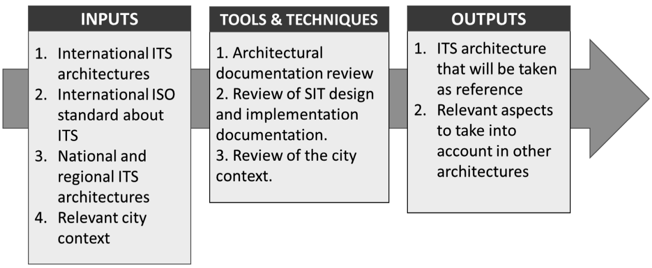

Fig. 1. Inputs, tools and techniques and outputs of stage 1.

Analysis of the Context of the City. The inputs of this stage are: methodologies for development of regional reference architectures and the context of the city in its broadest sense. As tool of the stage, in addition to the review of regional methodologies, context analysis tool called PESTLE is used. As a result, special considerations of city context are obtained, which allow to determine the components of the ITS architecture.

Determination of Architecture Components. The specific components that allow to establish the ITS architecture of the city depend on the selected base architecture. The most commonly used international reference architectures (such as the American or European one) consider a set of components of the ITS architecture; stakeholders and processes in the functional view; physical objects and subsystems in the physical view.

Design of Views of the ITS Architecture. With components of the ITS architecture of the city and the identified objective services, this stage propose designing of the views that describe architecture. The functional and physical views are usually designed, although views considered necessary can be added to clarify as much as possible.

4.2 Development of the ITS Architecture for *Popayán*, Following Methodology

The methodology described was applied for the city of *Popayán* (Colombian intermediate city with problems in road safety and traffic) as a case for the project.

For the determination of the reference ITS architecture, a comparison was made between the American ITS architecture ARC-IT [6], the FRAME architecture [27], the architecture of Malaysia [28], the ISO proposal [29] and Colombian architecture [14]. Sixteen services areas were considered with respect to five ITS architectures. The architecture with largest number of covered areas was the American.

After reviewing documentation of the architectures and the context of the city, it was confirmed that the more suitable ITS architecture was the American architecture (2017). Two service areas of another architectures were added as complements.

The PESTLE tool was used to identify the particular conditions that were relevant in the design of the ITS architecture. In this analysis, aspects such as extension (512 km^2) and inhabitants (approximately 400,000) were taken into account to have an idea of the required ITS dimension; the economic activities of the city, to determine the type of companies (*Popayán* is no industrial city); the laws and regulations at the national and regional level regarding ITS; the traffic safety and traffic management statistics of the city; and the conditions of the current public transport system.

The tools suggested by the methodology were used to identify the most relevant stakeholders and their needs. Later, a priority analysis of their needs were done, reducing the number to 17 needs, among them: reduction of accident rate, compliance with traffic regulations by drivers and pedestrians, and traffic information at critical points.

For determination of service packages considered in the ITS architecture for *Popayán*, prioritized needs of stakeholders and special considerations identified in the context of the city were taken into account. Finally, 35 service packages (33 selected from more than 100 service of ITS American reference architecture and 2 more from other architectures) were taken into account for the ITS architecture for *Popayán*.

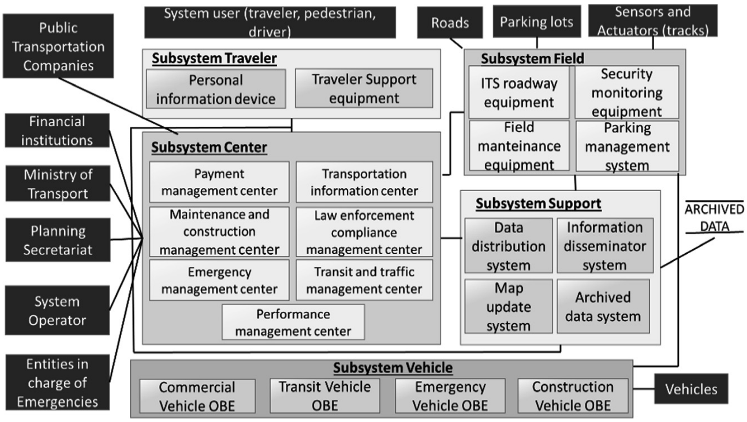

Fig. 2. Physical view, general ITS architecture of *Popayán* (adapted from ARC-IT [6]).

Then, each one of the components (functional and physical) of the architecture was identified. With these components, the views of the ITS architecture were designed. The functional view allows identify the selected processes and relationships between these processes. For general physical view of the architecture (obtained from functional view) presented in Fig. 2, the actors of the system, the subsystems, and the physical objects are taken into account. The general physical view (adapted from ARC-IT physical view) allows visualizing proposed "subsystems" and within each subsystem, the physical objects that it includes. Through them, the selected services are provided.

The advantages of the proposed methodology and its application in the city of *Popayán*, with respect to the reference ITS architectures and their application methodologies, are presented in the discussion and conclusions of this document.

4.3 Design of Intelligent Mobility Services for the City of *Popayán*

As previously mentioned, for the design of mobility services, the facilitating technologies were first identified to implement the ITS architecture of the city of *Popayán* and it was determined that the IoT was the adequate technology to do so.

With the adequate IoT architecture to implement a system (based in [25] mainly), an ITS architecture adapted to the IoT technology was obtained (presented in Fig. 3).

As previously mentioned, two services were selected (PT01 and TM05) to perform its detailed design, according to the parameters previously indicated. To define the "detailed diagram" of each service, the architecture presented in Fig. 3 was taken into account, to determine which objects should be considered and what changes should be made. In addition, the diagrams of the physical architecture proposed by ARC-IT (main reference architecture) were reviewed (as presented in Fig. 4 for service PT01).

The "detailed diagram" for the service "PT01" is presented as an example in Fig. 5.

Next, physical and logical objects, from each "detailed diagram" of the services, were described, presenting the specific functionality to be developed. In addition, it was determined with what elements (hardware, software, communications, interactions) the service could be designed. With elements and functionality described, the "specific

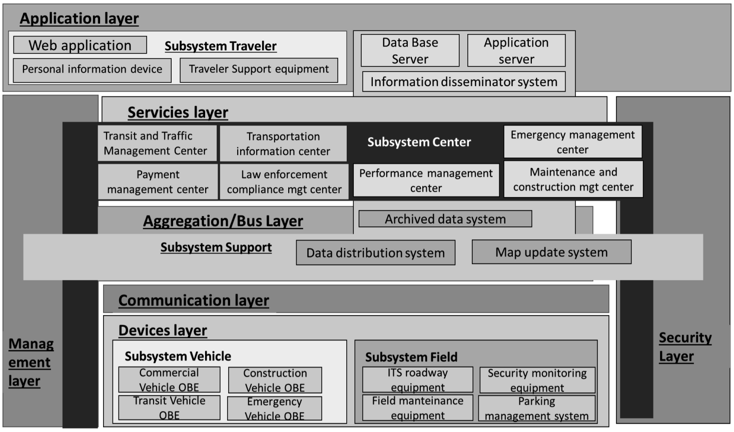

Fig. 3. ITS architecture adapted to IoT, developed using physical view (Fig. 2) adapted to [25].

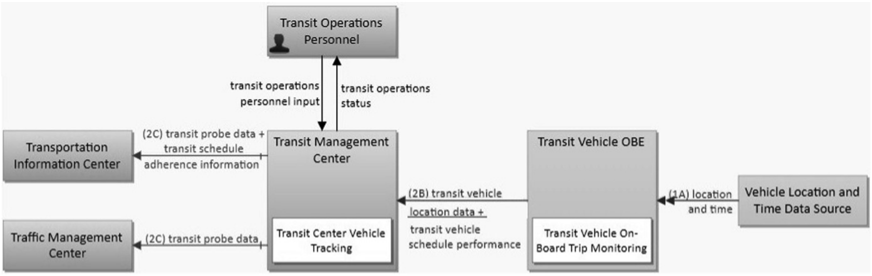

Fig. 4. Detailed physical architecture of PT01 service. Source: ARC-IT [6].

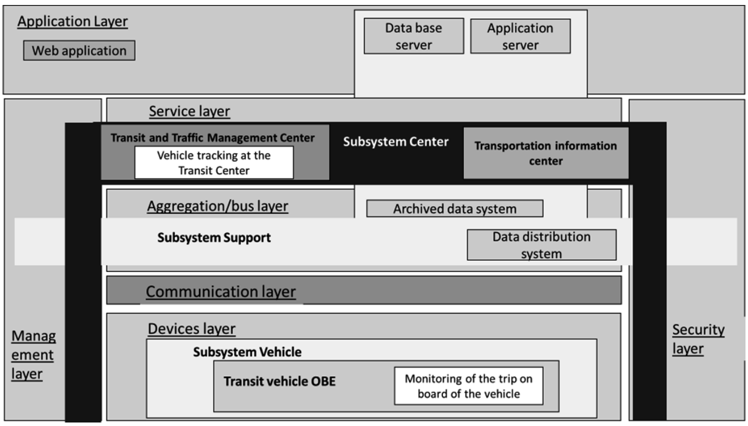

Fig. 5. "Detailed diagram" of the service "PT01".

design diagram" of each service (named in this way by the authors) was made, indicating the type of elements to be used, their physical location and the information flows. As an example of the "specific design diagram" of the service, the diagram made for the PT01 service is presented in Fig. 6.

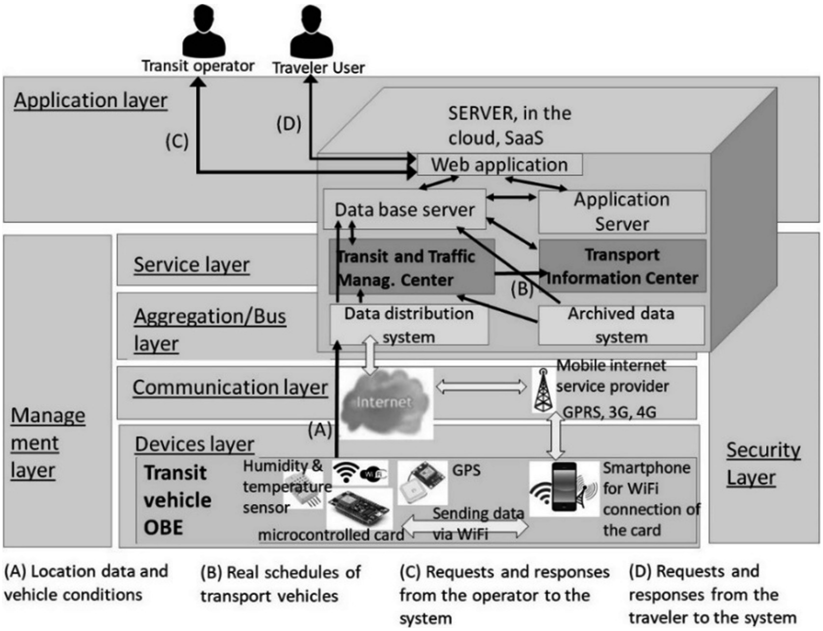

Fig. 6. "Specific design diagram" of the service "Public transport vehicle tracking". Developed by authors using "detail diagram" (Fig. 5) and selected technology.

From Fig. 6 it is important to highlight the hardware elements used in the "Transit vehicle OBE (On Board Vehicle)" which are: a microcontrolled card (with access to Wi-Fi) to which a GPS (Global Positioning System), and a humidity and temperature sensor are connected.

5 Discussion and Conclusions

Our methodology for the design of an ITS architecture for an intermediate city of a developing country and its application for the city of *Popayán*, have some advantages with respect to ITS reference architectures and standards. The ITS architecture developed for the city of *Popayán* applying the methodology can be used directly for an intermediate city with similar characteristics (in Colombia or another developing country); while international reference architecture and standards have too large scope and a context of development (economic, technological and cultural) totally different.

If the intermediate city (of a developing country), for which it is wanted to design an ITS architecture, has some characteristics that differ considerably from the city that is taken as an example (*Popayán*), it is possible use the proposed methodology to develop another version of ITS architecture that will be more adjusted to the context. The use of the methodology proposes the revision of several reference ITS architectures, not just one, which allows to use the best features of each one. Additionally, the detailed analysis of the city context allows an adequate and focused reduction of the services and components of the architecture.

The detailed process for the design of mobility services using the recommended IoT technology can be used starting from ITS architecture designed for *Popayán* (if it applies) or from another ITS architecture that is designed more precisely.

It should be considered that although the design of mobility services is a significant step, the development process of these services and operation tests is very important, to evaluate if the architecture developed for the city meets the requirements and allows obtaining services really integrated and interoperable.

As conclusions of the work we have that the identification and consideration of the particular conditions of an intermediate city of a developing country is a fundamental step to formulate an adequate ITS architecture, because it determines some important restrictions to be taken into account, among which are the selected services. Besides, a city that makes an incremental deployment of its portfolio of mobility services requires a reference architecture that allows the integration and interoperability of services.

The city of *Popayán* has a large number of challenges regarding mobility; among others, the road infrastructure is necessary to improve and expand it, the new means of public transport must be implemented, and compliance with traffic regulations to be improved. Some of these challenges can be achieved with help of mobility services, for which it is relevant to be able to continue with works related to the subject.

As future work is expected that a pilot of the services designed be developed, in a controlled environment. Besides, the collected data and results obtained must be presented with the aim of contributing to improvement of mobility of the city, which can result in the reduction of current traffic accident rates and an improvement of traffic.

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