DEVELOPMENT VALIDATION OF A FLEET MANAGEMENT AND CONTROL SYSTEM, BASED ON INTELLIGENT TRANSPORTATION SYSTEMS (ITS) SERVICES AND LONG-RANGE TECHNOLOGY (LORA)

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Degree work presented as a requirement to obtain the title of Electronics and Telecommunications Engineer

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DEDICATION

To my mother and her indispensable support and sacrifice for me throughout this adventure, to that great woman who no longer accompanies me in life but who always saw more in me than I saw and who was always there to serve, my sister with whom I shared my whole life and with whom I have to share my achievements, to my uncles for always providing me with a home when I needed it, to my closest cousins who are like brothers and synonymous with joy for me, to my thesis director for his support and shared knowledge in this final stretch, to my colleagues with whom I shared much of what I lived in these good years and with whom I hope to share many more, Cristhian my thesis partner, best friend and a great person, Pacha who never said no to anything and with whom I got along from the first day, Dani because of his great personality, that pleasant energy that he always made us feel and the shared friendship, and in general, all those who at that time were part of this , a great experience to lived.

To all, infinite thanks.

Beimar Jhoán Rojas Becerra

To my parents for their great love, their unimaginable efforts and for accompanying me all my way, to my sister with whom I shared my stories and for her support, to my cousin Sebastian who was my guide during my learning, Juan who was always on my side like my brother, my grandparents who always gave me their love, support and many food, my uncles who traveled by my side when I needed them most, Beimar who more than my thesis partner was my best friend and one of the most sincere, intelligent and loyal person that I know, Pacha, my roommate with who I shared so many years and good moments, my two best friends Eliana and Daniela, two beautiful and intelligent girls with whom I shared so many laughter and adventures, to my thesis director for sharing with us his knowledge and for the great work he has done, to ICESI university, its students and professors for their advices and providing us with tools for development of this degree work, to 'Universidad del Cauca', to its teachers and all the people I met along the way, finally to God for all the blessings received.

Cristhian Sebastian Bolaños Portilla

ABSTRACT

In medium-sized cities in developing countries, transit service without dedicated lanes has issues related to route compliance, schedules, speed control, and safety. An efficient way for dealing with this issue is the use of ICT (Information and Communication Technologies), to implement a Fleet Management and Control Systems (FMCS). Such implementation can be performed using Intelligent Transportation Systems (ITS), which allow integration of services and adequate standardization.

For those reasons, in this degree work we performed: a) A literature review, related to FMCS based on ITS and their enabling wireless technologies. b) Design of an ITS architecture of an FMCS based on the context (medium-sized city) and review results. c) Design and development of a prototype development unit for the proposed FMCS based on the results of the review and the proposed architecture. d) Evaluation of the FMCS prototype development unit in a controlled environment. e) Design and validation of quasi-experiments focused on evaluating the operation of the prototype, mainly in the modules related to the wireless communications technology. f) Design and development of the web application and database of the FMCS prototype.

The prototype development unit built for the FMCS took into account the designed ITS architecture, the research context and the results of the literature review. The wireless communications technology selected for the prototype (LoRa) was tested and analyzed in terms of coverage, in a case study in the city of Popayán. The FMCS prototype was initially validated with a first phase of tests in a controlled environment, obtaining good results; and later two new phases of tests (quasi-experiments) were carried out in a real environment (defining some routes in the city of Popayán and using vehicles to travel them performing the respective monitoring) with some aspects controlled. When executing the last two phases of tests, a data set was collected, important to analyze the results and that can be useful for future research on related topics.

The results obtained in terms of percentage of messages received, distances reached and signal levels obtained were good, considering various aspects such as LoS (Line of Sight) and power. The web application of FMCS prototype presented a good response in terms of the management and handling of the system, for the various components that make up. This enables the development and implementation of an FMCS on a larger scale and integrates it with other mobility services.

RESUMEN

En las ciudades medianas de países en desarrollo, el servicio de tránsito sin carriles exclusivos tiene problemas relacionados con el cumplimiento de las rutas, los horarios, el control de velocidad y la seguridad. Una forma eficaz de abordar este problema es el uso de las TIC (Tecnologías de la Información y la Comunicación), para implementar un Sistema de Control y Gestión de Flotas (FMCS). Dicha implementación se puede realizar utilizando Sistemas Inteligentes de Transporte (ITS), que permiten la integración de servicios y una adecuada estandarización.

Por estas razones, en este trabajo de grado realizamos: a) Una revisión de la literatura, relacionada con un FMCS basada en ITS y sus tecnologías de comunicación inalámbrica habilitadoras. b) Diseño de una arquitectura ITS de un FMCS en base al contexto (ciudad mediana) y revisión de resultados. c) Diseño e implementación de una unidad de desarrollo de prototipo para un FMCS basado en los resultados de la revisión y la arquitectura propuesta. d) Evaluación de la unidad de desarrollo de prototipo FMCS en un ambiente controlado. e) Diseño y validación de cuasi-experimentos enfocados a evaluar el funcionamiento del prototipo, principalmente en los módulos relacionados con la tecnología de comunicaciones inalámbricas. f) Diseño y desarrollo de la aplicación web y base de datos del prototipo FMCS.

La unidad de desarrollo del prototipo construida para el FMCS tuvo en cuenta la arquitectura ITS diseñada, el contexto de investigación y los resultados de la revisión literaria. La tecnología de comunicaciones inalámbricas seleccionada para el prototipo (LoRa) fue probada y analizada en términos de cobertura, en un caso de estudio en la ciudad de Popayán. El prototipo FMCS fue inicialmente validado con una primera fase de pruebas en un ambiente controlado, obteniendo buenos resultados; y posteriormente se llevaron a cabo dos nuevas fases de pruebas (cuasi-experimentos) en un entorno real (definiendo algunas rutas en la ciudad de Popayán y utilizando vehículos para recorrerlas realizando el respectivo seguimiento) con algunos aspectos controlados. Al ejecutar las dos últimas fases de las pruebas, se recopiló un conjunto de datos, importante para analizar los resultados y que puede ser útil para futuras investigaciones sobre temas relacionados.

Los resultados obtenidos en cuanto a porcentaje de mensajes recibidos, distancias alcanzadas y niveles de señal obtenidos fueron buenos, considerando diversos aspectos como LoS (Line of Sight) y potencia. La aplicación web del prototipo FMCS presentó una buena respuesta en cuanto a la gestión y manejo del sistema, por los

distintos componentes que lo integran. Esto permite el desarrollo e implementación de un FMCS a mayor escala e integrarlo con otros servicios de movilidad.

Table of Contents

TABLE LIST

LIST OF FIGURES

LIST OF ACRONYMS

API	Application Programming Interface
ARC-IT	Architecture Reference for Cooperative and Intelligent Transportation.
BAIS	Bus Arrival Information System.
BATPM	Bus Arrival Time Prediction Model.
BS	Base station.
BT	Bluetooth.
CIA	Confidentiality, Integrity and Availibility.
CMS	Collection Management System.
MINCIENCIAS	*Departamento Administrativo de Ciencia, Tecnología e Innovación,* Administrative Department of Science, Technology and Innovation.
C-V2X	Cellular Vehicle to Everything.
DSRC	Dedicated Short Range Communication.
FMCS	Fleet Management and Control System.
FRAME	Framework Architecture Made for Europe.
GIS	Geographic Information System.
ICT	Information and Communication Technologies.
IDE	Integrated development environment
IoT	Internet of Things.
IoTA	Internet of Things and Applications.
ISO	International Organization for Standardization.
ITS	Intelligent Transportation System.
LORA	Long Range.

LPWAN	Low power wide area network.
M2M	Machine to Machine.
NASA	National Aeronautics and Space Administration.
NBIoT	Narrow Band IoT.
OBE	On Board Equipment.
PMI	Project Management Institute.
RFID	Radio Frequency Identification.
RSSI	Received Signal Strength Indicator.
RTI	Research, Technological develop and Innovation.
SciMAT	Science Mapping Analysis Tool.
SETP/SPTS	*Sistemas Estratégicos de Transporte Público,* Strategic Public Transport Systems.
SINITT/NISITT	*Sistema Nacional Inteligente de Infraestructura, Tránsito y Transporte*, National Intelligent System of Infrastructure, Traffic and Transportation.
SMS	Short Message Service.
STPS	Strategic for Public Transportation System.
TRL	Technology Readiness Level.
UMTS	Universal Mobile Telecommunications System.
UL	Up Link.
V2I	Vehicle-to-Infrastructure.
V2V	Vehicle-to-Vehicle communications.
V2X	Vehicle-to-everything.
VANET	Vehicular Ad-Hoc Network.
WAVE	Wireless Access in Vehicular Environments.

1 INTRODUCTION

1.1 PROBLEM APPROACH

1.1.1 Problem description

Cities in developing countries such as Colombia face problems in their mobility, such as high traffic congestion on roads, high traffic accident rates, inadequate public transportation (at certain times of the day) and high levels of air pollution and noise. These cities have a high demand for transport and therefore for infrastructure, due to the growth of the population index and rapid urban expansion. But, that demand cannot easily be met, due to financial limitations [1].

Statistical data of Colombian cities show a worrying situation for medium-size cities, regarding traffic congestion and traffic accidents. According to the organization INRIX (company in charge of studying mobility in the world and looking for intelligent solutions), the high traffic problem not only occurs in large cities of the countries, medium-size cities also have similar problems [2]. Regarding traffic accidents, it is evident in death statistics that medium-size cities have a higher death rate than large cities [3].

Leading causes of traffic accidents in Colombia are speeding and non-compliance with traffic regulations [4]. These causes of accidents are generated by all types of vehicles; however, it is important to consider that the number of public transport vehicles (mainly the service called "collective" in medium-size cities) that are involved is relatively high. Furthermore, it is essential to highlight that there is a considerable number of injured passengers in this type of vehicle (26% of the total passengers that are injured in any type of vehicle) [3]. This information is very worrying considering the low number of public transportation vehicles (approx. 5%) concerning the total vehicles in the country.

Therefore, a project that seeks to improve control and monitoring of public transport vehicles in these medium-cities (*"*collective*" service*) could contribute indirectly to improve the mobility problems of this kind of cities in the country. It would be very complex for a project to focus on directly reducing congestion or traffic accidents, but it can provide mechanisms to reduce the principal causes of these problems (speed and non-compliance with regulations).

Information and Communication Technologies (ICT) appears as the best option for the implementation of an efficient transport system because they offer advantages in various characteristics such as centralized traffic control, navigation, security, access to travel information, and real-time assistance, among others [5]. In this way, the implementation of an efficient public transportation system, complemented by (cutting-edge) ICT, could contribute to minimizing the problems for a city with similar characteristics to *Popayán*, [6]. These systems are associated in this work to the context of the so-called ITSs (Intelligent Transportation Systems) and FMCSs (Fleet Management and Control Systems), which are detailed in subsections 2.4 and 2.6 of the theoretical framework.

The great disadvantage of most of the ITS services developed at the international and national level is that they are not based on adequate architecture, which means that it is not easy to integrate and interoperate those services. In other words, ITS services are created, but most of these services cannot communicate, nor reuse components to generate a real benefit in the mobility of a city [7].

On the other hand, at the international level, several FMCS models are proposed, however, most have the same problem mentioned above, FMCS implemented with services that are not based in an appropriate architecture. Besides, most FMCS use inconvenient technologies (currently) such as cellular telephony (GSM, GPRS or LTE), for communication that must be established between terminals or vehicles and a particular exchange or Gateway (Cell phone technologies involve some problems for FMCSs as mentioned in [8] and in this document in subsection 2.8).The use of technologies such as LoRa (Long Range), in the development of ITS services, can help to solve this type of disadvantages of cellular telephone networks, because they considerably reduce operating costs.

Although there are several approaches to regional ITS architectures, the proposed modeling is regularly very general and not suitable for cities with certain characteristics similar to *Popayán*, as mentioned in [9]. So, the development of an FMCS, without an adequate ITS architecture as a reference, and without the use of communications technologies that are at the forefront, could imply the problem of high operating costs, in addition to the lack of interoperability with other mobility services or with other smart services for the city.

1.1.2 Research question

How is it possible to improve the characteristics of the public transportation service called “collective” in cities such *Popayán*, regarding the management and control of vehicles, guaranteeing adequate standardization with other ITS services for the city?

1.1.3 Justification

According to the raised problem, the implementation of an FMCS through ITS services would entail several advantages that would be reflected mainly in the possible reduction of the accident rate, the improvement of vehicle congestion and the reduction of emissions of pollutants into the environment. These FMCS could also detect possible irregularities in the use of public transportation, the potential impact on fuel savings, as well as the improvement in service quality [7], [10].

Also, as indirect benefits, improvements in social and economic aspects of the city of *Popayán* would be obtained. With the improvement of transport mobility, an increase in the productivity of several sectors is inferred, thanks to the time savings obtained from the improvement in traffic congestion. Besides, it is important to highlight that transport has become a strategic industry for a globalized economy that demands greater facilities for the mobility of people and goods [11].

Both internationally and nationally, the number of FMCS implemented with specific ITS services in a suitable architecture are reduced, and even less, those that propose alternative communication technologies such as LoRa. At the international level, one example is the proposal of an Automatic Vehicle Monitoring (AVM) platform to configure multiple heterogeneous devices for fleet management, monitor traffic on the streets and provide high-level services to users, which It is based on an ITS architecture, but its communications network is established in GPRS. In the country, in [7] an FMCS is proposed for the context of Latin American intermediate cities, configurations in ITS architectures and also, design of two technology options suitable for implementation: LoRa and NB-IoT, however, this document reaches the design stage, no implementation is done.

Also, there are very few studies where systems of this type are developed (either in proof of concept mode) and operation experiments are carried out, so it is necessary to drive the models proposed in the real context and determine thus its effectiveness.

In [7] also mentions the development of Strategic Public Transportation Systems (SPTS) in the country for 8 medium-size cities, they are *Armenia, Montería, Neiva, Santa Marta, Pasto, Popayán, Sincelejo and Valledupar*. In 7 of the 8 systems, the advances that have been made, only focus on infrastructure and road adjustments. *Pasto* is the only city that has implemented technological advances in SPTS. It is evidenced in the progress of its traffic light system and the FMCS, based on GPS that is supported by a Geographic Information System (GIS).

For all these reasons, the progress and study for the development of FMCS in the context of medium-size cities (like *Popayán*) with adequate standards, could be very useful for those cities that wish to perform their implementation.

1.2 OBJECTIVES

1.2.1 General objective

Validate the development of a Fleet Management and Control System, in the public transportation of a medium-size Colombian city based on the development of ITS services and LoRa technology.

1.2.2 Specifics objectives

1. Design the adequate ITS architecture of a Fleet Control Management System (FMCS), in a medium-size Colombian city.
2. Develop a prototype development unit of the FMCS according to the designed architecture, which will serve as a reference for the future development of a complete prototype.
3. Evaluate the working together of the different components of an FMCS within a laboratory environment using ITS services, LoRa communications technology, and the required information security.
4. Design and execute a validation quasi-experiment of the developed FMCS, which allows obtaining results of availability of the FMCS, and also allows obtaining a “data set” for further analysis.

1.3 METHODOLOGY

During the development of the project, different methodologies will be used. For the initial phase of the project, as a first step, it was necessary to perform a science mapping analysis with the help of the SciMAT tool, in order to analyze the social, conceptual, and intellectual evolution of the interest area. In this way, identifying the issues and relevant aspects that a line should be carried out for the literature review and the development of the system. Based on the conclusions obtained in the previous process and as a complement, a systematic review was carried out, using the PRISMA methodology. In this way, the documents to be considered in the state of the art were selected and more information on the research topic were obtained. Finally, for the planning, design, construction, implementation and evaluation phases of the system, the Scrum framework will be analyzed to speed up the delivery of value.

The methodologies (and tools) used in the scientific mapping, systematic review, and project planning and implementation are described below.

1.3.1 Science mapping and SciMAT

Science mapping or bibliometric mapping is a spatial representation of how disciplines, fields, specialties, and individual articles or authors are related to each other [12].

It focuses on monitoring a scientific field and delimiting research areas to determine its cognitive structure and evolution [13], [14]. In other words, science mapping aims to show the structural and dynamic aspects of scientific research.

The process to perform an analysis to a science mapping is called General Flow, it has 8 steps [13], as can be seen in **Figure 1**.

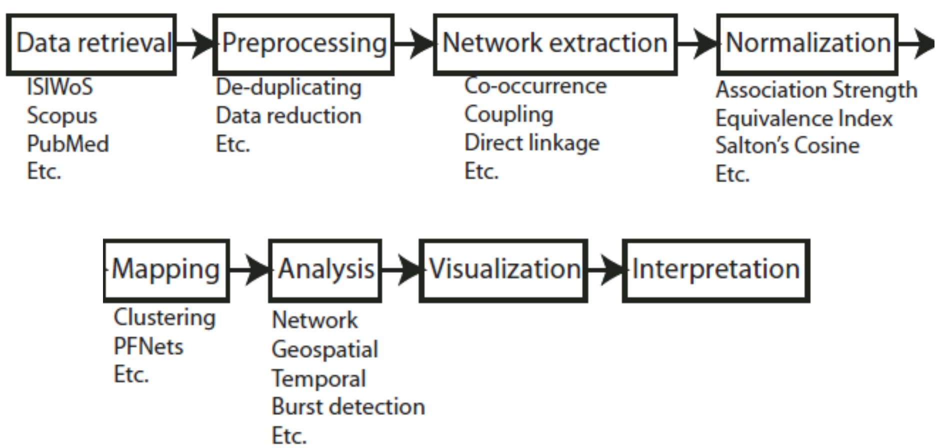


Figure 1. General flow in science mapping analysis. Adapted from source [15]

The first step is to obtain data, in general, these usually contain errors, so a technique called "Preprocessing" must be applied first. As a next step, the network should be built using an analysis unit with magazines, documents, cited references, authors and descriptive terms or words [13].

Subsequently, a standardization process is needed [16], after this process, the scientific map must be built.

Through the analysis process, useful knowledge is discovered from data, networks, and maps [14]. Now, to show the evolution of the detected groups, visualization techniques are used, it should be borne in mind that visualization and mapping are different, but also interdependent, in other words, the visualization technique used will vary according to the method selected for build the map. Finally, in the interpretation step, the analyst aims to discover and extract useful knowledge that can be used to make decisions.

The steps included between 2 and 7 presented in **Figure 1**, it was decided to perform them with the help of SciMAT, this tool allows the analysis of science mapping within a longitudinal framework and provides different modules that help the analyst to perform all the steps of the science mapping workflow [15]. Similarly, it allows the user to carry out studies based on various bibliometric networks (co-word, co-citation, author co-citation, journal co-citation, co-author, bibliographic link, journal bibliographic link, and author's bibliographic link).

Likewise, it allows the use of different measures of normalization and similarity on the data (strength of association, equivalence index, inclusion index, Jaccard index, and Salton's cosine), it also makes it possible to choose various grouping algorithms to narrow the data.

In the visualization module, three representations are used together strategic diagrams, cluster networks, and evolution areas), allowing the user to better understand the results.

Three characteristics differentiate SCIMAT from other science mapping tools, they are:

- Processing module: Detects duplicate elements, poorly written, among others.
- Use of bibliometric measures: It allows to carry out science mapping studies under a longitudinal framework, thus providing information on the interest and impact on the research community.
- A wizard to configure the analysis: Allows you to select the measurements, algorithms and analysis techniques used to carry out the science mapping analysis.

1.3.2 PRISMA Methodology

The systematic literature review using the Preferred Reporting Elements for Systematic Reviews and Meta-analyses (PRISMA) is explained below [17]. A systematic review attempts to collect all empirical evidence that fits the pre-specified eligibility criteria to answer a specific research question, based on explicit and systematic methods that are selected to minimize bias, thus providing reliable results from which conclusions can be drawn and decisions made. For its part, meta-analysis is the use of statistical methods to summarize and combine the results of independent studies [18].

PRISMA focuses on reporting reviews that evaluate randomized trials (in medicine) but can also be used as the basis for reporting systematic reviews of other types of research. The PRISMA guidelines consist of a four-phase flow diagram and a checklist of 27 elements. The flow diagram describes the criteria for identification, selection, eligibility, and inclusion of the reports to be evaluated, according to selected parameters.

First, the identification phase refers to searching for study documents in different databases according to their title, because a search string is chosen that provides results according to the research, and those that are not related to this according to the title of the document. Then, the rejection phase consists of reviewing the documents chosen so far based on certain basic criteria (such as the year of publication or the type of document). The review includes some parts of the document, such as the title, the summary and the conclusions. In this phase, the documents found with repeated titles obtained from different databases are initially deleted, then those with abstracts that disagree with the study are discarded. For its part, the eligibility phase is similar to the previous one, but it focuses on the choice of documents based on the study of all their content. For the said election, certain eligibility criteria are determined that facilitate the respective discarding of documents that do not meet them. Finally, the selection phase consists of the final selection of documents, but through a qualitative and quantitative synthesis, where according to the review carried out in the previous phase, the classifications are established according to the themes and eligibility criteria. of the available documents. So far, it is determined which groups can make a qualitative synthesis and which ones a quantitative analysis or meta-analysis. The following figure (**Figure 2**) shows this summary process.

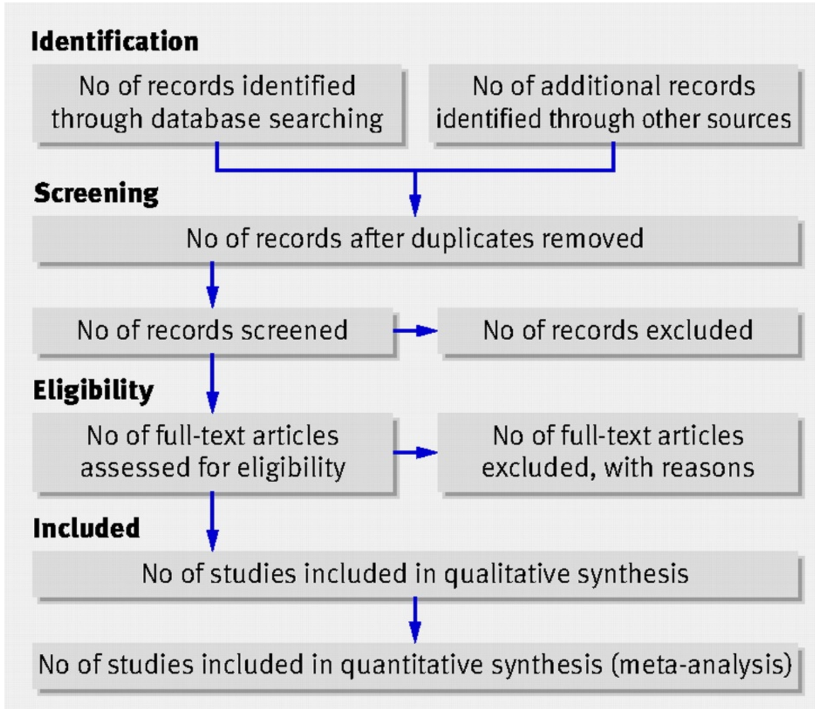


Figure 2. PRISMA Flow Diagram. Source [18]

1.3.3 SCRUM Methodology

Scrum is an adaptable, iterative, fast, flexible and efficient framework, designed to offer considerable value quickly throughout the project.

A key strength of Scrum lies in the use of inter-functional, self-organized and empowered teams that divide their work into short, concentrated work cycles called sprints. As many Sprints as required must be completed until all functionality of the project is completed. The **Figure 3** provides a flow overview of a Scrum project [19].

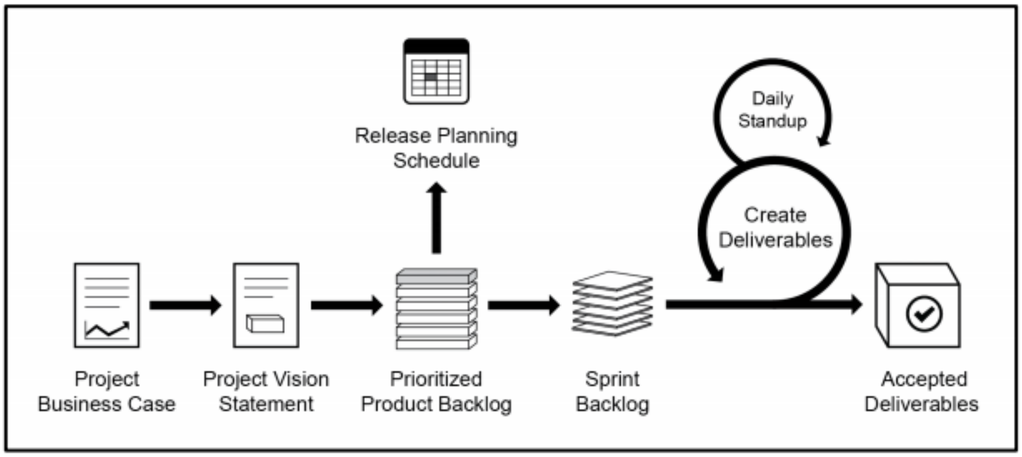


Figure 3. Scrum flow, based on [19]

This methodology follows a process divided into 5 fundamental phases:

- Start: In this phase, the vision of the project must be created, the “Scrum Master”, the “Product Owner” and the “Scrum team” must be identified, develop epics, create the “Prioritized Backlog of the product”, and carry out the launch planning.
- Planning and estimation: Here, the user stories are created, estimated and compromised, the tasks (activities) to be followed are identified and the Sprint Backlog is created.
- Implementation: It is the phase where deliverables are created, the “Daily Standup” is carried out and the “Priority Product Backlog” is refined.
- Review and retrospective: Sprint is demonstrated and validated.
- Launch: The last phase corresponds to the process of sending deliverables and retrospectives of the project.

Commonly the Start phase is only done once, the planning and estimation are done once the Start phase is completed, to define all the necessary sprints for the project (Prioritized Backlog of the product) and is done again at the start of each of the Sprints (Sprint Backlog). The implementation, review, retrospective, and launch are performed by each of the Sprints.

To apply the Scrum methodology in the particular project, as a first step, a start document will be made, where the functionality of the system will be described in detail from the point of view of the users. Said functionality (in the same start document) will be divided into what is called epics, to perform a "Product Backlog" assigning priority to each of them and determining tentative dates of realization of those epics in a general schedule.

Subsequently, a planning document will be made in which the epics identified and prioritized in the Start document will be divided, in User Stories, said User Stories will be prioritized and it will be determined which will be carried out in each of the Sprints. Consecutive (in the same planning document) all the necessary tasks (from the developer's point of view) of the Sprint 1 User Stories will be determined and a "Sprint Backlog" will be carried out where the periods will be determined in a detailed schedule of time of each of the user stories, tasks of Sprint 1, and those responsible for each of them. Once the general planning and detailed planning of the Sprint 1 has been developed, the development and monitoring of this will proceed. Once finished, a retrospective analysis of the Sprint should be carried out and subsequently the detailed planning of Sprint 2. This will continue until all the Sprints that make up the work are developed.

1.4 MONOGRAPH STRUCTURE

The following chapters of this monograph are organized as follows:

- **Chapter 2:** It presents the **Theoretical framework - concepts and generalities** which contains all the necessary concepts for the understanding of the document.
- **Chapter 3:** Exhibits the **State of the art**, where a scientific mapping and systematic review of the study topic is present.
- **Chapter 4:** It shows the **ITS architecture focused on FMCS for intermediate cities in the Colombian context** that relates to the design of an ITS architecture according to defined characteristics, the review of the state of the art.
- **Chapter 5:** Presents the **Coverage zone analysis** that shows a coverage study on the city of Popayán for the implementation of an FMCS.
- **Chapter 6:** Presents the **Design and development of FMCS prototype development unit and communication technology tests**, where a prototype development unit of FMCS and communication technology tests are presented.
- **Chapter 7:** Presents the **Design and development of the web application and database (of FMCS prototype development unit)**, where the web application design and development of the FMCS prototype is presented.

- **Chapter 8:** Releases **Conclusions**, where the main conclusions obtained from the study are presented and some ideas for future work are suggested.

1.5 PUBLICATIONS

The literary review, the proposal and some results that are presented in this work were published in an international Q2 (A1 for Colombia, according to the homologation of Minciencias of the year 2020) classification journal. This paper is accessible on Annex A ("Review article in Electronics Journal").

- Beimar Rojas, Cristhian Bolaños, Ricardo Salazar-Cabrera, Gustavo Ramírez-González, Álvaro Pachón de la Cruz, and Juan Manuel Madrid Molina. **Fleet Management and Control System for Medium-sized Cities Based in Intelligent Transportation Systems: From Review to Proposal in a City**
  - Status: Published
  - DOI: 10.3390/electronics9091383
  - URL: https://doi.org/10.3390/electronics9091383
  - Classification: A1

2 THEORETICAL FRAMEWORK - CONCEPTS AND GENERALITIES

In this section, is presented the theoretical base that is considered relevant for a better understanding of the present degree work. Initially, the levels of technological maturity are described, to justify and corroborate the scope outlined in the preliminary project and those achieved; with the same purpose, the differences between proof of concept, prototype, and development validation are explained. The other concepts and generalities offer the reader a knowledge base on the technologies and components that the proposed system uses.

2.1 Technology Readiness Levels

TRL (Technology Readiness Level) is a concept initially proposed by NASA in the '70s that aims to establish the degree of technological maturity of the different program proposals. This concept is used as a reference by MinCiencias in an adaptation to the TRL scheme, for the organization of activities related to research, technological development and innovation of the actors of the National System of Science, Technology, and Innovation [20]. In this way, the TRL serves to identify the correspondence of RTI activities (Research, Technological Development, and Innovation) with the different stages of technological development, as represented in the **Figure 4**.

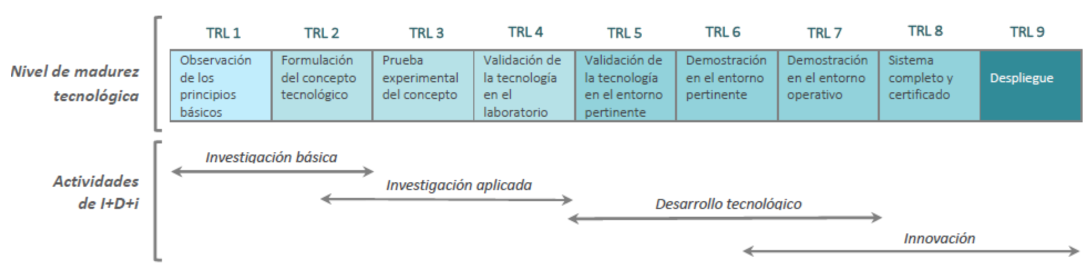


Figure 4. Relationship of TRL and RTI stages. Source [20]

In [20], the respective identification of the characteristics of each level is made, where the most relevant are exhibited below for each one:

- **Level 1, Observation of the basic principles:** At this level, the basic principles of the idea have been qualitatively postulated and observed, and the initial scientific research has been completed.
- **Level 2, Formulation of the concept:** Here practical applications are identified, which can reach an invention. The applications are still speculative and there may still not be detailed tests or analyzes confirming these assumptions. "Proof of concept" for the concepts of technology.
- **Level 3, Experimental proof of concept:** At this level, the activities that are carried out are strongly research and development, which include analytical studies and laboratory-scale studies to physically validate the predictions of the separate elements of technology. Laboratory tests are also included, but there is still no intention to integrate components into a complete system.
- **Level 4, Development validation in a laboratory environment:** The fourth level corresponds to the validation of basic components, to determine if the components will work together as a system that achieves proper functioning.
- **Level 5, Development validation in the relevant environment:** Here the technological components are integrated so that the configuration of the system is similar to the final application in almost all its features, clarifying that its operability is still at the laboratory level. The main difference with level 4 is the increase of fidelity and its environment towards the final application. The objective of this level can be defined as the last instance, as the development of a commercial prototype, for which life cycle evaluations and economic evaluation models have been validated.
- **Level 6, Demonstration of the development in pertinent environment:** The system is started to be evaluated in an environment of conditions relevant to the real operating conditions and a pilot prototype is generated with detailed design and with scaling conditions that allow to reach an operating system that is capable to develop all the functions required by it.
- **Level 7, Development demonstration in the real environment:** In this level, a complete prototype with a functional operating system demonstrated in a real environment is already developed and the first pilot run and real final tests are carried out. Here it is shown that the technology works, operates on a pre-commercial scale and issues of manufacturing and final operations are identified.
- **Level 8, Complete and certified development:** This level corresponds to the final complete system and evaluated through tests and demonstrations. Here all operational and manufacturing issues are resolved and documents are prepared for the use and maintenance of the product.
- **Level 9, Development deployment:** Corresponds to the operation of the system. Here the technology is in its final form and operable in a number

of operating conditions, which gives the product or technology for serial production and marketing.

Based on these characteristics and the association of each one with the RTI activities, it was determined that the scope of this proposal for grade work could reach level 3 or 4, which correspond to applied research activities, however, it is decided to discard level 3 (experimental proof of concept), because the research focuses on aspects such as analytical and laboratory-scale studies, on separate technological components and not on their incorporation for a complete system. On the other hand, at level 4 (Development validation in a laboratory environment), the realization of a prototype development unit, built in a laboratory and in a controlled environment, is achieved and is made up of the technological components studied at the previous level, to determine its operation altogether. Although it is clarified that the stage of preliminary life cycle evaluations and economic and social evaluation models are not planned to be performed in this work because they would exceed the scope that it was consider viable.

Therefore, the scope of this proposal in the maturity scale established by MinCiencias will be level 4, not including preliminary life cycle evaluations and economic and social evaluation models.

2.2 Proof of concept, prototype, and development validation

Based on **Figure 4** and the characteristics offered by MinCiencias for the different levels of TRL [20], some differences can be established between the definitions of proof of concept, prototype, and development validation. First, according to the level of least maturity or development, the proof of concept is located, which is defined as evidence, typically derived from a pilot experiment or project, which demonstrates whether a design concept or commercial proposal is feasible [21]. Based on this and applied to the framework of technologies, what is sought in this phase or level, is to physically validate (on a laboratory scale) the predictions made in a scientific article of the separate elements of technology, through research activities and development. At this level, there is no study of the functioning of the elements working together, or a system. This type of test is considered essential when creating a prototype of an operational and valid operation [22].

After the proof of concept, the level of development validation is found, where the different components of basic technology begin to be integrated to demonstrate that they can work together and their verification occurs in laboratories and in controlled environments [23]. In this phase through physical or performance tests, it is determined whether the requirements of a specification, product or system are met. These are done with respect to the user's needs, requirements and commercial processes performed to determine if a system meets the acceptance criteria [24], [25]. It is a stage where modifications can still be made to these components (because it is not yet considered a system or subsystem) and marks the beginning of the so-called technological development in TRLs.

Associated with this technological development, the term “prototype” or “demonstrator” appears, which is the model or first specimen developed very close to the commercial field, which serves for a later development of the final product [26] and reaches its final advance precisely at level 7 [23]. Based on this, the association with a prototype that appears in the level of development validation is presented in the construction of a prototype development unit, which is the objective of this level. The development of the prototype evolves as it rises in level, as it is acquiring functioning and operation characteristics at a pre-commercial scale, and validations carried out in laboratory environments, simulated environments, and real environments, thus developing a perception of the final appearance of the product and demonstrating its functionality [22].

Then, according to the TRL level that needs to be achieved to really obtain a prototype, with its respective functional and commercial characteristics, it was considered that this proposal cannot become a prototype, because the development and research objectives are achieved at level 4, where there isn't a final or close version of the prototype yet. For this reason, this proposal could reach the level of development validation.

2.3 Research Experiments

A research design is developed or selected based on a particular study context, in order to solve the research questions posed and meet study objectives. The term design refers to the plan or strategy designed to obtain the desired information in order to respond to the problem statement. If the design is carefully conceived, the final product of a study (its results) will be more likely to generate knowledge.

Experiments manipulate treatments, stimuli, influences or interventions (called independent variables) to observe their effects on other variables (the dependent ones) in a control situation. The experimentation, as mentioned in [27], it consists of three requirements for its realization, the first one consists of the intentional manipulation of one or more independent variables. The independent variable is the one considered as the supposed cause in a relationship between variables, it is the antecedent condition, and the effect caused by said cause is called the dependent (consequent) variable. The second requirement is to measure the effect that the independent variable has on the dependent variable or, in other words, measure the results obtained from a predefined action or factor. This is equally important and as the effect is observed in the dependent variable, the measurement must be adequate, valid and reliable. Finally, the third requirement is the control or internal validity of the experimental situation. Control refers, in this case, to know what is really happening with the relationship between independent and dependent variables, excluding other external factors.

In [27], there is also a classification of these designs in experimental and non-experimental, where in turn, a sub-classification of the experimental designs appears according to the level of control that is carried out in each one, these are pre-experimental, quasi-experimental and experimental.

Pre-experimental designs are called that because their degree of control is minimal and can be case studies of a single measurement, which are intended to administer a stimulus or treatment to a group of subjects or cases and then apply a measurement of one or more variables to see what the group level is in these.

The “pure” experimental designs are what achieve internal control and validity, through the fulfillment of two requirements: Comparison groups (manipulation of the independent variable) and equivalence of the groups. Thanks to this, these designs come to include one or more independent and one or more dependent variables.

On the other hand, quasi-experimental designs are related to the “pure” experimental ones, because they also deliberately manipulate, at least, an independent variable to observe its effect on one or more dependent variables, only that they differ from the “pure” experiments in the degree of security that can be had on the initial equivalence of the groups.

Due the realization of this project is performed on a laboratory scale; the classification considered was quasi-experimental. The determination of some factors does it is difficult to intervene, such as the topography of the city; but in others, it is possible, such as communications parameters or the number of devices (which would be located in each of the vehicles) with which tests will be carried out.

2.4 ITS architecture

An ITS is based on an architecture that defines the services offered to users, the entities responsible for their provision and the information and data flows between them [28]. This is a conceptual framework to guide the deployment of intelligent transport systems. It is a formal specification of requirements that defines in detail the functions that will be performed through the deployment of ITS, the necessary physical components, interfaces and communications necessary to allow the exchange of data and roles, as well as the responsibilities of the parties involved [29].

There are three pioneering world reference ITS architectures, ARC-IT (Architecture Reference for Cooperative and Intelligent Transportation) [30], European architecture FRAME (Framework Architecture Made for Europe) [31] and ISO 14813 [32].

These architectures define groups of services that are very similar in all three cases. It is important to clarify that, in addition to the general ITS Architecture, architectures such as American architecture are defined specifically for each service, these being a subset of the general architecture that offers a greater level of detail, thus facilitating the development of such services. Chapter 4 contains more information about these architectures.

The objective of developing services based on an ITS architecture is to make this project interoperable with ITS services developed under the same general ITS architecture. In addition to facilitating the development of future services by allowing the reuse of certain components that have already been developed. The foregoing considering that the lack of interoperability of the ITS services developed is the biggest problem in cities where these types of developments take place. Services have been made that seek to improve mobility in cities, in some cases called “ITS”, but that has not been based on adequate architectures, so that their interoperability is quite limited or nil and being able to implement it has a high cost and great time consumption.

2.5 ITS services

The services of an Intelligent Transportation System (ITS), are integrated applications of ICT in transport systems that contribute to the operations of road networks and aim to prevent accidents, achieve savings in time, money and energy, and guarantee an environmentally sustainable operation, among others. As mentioned in [9], ITS are an important alternative for sustainable mobility and offer an improvement in transport efficiency, promote safety and improve mobility.

Based on this concept, the majority of ITS Architectures worldwide defines a group of services to focus on, this is checked with the three main architectures worldwide (American, ISO, and European ITS architecture) that have a group of services very similar. Specifically, the services of the American architecture are the following: commercial vehicle operations, data management, maintenance and construction, parking management, public safety, public transportation, support, sustainable travel, traffic management, traveler information, vehicle safety and weather [33].

Our project will implement an FMCS that contains ITS services defined in the “Public Transportation” group.

2.6 Fleet Management and Control System (FMCS)

Fleet Management and Control Systems or FMCS are ITS focused on the area of public transportation responsible for administration and surveillance of public transportation fleets. These systems allow the monitoring and control of vehicles, design and control of adequate routes, control fuel consumption and even treat environmental impact [10], [34]. An adequate FMCS in a Colombian (or other Latin American country) medium-size city would be very useful to control speed, stops, and travel of public vehicles called “collective”. In this way, the large number of accidents involving these types of vehicles could be reduced and the high congestion that they generate permanently.

The FMCS design that was taken as a basis in this research is the one presented in the **Figure 5**. This design was taken from an ITS architecture for an FMCS, from a previous investigation [7]. This research was based on the ITS services related to an FMCS of the “Public Transportation” service group of the American ITS architecture.

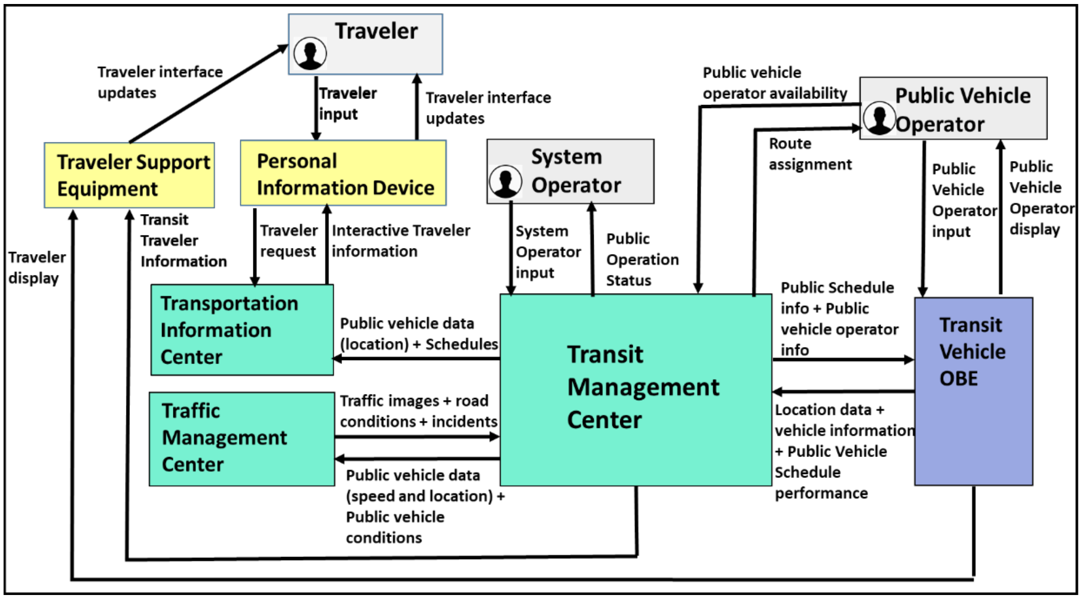


Figure 5. FMCS design that will be taken as the basis for the development. Source [7]

The **Figure 5** shows the components involved in the provided services by the FMCS which are: Transit Vehicle OBE (On-board Equipment), Transit Management Center, Transportation Information Center, Traffic Management Center, Traveler Support Equipment and Personal Information Device. The operators that interact with the system (Traveler, System Operator, and Public Vehicle Operator) and the messages that are exchanged between the components also can be seen.

In this work is planned to use the FMCS service model based on the ITS architecture proposed here, but taking the implementation to the real field, to evaluate the true benefits of the proposal.

2.7 LoRa and LoRaWAN

LoRa (Long Range) is a wireless communication technology that enables point-to-point sending and receiving of information, characterized by their great coverage it allows (up to 20 km with favorable conditions) and by the few resources it needs to do so. To achieve this, it uses the spread spectrum technique, where the signal to be sent uses more bandwidth than is theoretically necessary but allows the reception of multiple signals at different speeds. Its objective is to be usable in devices with a long battery life, where the consumption of energy is very important [35].

LoRa can commonly refer to two different layers:

- A physical layer: This uses the Chirp Spread Spectrum (CSS) radio modulation technique [36]. This enables long-range, low power and low-performance communications. It operates in the 433, 868, or 915 MHz ISM bands. The transmission payload can vary from 2 to 255 bytes, its data rate can reach up to 50 kbps and its sensitivity is in the order of 130 dBm.

  Thanks to its spread spectrum modulation that uses frequency chirps with a linear variation in time, it is possible to encode the information. Furthermore, due to the linearity of the chirp pulses, the frequency shifts between the receiver and the transmitter are equivalent to the timing shifts, which are easily eliminated in the decoder, this also makes the modulation immune to the Doppler Effect. This frequency offset between the transmitter and the receiver can reach 20% of the bandwidth without affecting the decoding performance [37].

  There are several parameters available for the customization of LoRa modulation, such as bandwidth (BW), spreading factor (SF), and code rate (CR). An increase in bandwidth decreases the sensitivity of the receiver, while an increase in the spreading factor increases the sensitivity of the receiver.

  The structure of a LoRa frame (**Figure 6**) is divided into 4 headers. It begins with a preamble, where their last two chirps encode the sync word, this is used to differentiate LoRa networks that use the same frequency bands so that a device configured with one-word sync stop listening to broadcast if the decoded sync word doesn't match to their settings.

  After the preamble, there is an optional heading. This indicates the size of the payload (in bytes), the code rate used for the end of transmission, and whether or not there is a 16-bit CRC for the payload at the end of the frame. Finally, there is the payload, this is limited to 255 bytes and a CRC to allow the receiver to drop packets with invalid headers.

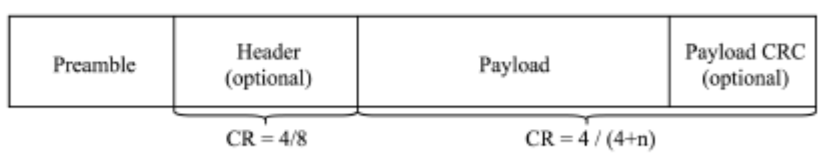


Figure 6. Structure of a LoRa Frame. Source [37]

- A MAC network layer protocol (LoRaWAN): For its part, LoRaWAN is a specification of LPWAN networks (mentioned above) that defines the communication protocol and system architecture for the network [38], which is responsible for joining and forming networks with various independent LoRa devices, managing their channels and connection parameters: channel, bandwidth, data encryption, etc. It is primarily designed for sensor networks, where the sensors exchange packets with the server with a low data rate and relatively long-time intervals. This protocol has a star network topology in which Gateways receive packets in uplink mode and nodes in downlink.

There are two ways z way to connect to a LoRaWAN server. Devices perform a network join procedure, during which a dynamic device address (DevAddr) is assigned and security keys are negotiated with the device. In ABP, end-devices are not provisioned with the root keys. Instead, they are provisioned with a set of session keys for a pre-selected network. The session keys remain the same throughout the lifetime of an ABP end-device [39].

Annex H ("Data set description") contains a more complete description of each of the characteristics of this type of communication and specifies the possible values to take, with their advantages and disadvantages.

2.8 Communication technologies in ITS

2.8.1 Wireless technologies for vehicle communication

In this subsection, a short study is performed on communications technologies, some alternative communication systems for ITS have been proposed providing benefits through the use of technologies such as LoRa (Long Range), NB-IoT (Narrow Band IoT), DSRC (Dedicated Short Range Communication) and C-V2X (Cellular Vehicle to Everything), they offer multiple advantages in terms of coverage range, low latency, data rate, device availability, among others [7]. In [40], it is stated that the use of these technologies improves the operation of ITS services; however, an adequate and independent analysis is not performed for each one of them, which hinders to determine which is the most appropriate technology to implement.

The **Figure 7** shows a comparison between various communication technologies, focused mainly on cellular technologies and LPWAN (Low Power Wide Area Network) technologies, where the required bandwidth is related to the range capacity, with what is inferred the advantages offered by LPWAN technologies, in terms of coverage capacity, working with lower bandwidths than those required by the cellular network. On the other hand, another advantage attributed to LPWAN technologies is the use of frequency bands, where for some technologies they are not licensed (LoRa for example), concerning cellular technology [41], which inflicts advantages in terms of versatility for the information that is transmitted, and the various applications that someone want to implement.

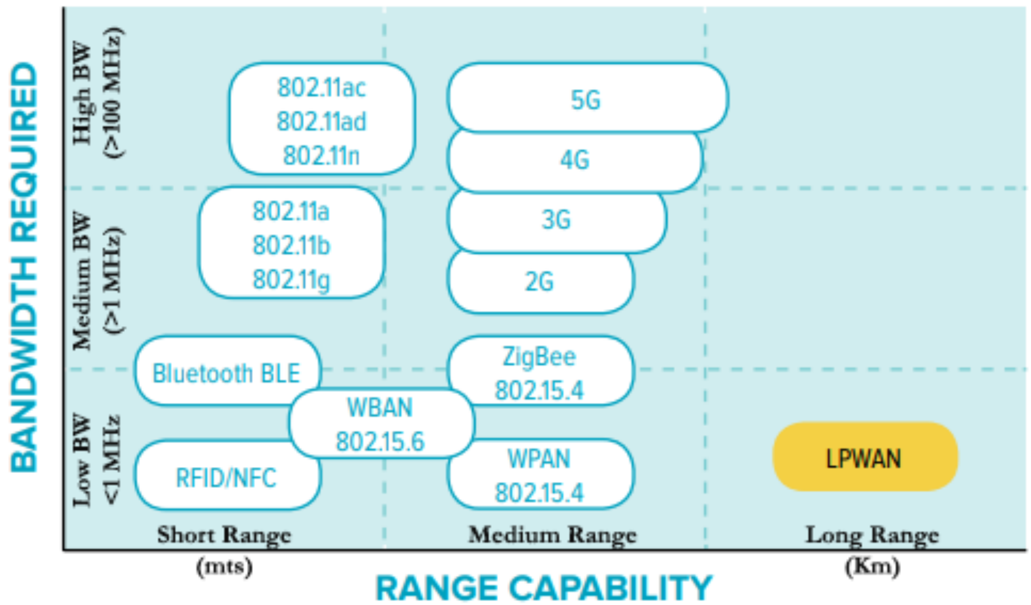


Figure 7. Required bandwidth vs. range capacity of short distance, cellular, and LPWAN. Source [42]

2.8.2 Cost Comparison

Entering the path of technologies comparison, in mobile networks, the costs imposed by mobile operators must be included, according to the data service plans that have been contracted. The following table (**Table 1**) shows what an estimate of these costs (in Colombian pesos) for 5 years of operation, for a total of approximately 443 buses operating in Popayán city [43]:

Technology	Approximate monthly plan cost	Annual plan cost per vehicle	Number of vehicles	Total for 5 years
Cellular (*)	$42.900(**)	$524.800	443	$1.140.282.000

Table 1. Total cost of data plans

On the other hand, the **Table 2** shows an approximate of the costs that would be generated for 5 years of operation with the use of LoRa technology in FMCSs, taking into account the number of vehicles again, and adding the total number of Gateways necessary to achieve coverage in the city of Popayán (512 Km^2). A theorical calculation is determined according to the approximate coverage that the Gateways provide in dense areas (28.3 Km^2 approx. for 3 Km [44]) and making an approximate coverage of 60% of the municipality (urban area), thus obtaining that approximately 10 Gateways would be needed, however in chapter 5 with a software help was concluded that 13 Gateways are necessary to give a total LoRa coverage to Popayán.

Technology	Approximate cost per OBE units	Number of vehicles	Total Gateways cost (x13)	Total (assuming device life for 5 years)
LoRa	$100.000(***)	443	$4.940.000(****)	$49.260.000

Table 2. Total cost of LoRa Technology

Summing up this information, it is necessary to mention that LoRa's operating costs are approximately 23 times less than the costs of using the cellular network.

(*) Claro prepaid plans: https://bit.ly/2ZmWiGB
(**) Price consulted on January 10, 2020
(***) LoRa Gateway: https://bit.ly/3gVV62Q
(****) OBE units: https://bit.ly/2CapRT5

3 STATE OF THE ART

This chapter presents the review studies related to fleet control and management systems. Firstly, a science mapping analysis was performed with the help of the SciMAT tool, in order to obtain the structural and dynamic aspects of the research field for the later to be included as inputs for the systematic review.

With the conclusions obtained in the science mapping analysis, a systematic review of the literature was performed in various databases. The review identified the different services and architectures of ITSs used in these control and management and fleet control systems, as well as the methods used for their development, communication technologies and the results obtained. The above suggests proposing a fleet management and control system related to current research topics in the field of study, which is based on a suitable ITS architecture, supported by efficient technology, and which allows it to be easily integrated with other mobility services for cities in the Colombian and Latin American context.

3.1 SCIENCE MAPPING ANALYSIS (USING SCIMAT)

Chapter 1 presents the objective of using the SciMAT tool. This tool was used to perform a science mapping analysis in a simpler and more standardized way; therefore, this section proceeds to explain some details of the results obtained. Annex B (“SciMAT Analysis”) contains a complete explanation of all the process and the results with their respective analysis and Annex C (“SciMAT Configuration”) has the process necessary to set up the tool used.

3.1.1 General Flow Settings

In this step, published documents from 2014 were obtained from the SCOPUS database with the following search string:

> *(Intelligent transport system **AND** (communications **OR** security))* ***OR*** *(fleet management and control system **AND** (communications **OR** security))* ***OR*** *(fleet management and control system **AND** LoRa)* ***OR*** *(intelligent transport system **AND** LoRa)*

In SciMAT tool, the knowledge base was built with a total of 1729 that were recovered. After, it was proceeded to clean this data of possible errors and duplicated information with help of the group concept of SciMAT, in special the groups of authors and words, obtaining 4765 and 1100 respectively. In the last step, the time segments were defined to allow a longitudinal analysis and discover the conceptual evolution of the field of study, three consecutive periods were considered: 2014–2015, 2016–2017, 2018–2020 with 434, 543, and 749 documents respectively.

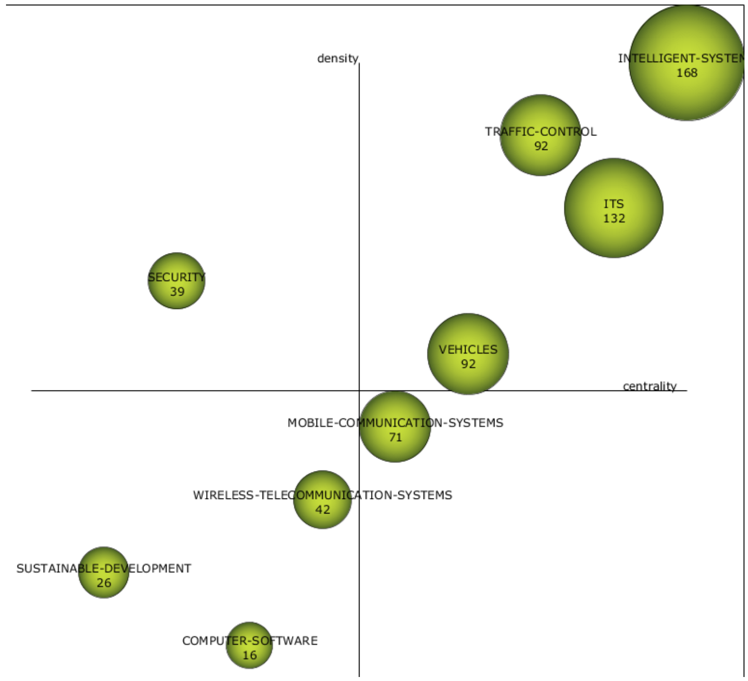
3.1.2 Analysis of results

To analyze the results obtained through SciMAT, the strategic diagrams were first considered, followed by a review of the evolution of the themes using longitudinal views of overlapping and evolution of maps.

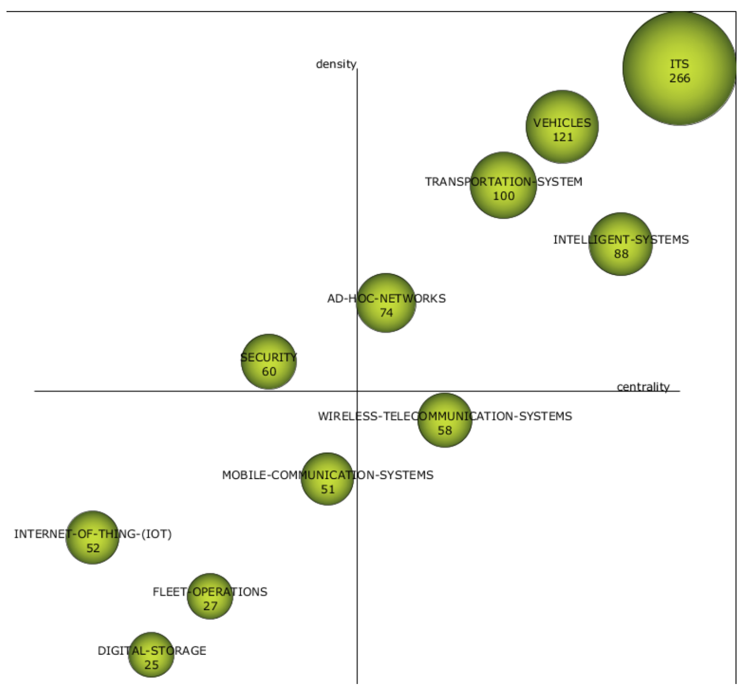
Strategic diagrams

To measure the performance, quality of the subject and subject areas detected, a quantitative and impact analysis is presented in each sub-period. To study the quantitative performance, the number of associated documents that belong to each topic and the thematic area is analyzed. To study the quality and impact, the number of citations and the h-index of each topic are used.

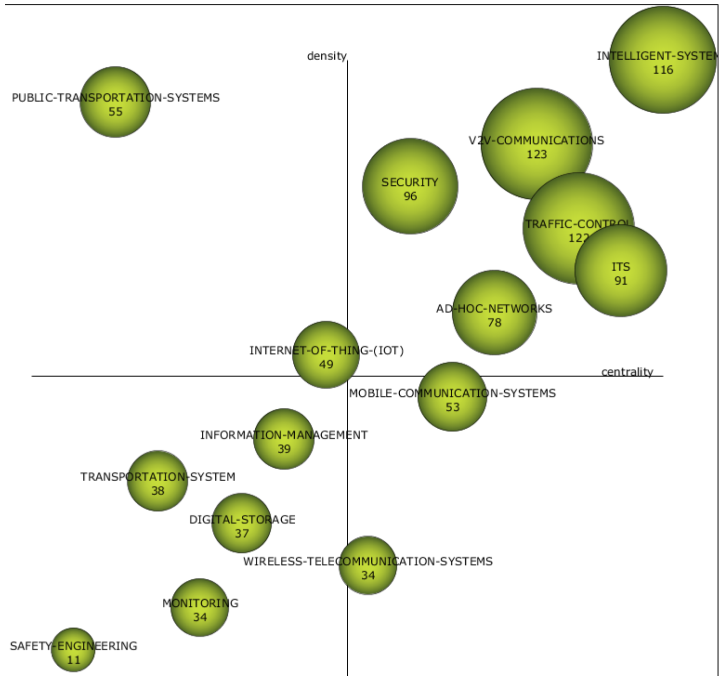
The strategic diagrams show that in all the studied sub-periods, the emerging (wireless-telecommunication-systems, sustainable-development, Internet of Things) and driving (security, intelligent systems, ITS, ad hoc networks) topics achieved the highest citations scores and impacts. It was also possible to determine a series of trends in the characteristics and technologies used for the systems under investigation, including security and Intelligent Transport Systems (ITSs). **Figure 8** presents the strategic diagrams of the three time periods considered, based on the number of published documents.


density
centrality
INTELLIGENT-SYSTEM
168
TRAFFIC-CONTROL
92
ITS
132
SECURITY
39
VEHICLES
92
MOBILE-COMMUNICATION-SYSTEMS
71
WIRELESS-TELECOMMUNICATION-SYSTEMS
42
SUSTAINABLE-DEVELOPMENT
26
COMPUTER-SOFTWARE
16

(a)


density
centrality
ITS
266
VEHICLES
121
TRANSPORTATION-SYSTEM
100
INTELLIGENT-SYSTEMS
88
AD-HOC-NETWORKS
74
SECURITY
60
WIRELESS-TELECOMMUNICATION-SYSTEMS
58
MOBILE-COMMUNICATION-SYSTEMS
51
INTERNET-OF-THING-(IOT)
52
FLEET-OPERATIONS
27
DIGITAL-STORAGE
25

(b)



(c)

Figure 8. Strategic diagrams based on the number of documents published: (a) 2014–2015 time period; (b) 2016–2017 time period; (c) 2018–2020 time period.

Evolution review

In this subsection, the evolution of the research field is studied through thematic areas. First, the evolution of the number of keywords and the number of shared keywords in the different sub-periods is analyzed. Then, the evolution of the themes is shown.

The **Figure 9** shows the evolution of the keywords. This figure presents that the community that studies this topic consolidates its terminology because the similarity index increased over time. Further, problem transversal keywords are ruled out due to their little transitory keywords.

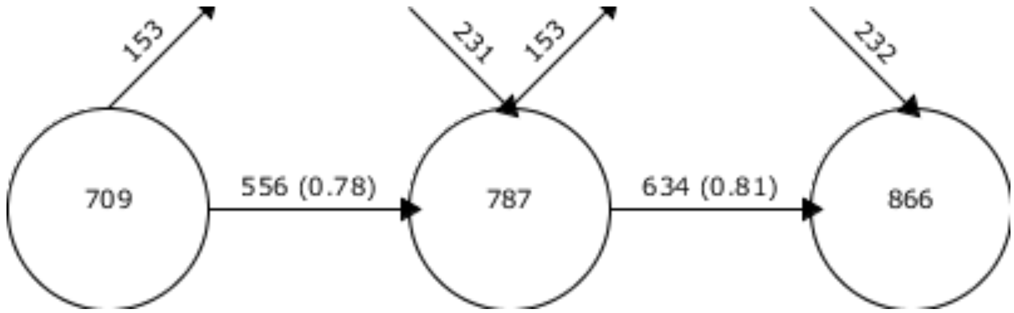
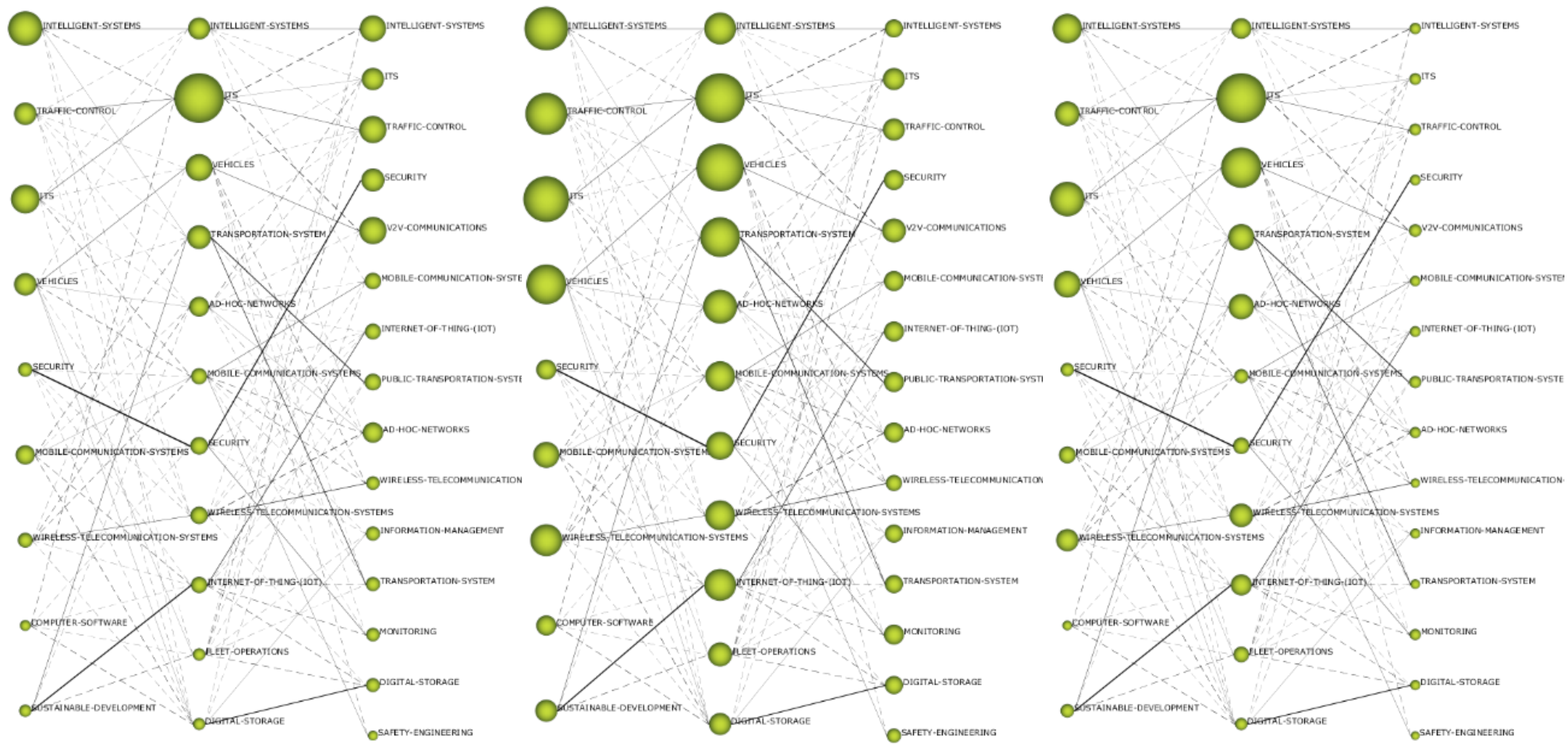


Figure 9. Overlay Map

Later, it was proceeded to study the thematic evolution of the research. The **Figure 10** shows the thematic evolution of the research field. Through the revision of this figure, it was evident that three themes (security, ITS, wireless communication systems) found in the strategic diagrams are identified as relevant, confirming their importance for the systematic review.



a. Evolution map based on the number of documents published

b. Evolution map based on the h index

c. Evolution map based on the number of citations

Figure 10. Evolution maps.

3.1.3 Conclusions

The SciMAT tool detected the evolution of the cognitive structure of a research field, allowing us to discover important knowledge related to its subjects and subject areas. It was discovered this approach by identifying the focal themes in each period because it achieves the highest dating problems and scores. Furthermore, it identified the thematic areas (see the **Figure 10**) and identified their evolutionary behavior. As example ITS has a growing trend or the MOBILE-COMMUNICATION-SYTEMS theme that has a decreasing trend.

These types of methodologies are very useful for finding relevant thematic areas. However, due to the impossibility of implementing with a considerable number of databases to obtain information and with the free access that can be obtained with these tools, it is not possible to obtain the specific documents to review, it is necessary to perform a systematic review.

Thanks to the different visualization tools, it is possible to easily detect themes and subject areas and understand their evolution, importance and possible future trends. Based on this statement, it is concluded that the topics related to security, ITS, public transport systems, wireless communication technologies, V2V communications, monitoring and IoT, should form an important part of this research topic as relevant topics in the systematic review.

SciMAT proved to be very effective, allowing information to be easily analyzed and discovered in each of the periods studied and from a global point of view.

3.2 SYSTEMATIC REVIEW (USING PRISMA)

PRISMA was the methodology used in the systematic review, which is detailed in chapter one. This was selected because of its usefulness for presenting reports of systematic reviews and meta-analyses. Furthermore, thanks to the order and standardization of the phases of this methodology, the process of research, analysis, extraction, and selection of attributes are perfectly adapted to the results obtained in the previously implemented methodology; thus enabling the purpose to be fulfilled, which was to identify the different systems developed for the control and management of public transport vehicles related to ITS architectures or services, the communication technologies used, the security of the exchange and storage of information, the monitoring of the system, the application of IoT and the context in which they are developed (developed or developing country).

Next, the results obtained in each phase of the PRISMA methodology are detailed to perform the systematic review, related to the topic of “fleet control and management systems”. This type of review uses systematic and explicit methods to identify, select and critically evaluate relevant research, it collects and analyzes data from the studies included in the review, and its main objective is to summarize the existing information about the field of work. [45], thus allowing to be at the forefront with knowledge of interest and providing necessary information for the development of a project or study. This review allowed for obtaining important information to proceed to develop the previously stated objectives.

3.2.1 PRISMA selection phases

Based on the definition of the PRISMA methodology and the aforementioned, the procedure that was performed following the 4 most relevant PRISMA phases for this analysis is described below.

Identification phase

A bibliographic search was performed on the following topics:

- Intelligent transport system
- Communications
- Security
- Fleet management and control system

The search was performed in databases other than SCOPUS (already used for scientific mapping), to obtain bases of comparison between documents published in different journals and conferences, thus achieving greater documentary richness. The three selected were: IEEE Xplore Library, eBook Academic Collection (EBSCO) and ScienceDirect, although other documents outside these databases were also taken into account, recommended by professionals in the field and a couple of degrees works developed in the University of Cauca.

The search string used was the same one used for the science mapping analysis (3.1.1). A filter was also made at the year of publication, for a maximum of 5 years old, that is, from 2014 onwards. The search was performed on December 9, 2019, for IEEE and EBSCO, and on February 5, 2020, for ScienceDirect and other databases.

In the ScienceDirect database, it was necessary to emphasize the research topics, because too many results were obtained that were not consistent with the research. For this, the following string was added in the search keywords field: "Fleet management OR LoRa OR ITS OR Communications OR Security".

In this process, the following number of results were obtained in each database, 1538 documents were obtained in the IEEE Xplore Library, in EBSCO 227, in ScienceDirect 357, 15 documents were included from other databases, and from the Unicauca repository 2 works, for a total of 2139.

After obtaining these results and considering the topics identified in the scientific mapping, it was proceeded to mainly review the title of each document. Documents related to some aspects were left out. These aspects were: impact studies on society and the environment, as well as their coupling to related systems with ITS and FMCSs services or architectures, studies or monitoring focused on drivers (for example, monitoring the face of drivers to study fatigue patterns or driving techniques), documents focused only on the definition, discussion, and comparison of related concepts with the search (ITS, FMCS, security, etc.), documents focused on ITS services of the nautical, air or rail type, documents focused solely on road infrastructure, or documents that differ completely from the case study. The research focuses on development issues that have to do with communications, security for ITS systems (architectures or services), FMCSs, monitoring, and IoT, for this reason, documents that are not related to these topics were excluded.

Thus, in this identification phase, 154 documents were obtained from the IEEE database, 96 from EBSCO, 27 from ScienceDirect, 15 from other databases, and 2 from the Unicauca repository, for a total of 294 documents.

Screening phase

As the first step in this phase, it was proceeded to join all the documents from the different sources, to subsequently review each one of them and thus eliminate duplicates. The total number of documents that were removed was 3.

The next factor for exclusion was the review of the summary of each document, those that did not show a direct relationship with the purposes of the review (mentioned above) were eliminated. At the end of this phase, a total of 104 documents were obtained, which underwent a more in-depth and detailed review within the eligibility phase. Annex D (“Systematic Review”) contains a short description of each of the 291 documents, as well as their general characteristics.

Eligibility phase

To discard documents in this phase, a review of the entire document was performed, where the following illegibility criteria were evaluated in-depth (which were constructed based on the previous phases of the systematic review and the results obtained from the scientific mapping).

- Those documents focused on improvement algorithms that are not related to communications and security of services and ITS architectures, or FMCSs were discarded.

- Documents with exclusive artificial intelligence proposals were not included because they exceeded the estimated scope.

- Documents that do not use or mention any type of communication technology were generally excluded.

- Documents proposing systems focused on minority populations (such as people with disabilities) were excluded because such systems are tailored to the characteristics of that population and are for exclusive use.

- Those documents that are not related to mobility services were discarded.

- Documents focused on traffic light control based on traffic were discarded.

- Works related to technologies that are not yet implemented on a general scale (such as 5G) were also discarded.

- Documents that address different security issues (authentication, encryption, reliability, availability, etc.) were included, but that are directly related to ITS systems, FMCS or mobility services.

- Likewise, documents were also included where monitoring techniques and methods are implemented or studied for different mobility-related systems.

- As a final criterion, the documents that provide knowledge for the grouping and interconnection of devices (feasible within the study context) through a network (IoT) were included.

Included phase

According to the results obtained in the previous phase, the results were synthesized in four different groups. Subsequently, a qualitative synthesis was performed for all groups and according to the parameters defined for each one, a quantitative synthesis for the same four groups.

The groups that were identified were the following:

- Articles related to mobility services of fleet control and management systems
- Articles that are related to mobility services other than fleet control and management
- Articles that are related to implementation algorithms and improvements
- Articles that are related to information security

The qualitative synthesis focuses on the individual characteristics of each group, which make it possible to determine in a general way the focus of the parameters evaluated, although a review is also performed on aspects in conjunction that make it possible to determine how close the documents were to this proposal.

The characteristics determined to be able to carry out a quantitative synthesis are based on the possibility of comparing the communication technologies that are used, an aspect that serves to identify which technologies are being prioritized. Similarly, it should be possible to evaluate whether the proposal is based on ITS services or architectures, which is part of the proposed proposal and which ensures interoperability with various applications focused on the mobility framework. The other three aspects that have been taken into account are the level of application of the proposal (levels of maturity of the technology), the environment or the city in which it is implemented (to compare concerning medium-size cities in the Colombian and Latin American context) and the implementation or not of any security application in the proposal.

In this way, the respective review of the selected documents was performed, obtaining a total of 56, in annex D is the distribution of the documents corresponding to this last phase and their respective description.

3.2.2 Results

The **Figure 11** summarizes the results of exclusion and inclusion obtained in each of the phases.

The review that includes all the works that resulted from this process is presented in Annex E ("Systematic Review - Synthesis - Description – Limitations – Revision tables"). The **Figure 12** shows the distribution obtained from the articles in each group.

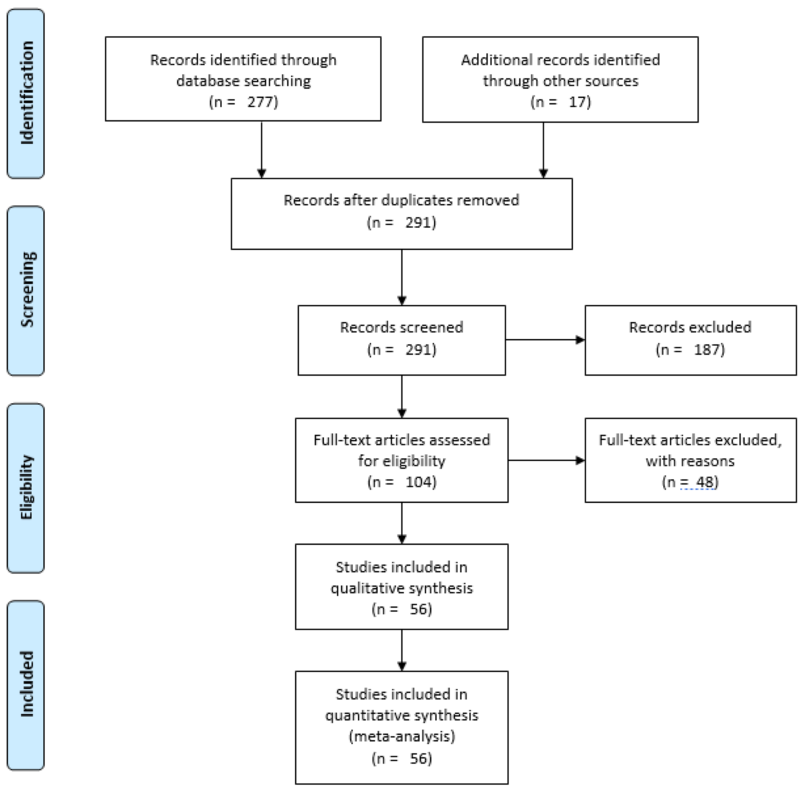


Figure 11. PRISMA Flow Diagram Results

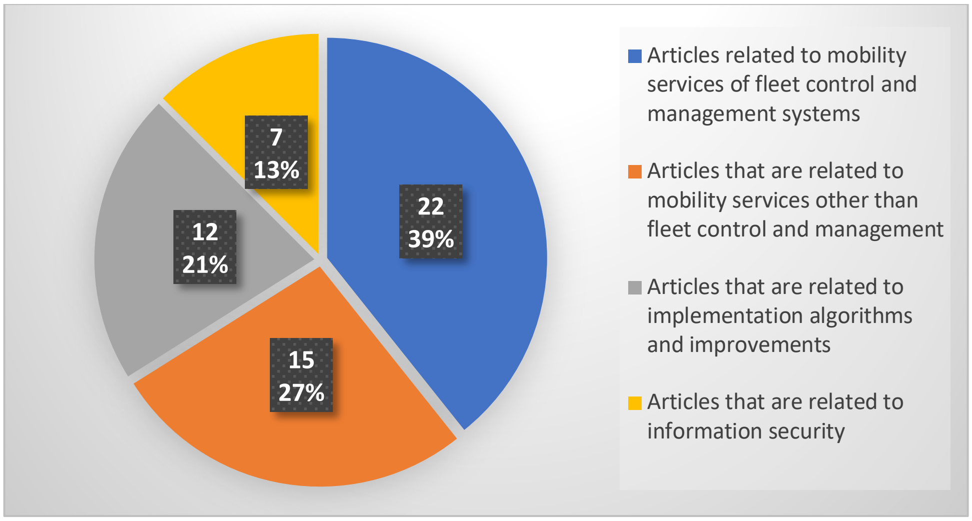


Figure 12. Classification by groups

According to these obtained results, the respective syntheses were made for each of the groups that were defined.

Documents related to Mobility Services of FMCS

According to the total of studied articles in the qualitative synthesis (56), it was determined that 39% (22) belong to articles related to FMCSs, to which some parameters were defined for study such as the type of technology used in communications, the application environment, the use of security, ITS fundamentals and type of implementation. Of the 22 documents related to FMCs, it was found that the most used communication technology is the cellular network (71%), followed by Wi-Fi (28%), ZigBee (14%), Bluetooth (9%), LoRa (9%), Ethernet (9%) and RFID (9%). (Here it should be borne in mind that, in some cases, more than one type of technology is used, so the percentages exceed 100%).

For articles that are based on ITS architectures or services, it was determined that more than half of the 22 documents related to FMCS (59%) do not make use of these. Additionally, of the mentioned 22 documents, 18 indicate where it is implemented, of which the vast majority (83%) perform the implementation in real environments; however, only 26% of the 18 documents are related to the context of Colombian or Latin American medium-size cities.

Finally, only 13% make use of some type of information-related security, these data are shown more clearly in the **Table 3**. Based on these data, it was determined that no work combined all the parameters that are planned to use in the proposal.

LoRa technology only appears in two of the 22 documents, the first ([7]), although it applies to the context of Colombian or Latin American medium-size cities and is based on an ITS architecture, it does not implement the proposal to determine its veracity and does not implement any type of security. On the other hand, in [46] the proposal is tested, however, the level at which it is developed (with a single-vehicle) is not sufficient to determine its operation on a larger scale, in addition, the proposal makes no mention of some implementation of ITS architecture or service. For these reasons, it is necessary to perform validation on this type of communication technology in order to verify its usefulness applied to the context of intelligent transport systems, thus contributing to the objective scientific field of research, especially the subject of wireless communications that, as observed in the science mapping analysis, is a motor theme that is conceptually related. It is considered that the appearance of LoRa technology in these types of systems is still low because it is an emerging technology in these types of applications. The use of technology was evidenced in the most recent articles.

Article	**Communication technology**	**Based on ITS services or architectures**	**Implementation type**	**Applied environment**	**Use of security**
Architecture based on open-source hardware and software for designing a real-time vehicle tracking device. (English) [47].	Cellular network (GSM)	No	Real	Medium size city for Latin American context	No
Performance analysis of advanced bus information system using LTE antenna [48].	Cellular network (LTE)	Yes	Not specified	Not specified	No
IoT-based predictive maintenance for fleet management [49].	Wi-Fi and cellular network	Yes	Real	Not specified	No
A Decision Support System based on smartphone probes as a tool to promote public transport [50].	Cellular network (GSM, GPRS and UMTS)	Yes	Simulation	Small town for European context	No
TransMilenio: A High Capacity - Low Cost Bus	Cellular network	No	Does not apply	Big city for Latin	No

Rapid Transit System Developed for Bogotá, Colombia [51].				American context	
Study on Real-time Bus Arrival Information System Based on Bluetooth [52].	Bluetooth and cellular network	Yes	Not specified	Not specified	No
An Internet-of-Things Enabled Connected Navigation System for Urban Bus Riders [53].	Wi-Fi and cellular network	Yes	Real	Big city for European context	No
Fleet Management and Control System from Intelligent Transportation Systems perspective [7].	LoRa	Yes	Not specified	Medium-size city for Latin American context	No
Data analysis and information security of an Internet of Things (IoT) intelligent transit system [54].	Wi-Fi	No	Real	Small town for American context	Yes
A low cost M2M architecture for intelligent public transit [55].	ZigBee and cellular network	No	Real	Not specified	No
Real time vehicle fleet management and security system [56].	Cellular network (GSM)	No	Real	Not specified	Yes
Monitoring System for Intelligent Transportation System Based in ZigBee [57].	ZigBee	No	Simulation	Medium-size city for Latin American context	No
IoT enabled intelligent bus transportation system [58].	RFID and Cellular network	No	Real (laboratory)	Not specified	No
Smart Bus Station-Passenger Information System [59].	Wi-Fi and Cellular network	No	Real	Cities in a European context	No
GPS based Public Transport Arrival Time Prediction [60].	Cellular network (GSM)	No	Real	Big city for Asian context	No
A New Framework of Intelligent Public Transportation System	ZigBee, Bluetooth and Cellular network	Yes	Real	Big city for Asian context	No

Based on the Internet of Things [61].	(GSM, GPRS and 4G)				
Public Transport Vehicle Tracking Service for Intermediate Cities of Developing Countries, based on ITS Architecture using Internet of Things (IoT) [62].	Cellular network and Wi-Fi	Si	Real	Medium-size city for Latin American context	Yes
A smart cost effective public transportation system: An ingenious location tracking of public transit vehicles [63].	RFID and Ethernet	No	Simulation	Not specified	No
Technological web platform for integrated public transport system (SITP) of the West Center Metropolitan Area in Colombia [64].	Does not apply	No	Real	Medium-size city for Latin American context	No
Integration of Smartphone and IoT for development of Smart Public Transportation System [65].	Cellular network (3G)	No	Real	Not specified	No
Systematic Development of Intelligent Systems for Public Road Transport [66].	Wi-Fi	Yes	Real	Not specified	No
Análisis De Tecnologías Radio Para La Transmisión De Información Al Usuario De Un Sistema De Control De Flota [46].	LoRa and Ethernet	No	Real	Medium-size city for Latin American context	No

Table 3. Documents of mobility services of Fleet Management and Control Systems (FMCS)

Documents related to mobility services other than FMCS

The group corresponding to articles related to mobility services other than fleet management (see the **Table 4**), contains 27% (15 documents) of the articles studied. The study parameters defined for this group are similar to the previous one, except that the mobility environment in which the service is applied is added here.

For this group, cellular technology is again the one that predominates in the use for communications, with 46% participation (7 of the 15 total documents), although greater use is made of ZigBee, Bluetooth and Wi-Fi technologies with 20% for each one. The LoRa technology is the least used, as it has only two occurrences, which correspond to 13% of cases (consider that in some cases more than one technology is used, so the percentages do not correspond to 100%). As for the mobility services in which the documents focus, the majority corresponds to traffic services in general (53% of the total), the rest corresponds to cargo truck fleets (20%), and emergency vehicles (13 %), bicycle monitoring and school transport (7% for both cases).

It is important to clarify that, in this group, a little over half of the documents make use of ITS services or architectures (53%), surpassing fleet management systems by 18%. With this information, it is deduced that there is a gap regarding the use of ITS architectures specifically for services or fleet management systems.

Of the 11 documents that present some type of implementation, 63% do so in real settings, but only 18% (of the 11 documents) apply it to medium-size cities in the Colombian or Latin American context. Regarding security-related issues, 33% (the total number of documents in this group (15)) implement this topic in their systems.

The use of alternative technologies to the cellular network is greater in the case of mobility services that do not correspond to fleet management, in addition, greater use is made of ITS services or architectures. The increase in the use of security for these types of services is also evident, although its application in real environments is reduced.

As with the previous group, LoRa communication technology has low participation (as mentioned above, it is an emerging technology in these types of systems), thus confirming the need to validate this type of technology. Additionally, it was evidenced that the proposed systems do not comply with the complete specifications defined above (ITS architectures and services, security, city context and level of implementation).

Article	**Communication technology**	**Service**	**Based on ITS services or architectures**	**Implementation type**	**Applied environment**	**Use of security**

Internet of Bikes: A DTN Protocol with Data Aggregation for Urban Data Collection [67].	Wi-Fi	Bicycle tracking	Yes	Simulation	Medium-size city for European context	No
Sistema de Transporte Inteligente Heterogéneo en la ciudad de Quito bajo el paradigma del estándar SWE-SOS y notificaciones IoT. (Spanish) [68].	Cellular network (GSM)	General traffic	Yes	Real	Medium-size city for Latin American context	No
A vehicular network–based intelligent transport system for smart cities [69].	Wi-Fi	General traffic	Yes	Simulation	Cities for Asian context	Yes
Cloudthink: a scalable secure platform for mirroring transportation systems in the cloud [70].	Cellular network (GPRS)	General traffic	Yes	Real	Not specified	Yes
A mobile platform system to driving assistance [71].	Cellular network, Bluetooth and Wi-Fi	General traffic	Yes	Not specified	Not specified	Yes
Fleet Management System for Truck Platoons - Generating an Optimum Route in Terms of Fuel Consumption [72].	Cellular network	Cargo truck fleets	Yes	Not specified	Not specified	No

Fleet Management Cooperative Systems for Commercial Vehicles [73].	Cellular network	Cargo truck fleets	Yes	Not specified	Not specified	No
Smart fleet monitoring system using Internet of Things (IoT) [74].	Cellular network (GSM)	Truck fleets	No	Real	Not specified	No
Intelligent transportation system based on the principles of service-oriented architecture [75].	Cellular network (3G y 4G)	Emergency vehicles	No	Real	Big city in the Asian context	Yes
Analysis of handshake time for Bluetooth communications to be implemented in vehicular environments [76].	Bluetooth	General traffic	No	Real	Not specified	No
Field testing of Bluetooth and ZigBee technologies for vehicle-to-infrastructure applications [77].	Bluetooth and ZigBee	General traffic	No	Not specified	Not specified	No
The Application of ZigBee Technology to the Intelligent Bus Query System [78].	ZigBee	School transportation	No	Real	Not specified	No
A novel approach of using security enabled Zigbee in vehicular	ZigBee Area Network	General traffic	Yes	Simulation	Not specified	Yes

communication [79].						
i-Car System: A LoRa-based Low Power Wide Area Networks Vehicle Diagnostic System for Driving Safety [80].	LoRa	General traffic	No	Simulation	Not specified	No
Prototipo de Gestión de Movilidad Semafórica para Ambulancias, Bajo el Concepto de Ciudad Inteligente [81].	LoRa	Ambulance system	No	Real	Medium-size city for Latin American context	No

Table 4. Documents of mobility services other than FMCS

Documents related to implementation algorithms and improvements

Following an order of percentages, the category of documents related to implementation algorithms and improvements is now studied, which accounts for 21% (12) of the documents studied. In this case, aspects such as communication technology are also evaluated (in case it is used), the use of ITS aspects, its implementation, security and the study of the application of the proposed algorithm is added (see table 4 in annex E).

In this group, the use of cellular technology is greatly reduced, because of 8 documents that make use of some technology, only 25% make use of the cellular network, the technology that stands out is Wi-Fi, with 50% participation. Other fewer intervention technologies also appear, such as LoRa, ZigBee, TETRA, and Ultra-Wideband, corresponding to 12% use for each one.

The types of implementation for which the algorithms are designed do not differ much in their intervention, because of 12 documents found in this group, those that focus on issues of communications, ITS architectures, transmission capacity and generation of alerts have the same number of occurrences corresponding to 17%, while those related to routing and data management account for 8% of the total, and the one with the most participation is “data collection”, which has 25%. The use of ITS services or architectures, shows an increase with respect to the other groups, in this case, the documents that are based on these concepts correspond to 75%. In the implementation that is performed, the majority of the works are carried out in simulations (63% of the total), while the use of some type of security scheme occurs only in 33% of the works.

Here the Wi-Fi technology stands out because, as they are algorithms, in general simulations are performed for their implementation, which proposes technologies that are standardized and that have their parameters defined, in this case, the use of WAVE (wireless access in vehicular environments). Again, the pattern of use of LoRa technology is repeated, because it is only used once, a fact that confirms that the use of this technology in communications for vehicular environments is still emerging.

Analyzing the high percentage of documents related to “data collection” and the science mapping analysis (specifically the strategic diagrams for the period 2018-2020, **Figure 8**), it is realized that these are highly related to digital storage (“DIGITAL-STORAGE”) And monitoring (MONITORING), two emerging issues within the field of research. Therefore, it is concluded that these issues are taking on great importance within the fleet control and management systems, so it is important to consider them in the proposed system.

Documents related to security applications

This last group is the one with the lowest number of documents because its percentage corresponds to 13%, 7 documents out of the 56 analyzed. The parameters studied for this grouping focus on the security issue that is implemented for some ITS system or an FMCS, so the context to which the security is applied and the proposed method are taken into account. In most cases, security is applied to the field of communications and authentication, which correspond to 43% of cases, the rest of the participation is attributed to information security, data management and security in ITSs, all with 14% occurrences. This group has the second-best percentage in terms of the use of ITS services or architectures, corresponding to 71%, while simulations prevail in the type of implementation, with 80% of cases. See the table 5 in annex E for details of this group.

Based on these data and those of previous groups, there is a significant increase in the use of security for their systems, so it follows that it is an issue that is taking on importance within the context of the study, a conclusion that ratifies the results of the science mapping analysis and verifies the need to implement this theme for the development of the proposed system. Similarly, the relationship between ITS architectures and security is observed, which implies the importance of this topic in systems correctly defined that achieve interoperability and scalability.

3.3 RELEVANT CHARACTERISTICS IDENTIFIED FOR A DEVELOPMENT VALIDATION OF AN FMCS, BASED ON ITS SERVICES AND LORA TECHNOLOGY

According to the science mapping analysis performed with SciMAT and the articles reviewed in the systematic review, the following aspects related to the necessary characteristics were identified in a development validation of an FMCS (based on ITS services and LoRa technology in the context of a medium-size city in Colombia or Latin America and taking into account information security characteristics):

- The characteristics of communication technologies for mobility services such as fleet management, applied in the context of medium-sized cities in the case of Latin America, specifically in Colombia, must also involve low costs (due to budget conditions) that these types of cities have). In most of the proposals studied, the cellular network is used, which, as already mentioned in the previous chapter, involves high costs mainly in terms of operation, and it is also important to highlight that this type of communication is decreasing for the implementation of this type of systems, as observed in the different diagrams obtained with SciMAT.
- Various technologies such as Wi-Fi, ZigBee, and Bluetooth, can be alternatives to minimize communication costs, however, they also offer some disadvantages associated with the range of operability, continuity of monitoring and work, and the consumption of resources such as the battery.
- In some cases (the most recent mainly, as it is an emerging technology in this type of applications), the LPWAN LoRa technology is mentioned, as a means for communications between vehicles and control stations, this technology could offer advantages over the others, mainly related to its low acquisition cost, the low consumption of resources it uses, the wide range of operation, which is suitable for the context of the cities in the case study.
- Regarding the use of information security, there are few cases in which it was performed. However, it is considered that it must be taken into

account in the implementation of these systems because it is essential to guarantee trust and integrity.

- Most of the security schemes implemented are related to vehicle communications and authentication. In the first, some proposals are presented to improve aspects such as reliability, range of operation, transmission rates or attack prevention; while in authentication, the focus is towards the identification and access of system users, which in turn enable validity in the information they transmit and receive.
- The level of development of the proposal must be brought to a point where it is close to commercial technological development because it is necessary that the proposal be truthful in its adequate and expected operation (an aspect that in many of the proposals does not occur), this implies that the proposed system must be validated within a laboratory, with which an appropriate level of technological maturity will be obtained and could be valued within the relevant environment.
- The data census must correspond to the context of fleet management and control systems. The main aspect that is generally measured is the positioning in which GPS technology is mainly used.
- The use of suitable ITS architectures, and the ITS services they propose, facilitate scalability and interoperability with other services. In most of the cases studied, these principles are taken into account, however, a large percentage of these do not correspond to architectures or services that are appropriate to the context of cities with particular characteristics with Popayán.

In this way, it is considered that the development validation of an FMCS should comply with the following characteristics (presented in the **Table 5**).

Characteristic	**Related to**	**Proposal**	**Observation**
Implementation of the proposal at a level close to a prototype	Level of development	Technology readiness level 4 (development validation)	To determine the veracity of the proposal it is necessary to perform an adequate implementation. In the review carried out, there is greater confidence in those proposals taken to the real field and that validate their operability

Use of a service that allows interoperability in the context where it is implemented	ITS framework	Use of appropriate ITS architecture for service and context.	From the studies reviewed, it was defined that the architecture proposed in [7] is appropriate for the context because it is specifically designed for medium-size cities such as Popayán
Use of low-cost communication technology and performance suitable for the application context	Communications	Use of LoRa technology	According to the study of all technologies, it was determined that LoRa is the one that offers some notable advantages over other technologies in the context of the city in which it wants to be implemented because its cost-benefit ratio allows it to be properly implemented for conditions imposed by the city
Implementation of algorithms that guarantee confidence in the information that is handled	Security of the information	Implementation of digital signatures	The issue of security is dealt with in a few documents of those studied, however, it is considered convenient to implement for the proposal, a digital signature mechanism for each message sent between the different devices
Measurement of parameters according to the fleet management system	Data census	Use of GPS, additional software and a system for counting passengers	In most cases, GPS technology is used, because it is the most convenient for positioning work. Also, depending on the proposed system, factor monitoring should be performed to allow various useful applications in the future

Table 5. *Characteristics determined for the development validation of an FMCS*

The proposal should be based on the use of an appropriate ITS architecture in the context of medium-size cities, the implementation of information security and a communication system through LoRa in the main critical components.

Taking into account the previous information, in the next chapter the different ITS architectures developed for FMCS services are studied, in the same way, the ideal architecture for intermediate cities in the Colombian context is proposed and designed.

3.4 CONCLUSIONS

At a general level and based on the comparison tables presented, it is observed that no document of those studied meets the complete specifications that were previously raised. In none of them is it possible to propose and develop a fleet control and management system, based on ITS services and that makes use of LoRa technology for communications. Validation through the respective implementations to corroborate the operation of the proposal is another relevant aspect that is not found in most proposals. It is also worth noting that in most cases, cellular technology is used, for which the consequent problems involved are already mentioned. In the vast majority of cases in which technologies such as LoRa are used, the developed systems are not based either on an architecture that is adapted to the context of medium-size cities or on an ITS service.

Finally, it was found that the scalability in the tests or validations carried out on the systems is an aspect to improve. The tests in most cases are simulated and in others, they are not done with enough vehicles, so the implementation of tests on a larger scale is necessary for a correct analysis of the proposed systems.

Based on this review, it can be concluded that despite the fact that the concept of ITS is mentioned in many works, in most of them an architecture that allows scaling the system is not implemented, this can be seen more clearly through scientific maps, where there is great importance in issues related to ITS, but a topic that is related to some type of architecture is never observed.

4 ITS ARCHITECTURE FOCUSED ON FMCS FOR INTERMEDIATE CITIES IN THE COLOMBIAN CONTEXT

In general terms, ITS architecture offers a vision of what an Intelligent Transportation System will be like from a system design perspective, its main focus is on the exchange of data and control instructions that pass between the different components of the ITS and the external interfaces (operators, Stakeholders and other systems) [82]. As already mentioned, there are three pioneering architectures of worldwide reference (ISO 14813, ARC-IT and FRAME), which establish certain groups of transport services and as such, their interoperability. An ITS architecture can be presented at various levels of detail, depending on the scope of the system you have. If it is ITS at a national level, the architecture presented will not reach a high level of detail (general modules and the main data exchange will be presented commonly). If it is an ITS at the local level (city, for example) and focuses on a particular service (an FMCS, for example) the level of detail will be much higher (presented: modules, sub-modules, detailed data exchange and some other aspects). The objective of this chapter is the definition of an ITS architecture for the service of interest in this document (FMCS) for a Colombian intermediate city (such as Popayán), considering the international reference architectures mentioned and some other initiatives; and that it also considers the needs established in the previous point by the PRISMA methodology.

For the architecture design, it was chosen a base (or reference), which was later adapted to some of the needs established in **Table 5** (which summarizes the results obtained with the systematic review). In order to select an adequate reference, it was necessary to review in the first instance the reference architectures mentioned, their operation and service areas (which in all three cases turn out to be similar); mainly what these architectures propose for the particular study service, a FMCS.

4.1 Review of reference ITS architectures

4.1.1 ARC-IT (Architecture Reference for Cooperative and Intelligent Transportation)

The American architecture is a reference architecture that provides a common framework for conceiving, designing, and implementing systems using the same language as the basis for delivering ITS, but does not require any particular implementation. ARC-IT includes a set of components organized into a set of four views that focus on four different architectural perspectives [30], [83]. The design of this architecture allows starting working with any of the components, although it is more common to start from the services of interest.

The views are shown in Figure 13 and are organized as follows:

- **Enterprise View**: Refers to the business or organizational framework of ITS, in this view stakeholder organizations or business objects are identified.
- **Functional View:** It is a view related to the functional perspective of ITS, here the functional requirements that support the needs of ITS users are defined.
- **Physical View:** It is related to the systems and devices that provide the ITS functionality.
- **Communications View:** It is where communication standards and profiles are defined that specify how information can be shared reliably and securely between physical objects.

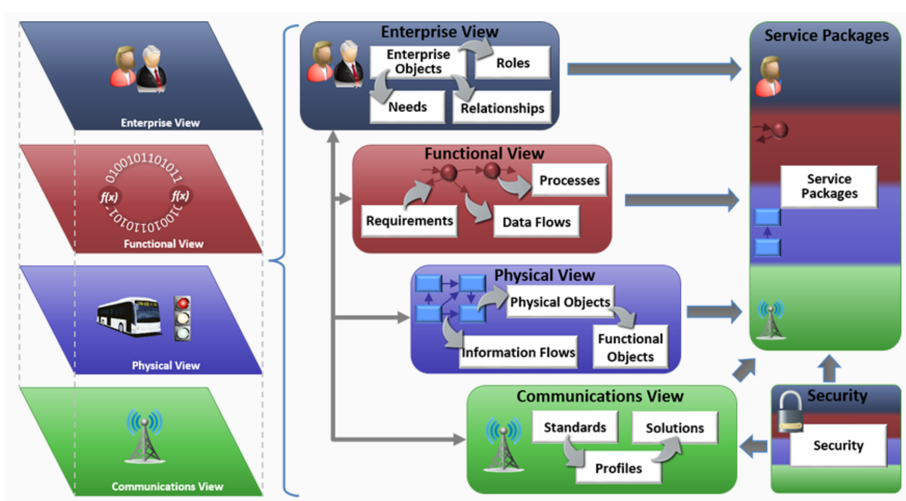


Figure 13. Architecture Overview ARC-IT [83]

ARC-IT establishes 12 service areas [84]. These areas are:

- Commercial Vehicle Operations
- Data Management
- Maintenance and Construction
- Parking Management
- Public Safety
- Public Transportation
- Support
- Sustainable Travel
- Traffic Management
- Traveler Information
- Vehicle Safety
- Weather

The services of interest for this work are within the area of Public Transportation and are called Transit Vehicle Tracking and Transit Fleet Management (PT01 and PT06, in their short names respectively). The physical diagram of these services is shown in **Figure 14** and **Figure 15**.

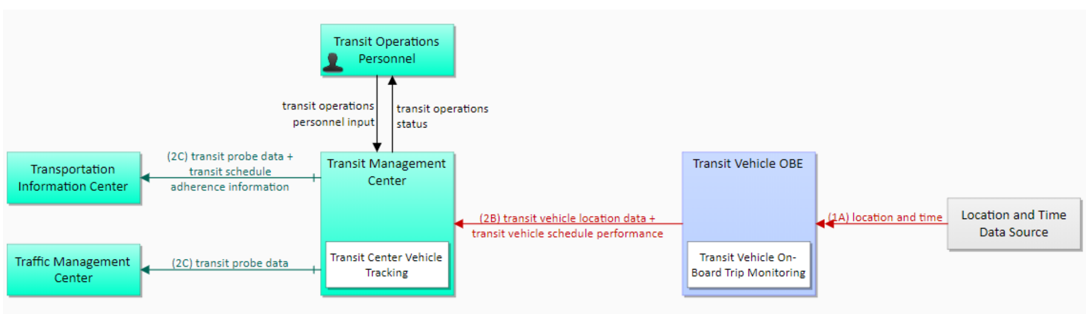


Figure 14. ARC-IT Architecture - Transit Vehicle Tracking (PT01) [85]

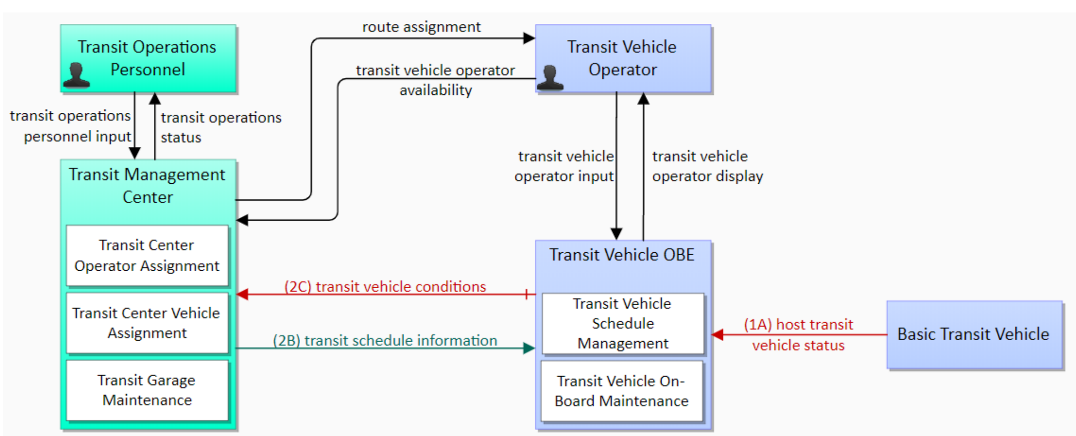


Figure 15. ARC-IT Architecture - Transit Fleet Management (PT06) [86]

Both architectures (PT01 and PT06) have certain similarities in their structure. For PT01, the **Transportation Information Center** object is in charge of collecting, processing, transmitting, and disseminating transportation information for both the system operators and the travelers who make use of it. **Traffic Management Center** represents the centers that manage a wide range of transportation facilities, including highway systems, rural/suburban highway systems, and urban and suburban traffic control systems, it is in charge of monitoring and controlling traffic on the highways. The **Transit Management Center** manages the fleets of transit vehicles and coordinates with other modes and transportation services, it is the one that provides operations, maintenance, customer information, planning and management functions for the transit property, it is the module that allows interoperability with other services such as emergency response and traffic management systems. The **Transit Vehicle OBE** is the one that provides the sensory functions of processing, storage, and communications necessary to support the safe and efficient movement of passengers provides information to the traffic management center on the conditions of the vehicle and passengers information in real-time about routes, schedules, rates, and transfer options. For its part, the location and time data source represent any technology that provides a fixed location of the vehicle and time with sufficient precision. The only stakeholder in PT01 is the **Traffic Operations Personnel**, who represent the people responsible for fleet management, maintenance operations, and traffic system programming activities, they are the ones who do the planning, development, and modification of the routes or schedules based on abnormal traffic situations, also, they can become those who assign routes to the operators of transit vehicles, verify their entrances and exits, and manage the problems of traffic stops.

The architecture shown in **Figure 15** (PT06) has two actors, the **Transit Vehicle Operator**, and the **Transit Operations Personnel**. The operator is the one who receives and provides specific information to operate the ITS functions in all types of transit vehicles, the information received is related to instructions for changes in schedules or routes and on the status of the systems onboard the vehicle, while that the operations personnel fulfill the same functions established for PT01. The physical object **Basic Transit Vehicle** represents the vehicle that houses the onboard equipment that provides its functions, then **Transit Vehicle OBE** fulfills the same functions already mentioned for PT01. The same occurs with the physical object **Transit Management Center**, which fulfills similar operations, but now it's focused on assigning routes, schedules, and reports on the vehicle operator and the transit vehicle. [85], [86].

4.1.2 FRAME (Framework Architecture Made for Europe)

It is the European ITS architecture (**Figure 16**), its objectives are similar to those of the American architecture, because it was created to provide a common approach or “language”, for use throughout the European Union. So that the implementation of integrated ITS can be planned and interoperable. Like ARC-IT, the implementation of the architecture is made from the services or applications of interest that are selected with the help of computer tools, to later be identified within the architecture and later select a subset that is customized from according to the region of implementation [31], [87].

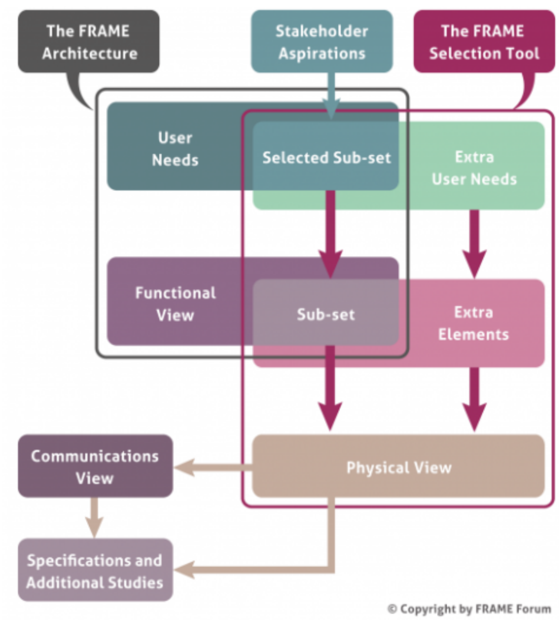


Figure 16. FRAME Architecture [87]

FRAME has 10 service areas that are presented below:

- Electronic Fee Collection
- Emergency Notification and Response – Roadside and In-Vehicle Notification
- Traffic Management – Urban, Inter-Urban, Simulation, Parking, Tunnels and Bridges, Maintenance, together with the Management of Incidents, Road Vehicle Based Pollution and the Demand for Road Use

❖ Public Transport Management – Schedules, Fares, On-Demand Services, Fleet and Driver Management
❖ In-Vehicle Systems – includes Cooperative Systems
❖ Traveler Assistance – Pre-Journey and On-Trip Planning, Travel Information
❖ Support for Law Enforcement
❖ Freight and Fleet Management
❖ Provide Support for Cooperative Systems – specific services not included elsewhere such as bus lane use, freight vehicle parking
❖ Multi-modal interfaces – links to other modes when required, e.g., travel information, multi-modal crossing management

The "Manage Public Transport Operations" service area is the one corresponding to this work and includes 7 high-level functions (see **Figure 17**). Each function covers various specific fleet management services, where the programming of services and the generation of information available to travelers, an operation based on demand executed with the help of other services such as traffic management, service change requests, and management of submitted incidents [88].

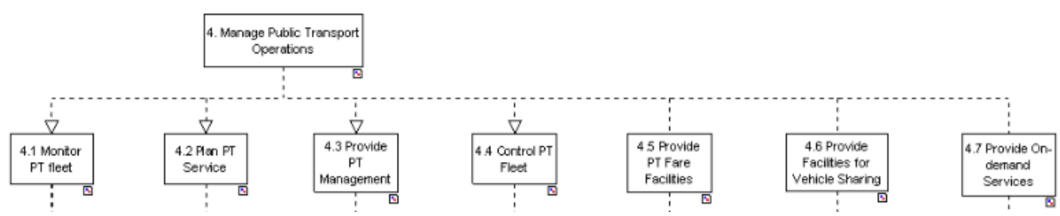


Figure 17. Functional Tree of Area 4 [88]

According to the characteristics of each function, which are adapted to the context of study in this work, where it is planned to continuously monitor the vehicles and have management and control over the routes, vehicles, and users of the system depending on the environment of work, the chosen high-level functions were 4.1 (Monitor PT Fleet), 4.2 (Plan PT Service), 4.4 (Control PT Fleet) and 4.7 (Provide On-demand Services).

Monitor PT Fleet It is designed for continuous and real-time monitoring of public transport vehicles moving along the routes.

Plan PT Service is responsible for the management and administration of both current and historical data, with which it carries out the strategic planning of all public transport services.

Control PT Fleet focuses on direct real-time control of the progress and operation of public transport vehicles, in order to guarantee service reliability and adherence to schedules.

Provide On-demand Services It refers to the provision of public transport service, depending on demand, because schedules and routes are personalized according to the passengers who require them.

4.1.3 ISO 14813

As with previous architectures, the ISO 14813 architecture is designed to aid the integration of services into a consistent reference architecture, plus interoperability and the use of common data definitions. Unlike the previous ones, ISO 14813 is not freely accessible, so it is difficult to access its architecture and specific services, however, the 13 service areas that this standard establishes can be found [89]:

- Traveler information
- Public passenger transport
- Electronic payments
- Data management
- National security
- Safety of people
- Vehicle safety
- Emergency care
- Responses to disasters
- Weather and environmental conditions
- Cargo transportation
- Traffic management and control
- Performance management of the transmission network

The user needs or user service requirements in a similar way to the previous architectures, are defined from the services contained within the groups or service areas, depending on the methodology used to develop the resulting ITS architecture functionality, together with the definition of applicable data within data dictionaries, as well as applicable communications and data exchange standards [90].

This architecture will not be taken into account for the definition of the ITS architecture of this work due to the limitations in terms of access to the information it infers, however, its importance in the field of ITS must be recognized.

4.1.4 ITS architectures at the national level

In Colombia, there is no established ITS architecture that serves as a model for the subsequent development and interoperability of ITS services. Although some ITS services have been established in the past, currently work is being done on the adoption of the services established only by the ISO 14813 standard. [91], to obtain consistency in the national ITS plan.

Similarly, in 2010, the National government developed a National ITS architecture to implement it in different cities of Colombia, this was based on the ARC-IT architecture. The objective was connecting the different actors of the system, managing to share information efficiently and safely. However, despite being a good initiative, it was a proposal that was forgotten and no update was carried out, in the same way, no implementation results could be found [92].

On the other hand, there are various Strategic Public Transport Systems (SPTS) proposed in 2008 and updated in 2015 through the “CONPES” documents, where 8 apply to the case of intermediate cities, however, none of them these systems have a properly defined ITS architecture. The 8 systems were planning for the cities of Armenia, Montería, Neiva, Santa Marta, Pasto, Popayán, Sincelejo, and Valledupar. In 7 of the 8 systems, the progress made is only focused on infrastructure and road adjustments. Pasto is the only city that has implemented technological advances in SPTS. It is evidenced in the progress of its traffic light system and the FMCS, based on GPS that is compatible with a Geographic Information System (GIS) [7].

When talking about ITS in the national context, in addition to projects or architectures already defined above, the Colombian regulations must be analyzed. Article 84 of Law 1450 of 2011 defines SITs and explains the process of implementation of this type of systems, specifying that the technical regulations, standards, and technology protocols must be adopted [93]. Decree 2060 of 2015 regulates these systems, establishing parameters to issue regulations and standards, adding that the Ministry of transport will be the only entity in charge of creating, implementing, and operating the SINITT (National Intelligent System of Infrastructure, Transit and Transportation), this to guarantee the centralization of information and therefore the interoperability of the different systems [94]. Based on this information, it is necessary to implement a collection module and a connection, visualization and control method for the Ministry of transport.

Another important national contribution is presented in [7], here a fleet management and control system is proposed for intermediate cities in the Latin American context. This is based on the American architecture and implements several of its services, unfortunately, no tests of its operation were carried out, so results cannot be concluded. **Figure 5** shows the general diagram of the FMCS service proposed by the authors. Due to its similarity to the work objective, the architecture proposed in the following point takes into account the architecture that is presented in the **Figure 5**.

4.2 Definition of the proposed architecture

Taking into account the information obtained and analyzed, it was decided to take the American architecture ARC-IT as a reference (complementing it with some FRAME functionality), due to the level of detail that it presents for each service, which facilitates their development, besides, as mentioned in [7], Comparing the service areas of the different architectures, ARC-IT is the one with the largest covered areas, which gives it a higher development factor. However, this architecture must be adjusted according to the context of intermediate-sized Colombian cities. The ITS architecture must also take into account the aspects identified in the systematic review as important characteristics in this type of system (FMCS). One of these characteristics that is very important is security in various aspects (communications, reliability, authenticity, among others). Other relevant characteristics are the measurement of suitable vehicle parameters and the choice of reliable and low-cost communication technologies.

Taking the information from the theoretical framework as a reference, the ITS architecture review presented in section **4.1**, and the characteristics of a FMCS identified in the systematic review developed, a special architecture was designed for medium-sized cities in the Colombian context, this is observed in the **Figure 18**. Here a series of submodules were defined on the physical objects proposed in [7] and on which it is planned to work in the project (Transit Management Center and Transit Vehicle OBE, already explained above), in addition, a new object was included in which functionalities for the equipment on the road can be included, the ITS Roadway Equipment, finally, two new actors (System Administrator and Enterprise Administrator) and new communication information were added. Thus, the ARC-IT base is preserved, keeping the Transit Vehicle OBE, the Transit Management Center, and the Public Vehicle Operator actor along with most of the initial functions. As mentioned, several operations of the high-level functions of Manage Public Transport Operations (FRAME) were also included, such as operational functions, continuous monitoring, continuous data collection, management of routes and schedules, provision of information for travelers, among others. In addition, the on-demand service provisioning function by Provide On-demand Services was added, included within the Traffic Management Center object.

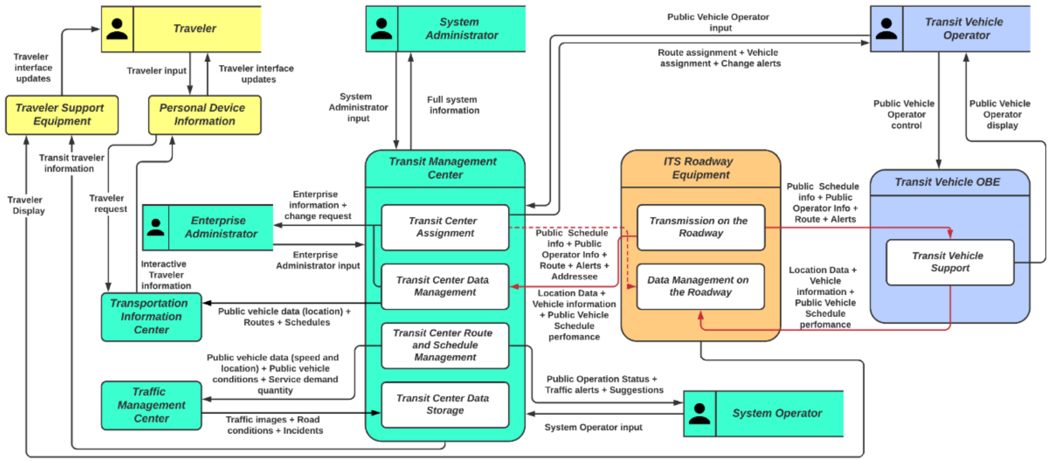


Figure 18. ITS architecture proposal in this research for FMCS

Components of the proposed architecture

The scope of the proposal (in this research) is limited to the functional controls of the FMCS and not in the information to the traveler, in this part only the components related to the Transit Management Center, the Transit Vehicle OBE and, the ITS Roadway Equipment are explained, the rest of architecture is left raised.

- **Actors**
  - *Transit Vehicle Operator:* It is in charge of the operational functions of the vehicle. This operator receives the relevant information from the system (schedules, route), through a display located on the OBE device.
  - *System Operator:* It is in charge of the general administration of the system, that is, it is in charge of the administration of all the companies' user of the system, as well as the management of its status.
  - *Enterprise Administrator:* It is the actor in charge of business-type functions, because in the proposed architecture it was considered there are several public transport companies, each one controlling their working conditions. Although all companies must comply with the general rules of service.
  - *System Administrator:* It is the "master actor", this actor has control over all the operations or functions of the system, as well as the other actors.

- **Physical Objects**
    - *ITS Roadway Equipment:* It is the ITS equipment distributed throughout the city roads, which is strategically distributed according to the geographical characteristics. Its functionalities are mainly focused on partial analysis and bidirectional retransmission of collected data and notification type data.
    - *Transit vehicle OBE:* Set of devices that make up a monitoring, control and information system for each vehicle.
    - *Transit management center:* It is the main object of the architecture; it will be distributed in the cloud and its main functionalities are the exchange of information between the different components and the administration of the system.

- **Functional objects**

    TMC functional objects

    - *Transit Center Assignment:* Its functionality allows vehicle and time assignments to the Transit Vehicle OBE (first passing through the ITS Roadway Equipment), and to the Transit Vehicle Operator. Besides, it generates alarms or notifications for them, when the change of these work parameters is approved by the enterprise administrator, as well, it is the one that informs the enterprise administrator about the suggestion by the operator for the change of routes or schedules.
    - *Transit Center Data Management:* It is mainly responsible for the processing of information supplied by the Transit Vehicle OBE, on the parameters collected from the vehicles. In the same way, it is in charge of supplying the information required by the actors, related to statistics and other data of the system, also, it controls the access of the actors to the system. It also provides specific information about vehicles for travelers.
    - *Transit Center Route and Schedule Management:* This functional object allows the managing of routes and traffic schedules based on traffic conditions, accidents, or demand in general, according to the information provided by the Traffic Management Center. It is also in charge of sending information collected and processed from vehicles to the Traffic Management Center, which could be viewed as a feedback loop.
    - *Transit Center Data Storage:* All the system information is stored in this object; it corresponds to a series of databases that receives and supplies data to the Transit Center Data Management.

    ITS Roadway Equipment functional objects

- *Transmission on the Roadway:* It is the module in charge of the two-way data retransmission, it communicates the Transit Vehicle OBE with the Transit Management Center (TMC).
- *Data Management on the Roadway:* This object is responsible for the analysis of part of the information that reaches the Transmission on the Roadway, with this it determines the routing that the information must follow and the possibility of sending it to the respective receiver based on its availability.

Transit vehicle OBE functional objects

- *Transit Vehicle Support:* This module receives and presents to the vehicle operator the working parameters that it has (route and schedules). It is also in charge of measuring vehicle parameters such as its location so that it is subsequently transmitted to the Transit Center Data Management.

- **Information flow**

Transit Vehicle Operator – Transit Vehicle OBE

- *Public Vehicle Operator control:* It is a manual interaction to start or end the operation with the device. It also includes a confirmation of receipt of alerts when they are generated.

Transit Vehicle Support – Transit Vehicle Operator

- *Public Vehicle Operator display:* Summary information about the vehicle operator's work parameters, such as the assigned route number, schedules for the route, and alerts generated from the Transit Management Center.

Transit Vehicle Operator – Transit Management Center

- *Public Vehicle Operator input:* Input or access data that the vehicle operator sends to the system when he wants to access the functionalities with which this account.

Transit Center Assignment – Transit Vehicle Operator

- *Route assignment + Vehicle assignment + Change alerts:* It includes detailed information on the vehicle operator's work parameters (routes, schedules, operating vehicle, current location, number of passengers, etc.), it also includes detailed alerts on changes.

Transmission on the Roadway – Transit Vehicle Support

- *Public Schedule info + Public Operator Info + Route + Alerts:* Specific information on schedules and routes assigned to the corresponding vehicle that requests it, and will be displayed on the OBE screen, this information is generated every time Transit Vehicle Support is initialized.

Transmission on the Roadway – Transit Center Data Management

- *Location Data + Vehicle information + Public Vehicle Schedule performance:* This is the same information collected by the Transit Vehicle OBE, unlike the fact that it has already been verified here and is passed on to the Transit Center Data Management for further processing.

Transmission on the Roadway – Data Management on the Roadway

- The information transmitted between these two objects is linked to addressing and information checking.

Transit Vehicle Support – Data Management on the Roadway

- *Location Data + Vehicle information + Public Vehicle Schedule performance:* Vehicle's parameters measured by Transit Vehicle Support. This information is sent very frequently (every fifteen seconds approx.), in order to monitor the vehicles in real-time.

Transit Center Assignment – Data Management on the Roadway

- *Public Schedule info + Public Operator Info + Route + Alerts + Addressee:* It is the same information supplied to Transit Vehicle Support, but it also includes a more detailed address field that will identify the recipient.

Transit Center Route and Schedule Management – System Operator

- *Public Operation Status + Traffic alerts + Suggestions:* This is general information about the system, information related to traffic alerts generated and, suggestions for changes in routes and schedules.

System Operator – Transit Management Center

- *System Operator input:* Input or access data that the system operator sends to the system when he wants to access the system functionalities.

System Administrator – Transit Management Center

- *System Administrator input:* These are the access parameters of the system administrator (similar to the other actors) and information on requests.
- *System Information:* This information includes data from other actors and the system (statistics, records, vehicle positioning, routes, real-time monitoring, etc.).

Transit Center Assignment – Transit Center Data Management – Enterprise Administrator

- *Enterprise information + change request:* When the information is generated by the Transit Center Data Management, it refers to responses to requests made by the enterprise administrator. When it is generated from the Transit Center Assignment, it is information about requests to change routes and schedules for the administrator.

Enterprise Administrator – Transit Management Center

- *Enterprise Administrator input:* These are access parameters and requests for information from the enterprise administrator, here are also responses of approval or not to requests to change the work parameters of the vehicles.

Traffic Management Center – Transit Center Data Storage

- *Traffic images* + *Road conditions* + *Incidents:* Corresponds to predefined messages sent by "Traffic management center" to detect different traffic conditions, it has the possibility of sending images, information about road conditions and / or accidents that occur.

Transit Center Data Management – Traffic Management Center

- *Public vehicle data (speed and location)* + *Public vehicle conditions* + *Service demand quantity:* This is information related to different measured and processed parameters of the vehicles (sent very frequently, almost sequentially with that supplied by the vehicles).

Transit Center Data Storage – Transit Center Data Management

- The two-way information exchange that occurs here is about requests and responses, because the management center is repeatedly receiving and analyzing information (information collected from vehicles, access parameters and requests) that later passes to the storage center.

Transit Center Route and Schedule Management – Transit Center Assignment

- The information here always occurs towards the assignment center and is about work parameters associated with the system vehicles (routes and schedules) and the routing that must be followed to reach the Transit Vehicle Support of the corresponding vehicle.

Transit Center Route and Schedule Management – Transit Center Data Storage

- The flow of information that happens here are requests for information related to the state of traffic (images, text, coordinates, etc.) that the storage center contains and with which it responds respectively.

To comply with the security characteristics that were initially established, it is established that the messages that go through the “Transit Vehicle OBE” and “TMC” modules need layers of security to guarantee the CIA (confidentiality, integrity and availability) of the information. The messages to which it has been decided to apply layers of security are indicated with red lines. In the same way, for all information communication services between actors and modules, authentication methods are applied.

The importance of this architecture lies in the distribution of obligations for different modules or entities of the system, in the same way it allows the aggregation of different processes that may be presented. Performing this type of architecture also facilitates the update of different processes or technologies (problems found in other systems).

5 COVERAGE ZONE ANALYSIS

As mentioned above, ITS architecture is built by different modules. The proposal in this paper has two very important modules (Transit Management Center and Transit vehicle OBE), which communicate with each other through a low-cost, long-range communication system. In chapters 2 and 3, it was concluded that the best technology to achieve this objective is LoRa, this due to its great advantages over other technologies (supported by sections 2.7 and 2.8).

However, due to the lack of infrastructure of this type of communication technology in the city object of the research (used for the case study), it was necessary to develop a coverage plan that allows dimensioning the complexity of the deployment necessary to cover the service demand. With this, it would be possible to correctly distribute the different Gateway devices in the context (Popayán for the tests performed) and, a correct communication is provided between the different devices with the appropriate number of resources. To carry out this process, a tool developed at the University of Cauca by engineers Edward Oswaldo Navarro Astudillo and Víctor Manuel Quintero Flórez was used [95].

This chapter explains, initially, the type of software, later the mapping and device configuration process, and finally a LoRa coverage analysis for the city of Popayán.

5.1 Review over tool for estimation radio-electrical coverage

This tool is a software prototype that allows the estimation of radioelectric coverage of Base Stations (BSs) for planning an IoT network [95]. It was decided to use this software for different factors, among them its open code, its robustness and the implementation of topographic measures for the city of Popayán.

The software was implemented in a Geographic Information System (GIS) called QGIS, to which different algorithms and complements were made (using python language), to handle geographic information of the Colombian territory, manage the BSs, and the creation of coverage maps around these elements. Here it is important to clarify, when the term BSs is mentioned, in this research context it refers to the Gateway LoRa devices (located in the “ITS Roadway equipment” module).

5.2 Setup process

5.2.1 Cartographic setup

As a previous step, QGIS software was installed, to which the add-ons were developed in [95]. Subsequently, the topographic configuration was performed for the generation of terrain profiles and the generation of coverage areas. The authors provided these data for the department of Cauca.

In this process, some layers that contribute cartographically were added. A shadow map or “Hillshade” was added as the first layer, to improve the visual quality of the cartographic file, assign values to each pixel depending on the angle of incidence of the sun. The second layer corresponds to an elevation map or "DEM", this specifies the height values above sea level, and a style was also added to improve the visualization of this layer. Next, a layer was added to represent the geographic division of the different municipalities.

Among the most important information to perform a correct analysis of urban coverage were the obstacles that may arise (mountains and/or buildings), in the “DEM” layer the height above sea level of the geographical area were added rural. However, it was also necessary to add the height of buildings to obtain a correct analysis, for this reason, a "Constructions" layer was added. The Google Maps layer was also added, to be guided by directions and obtain a map with greater characteristics.

Finally, the software was pre-configured cartographically. The resulting map is presented in **Figure 19.**

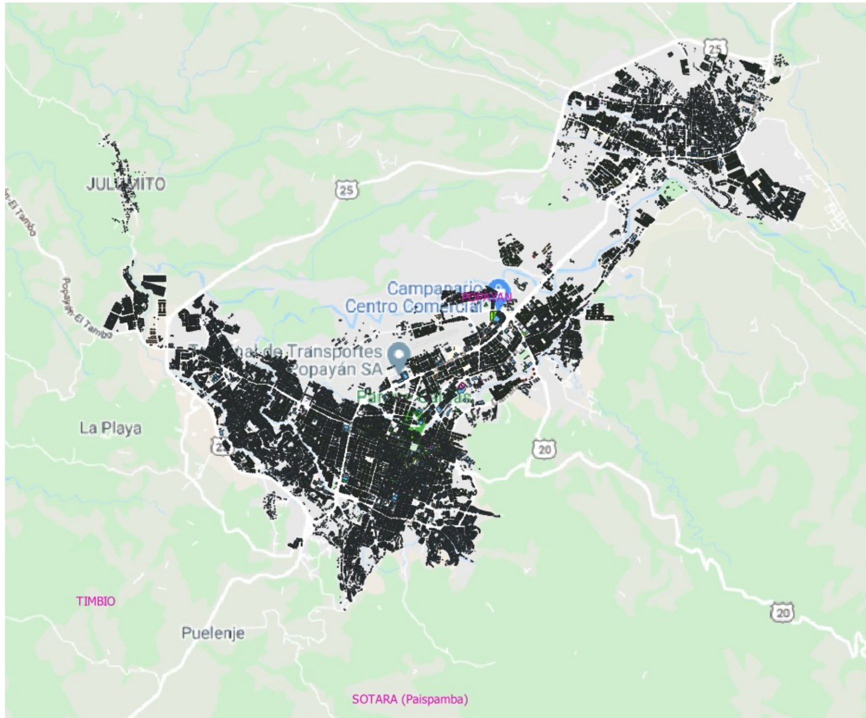


Figure 19. Popayan pre-configured map in QGIS

5.2.2 Device configuration

The creation of the BSs continued at this step. This process was one of the most important, because the devices must be located in areas that provide the greatest possible range. Taking into account characteristics such as height, access to an energy source, internet connection, security, and ease of access to support the equipment. A total of 13 BSs were located. The location parameters of each of these BSs are shown in **Table 6**. Additionally, for each Base Station and OBE were assigned the work parameters (radioelectric parameters), which depend on the type of device used. For BS (Gateway) a "Dragino LPS8 Indoor LoRaWAN Gateway" device was used, while for the OBE, a "HELTEC WiFi LoRa 32 (v2)" was used, the parameters of these are shown in **Table 7**.

Id	Location	Latitude	Longitude	East (UTMX):	Nort (UTMY):
1	Bloques de Moscopán	2,434026	-76,603815	321672,1	269140.6

2	Universidad del Cauca (Facultad de ciencias contables)	2,446947	-76,598618	322251,73	270568.81
3	Condominio Barcelona	2,441255	-76,606541	321369,8	269940.4
4	Bosques Garzas	2,457812	-76,641816	317448,8	271776
5	María occidente	2,45757	-76,632465	318488,83	271747,95
6	Iglesia pentecostés	2,446908	-76,629448	318822,9	270568,6
7	Luxor	2,44446	-76,613775	320565,7	270295,8
8	Tequendama	2,439428	-76,608358	321167,5	269738,6
9	Casa Caldas	2,443115	-76,604008	321651,8	270145,8
10	Bello horizonte	2,484251	-76,564166	326088,26	274689,08
11	Torres de milano	2,488607	-76,583911	323892,9	275173,4
12	Villa del norte	2,474195	-76,558080	326763,8	273576,3
13	Susana López	2,437214	-76,62174	319678,5	269495,6

Table 6. BSs localization parameters.

Object	Reference	$P_{tx[dBm]}$	$Gain_{dB}$	$Loss_{[dB]}$	$S_{Rx[dBm]}$
BS (Gateway)	Dragino LPS8	20	3	2	-140
OBE	Heltec LoRa 32	18	3	2	-137

Table 7. Radio parameters for BS and OBE used *[96]–[99]*

The frequency used by the OBE devices was configured to work in sub-band 2 (channels 8 to 15) which includes values between 904.1 MHz and 905.3

MHz, with a 125kHz separation between channels. This due to the compatibility between devices and the support offered in this band by the TTN platform (this is explained in detail in Chapter 6).

Additionally, “indoor” losses were added because the Gateway was located inside a building. In the same way, the height per floor of each construction was configured at 2.5 meters, and the radius to calculate the coverage of each BS at 2 km. The urban resolution (linear and radial distance between measurements) was established as the lowest possible value to increase the reliability of the results.

It should be clarified that the coverage analysis was performed for a Up Link (UL) communication, i.e., a communication directed from the OBE to the Gateways. This because the largest number of messages would be sent in the system in that direction. Also, it is the type of communication that can present the most problems.

Finally, the propagation model was chosen for the simulation. In [95] It is concluded that the Okumura-Hata model, with a scenario configuration for a medium city with a correction of 3dB, was the one with the highest degree of correlation (57%) for the city of Popayán. Also, this configuration had one of the lowest mean errors of the tests performed on the work, so it was decided to use this model for propagation calculations by adding miscellaneous losses by a factor of 3dB.

5.3 LoRa coverage analysis

In **Figure 20** the coverage area for the first BS is shown (id = 1), the buildings and the terrain affect the coverage area, limiting it to a coverage radius of no more than 1km within the city. The same area is appreciated in **Figure 21** using Google Earth on a 3D modeled map. The colored styles indicate the power level, blue is a low power level and red is the highest. These values are presented more clearly in **Table 8.**

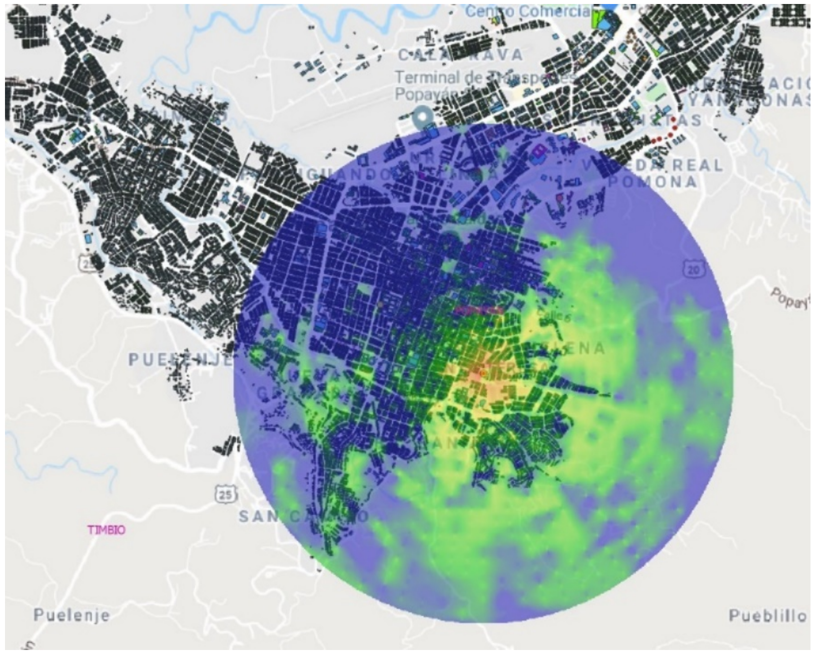


Figure 20. Coverage area for the first base station.

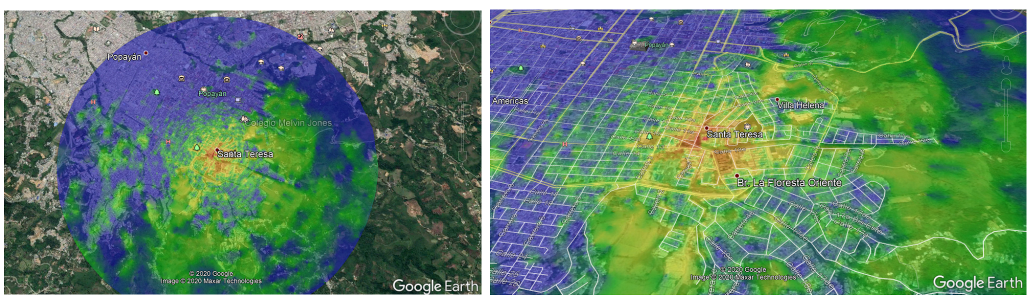


Figure 21. Coverage area for the first base station in 3D view with Google Earth.

Value [dBm]	-150	-125	-100	-75	-50
Color					

Table 8. Visual interpolation of power level

After adding and configuring each of the BSs, their coverage area was generated individually, to establish their layers with the received power values at each point. Then, the joint coverage was created using algorithms of the QGIS software for joining the raster layers ("Mosaic raster layers"), where the layer superposition method was selected by the maximum value of the received power level in such interceptions.

Figure 22 shows the map with the joint coverage area. This graph shows the geographic region where the BSs offer coverage, obtaining a total of 13 transmitters (Gateways) to cover Popayán completely. All the files generated in the development of this chapter are presented in Annex F ("Coverage zone analysis QGIS"), and **Figure 23** also shows the coverage area but in a 3D model provided by Google Earth.

Finally, it is important to clarify that the software is designed to be used in any type of IoT network. Therefore, it only gives a limited approximation to how the coverage area would be, because it does not take into account factors, such as widening, frequency jumps between the different channels (used in LoRaWAN) and different factors. Which is why in Chapter 6 the experimental results are studied and compared with those obtained here.

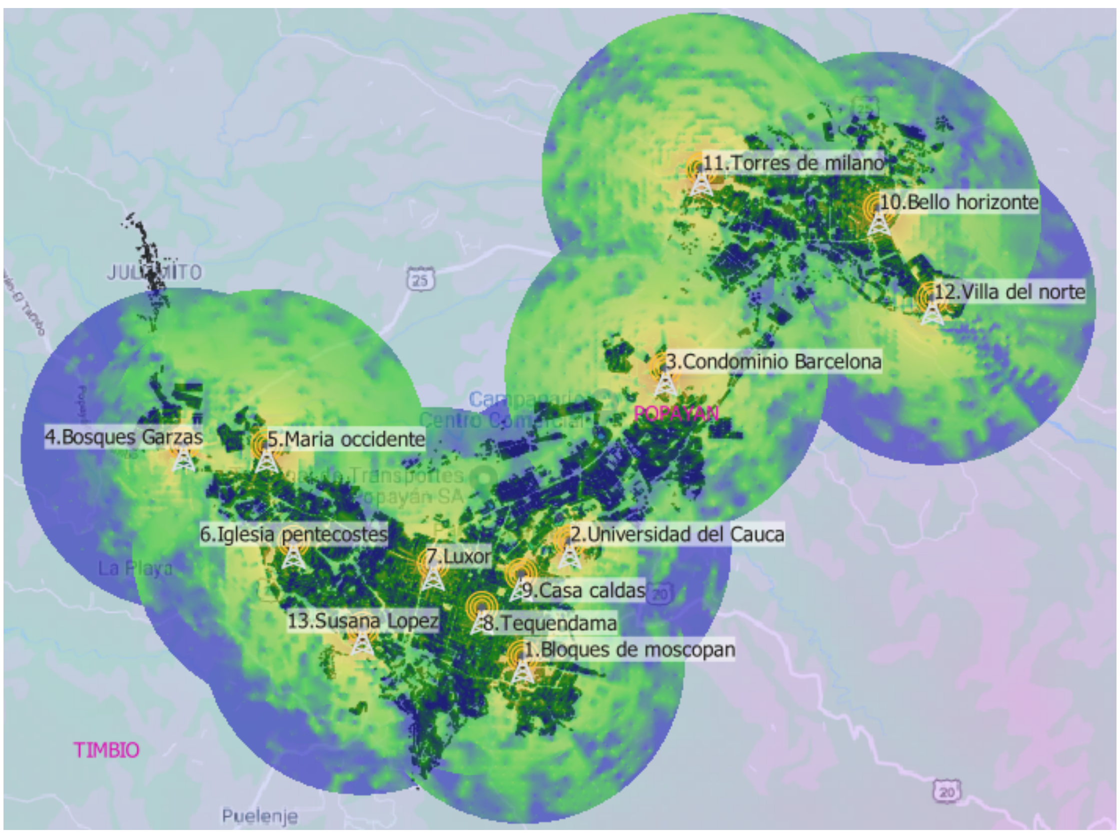


Figure 22. Coverage area for 13 BSs that cover Popayán

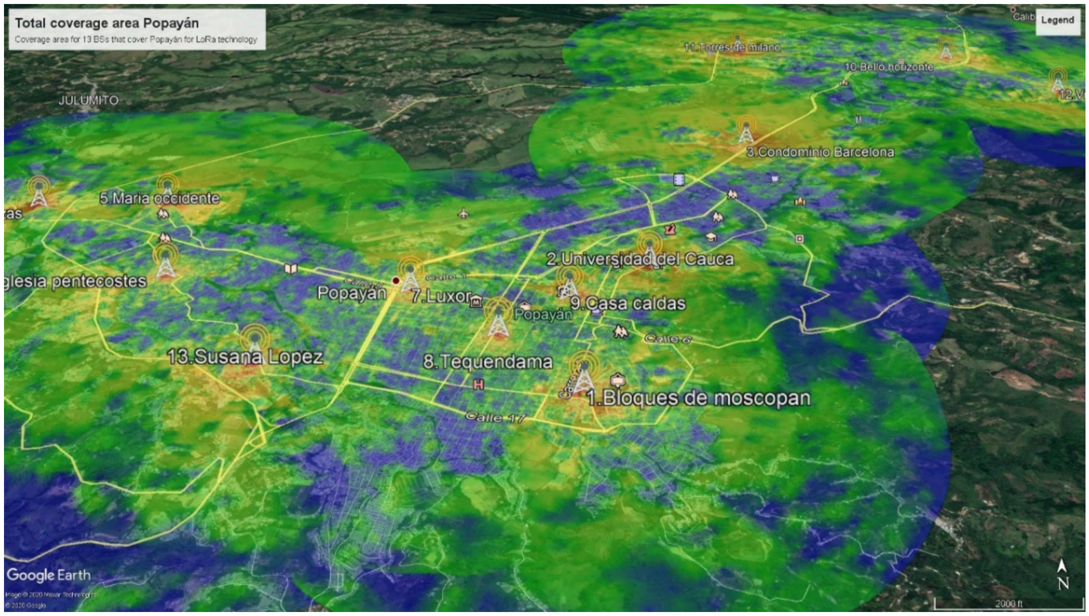


Figure 23. Coverage area for 13 BSs that cover Popayán in 3D view with Google Earth.

6 DESIGN AND DEVELOPMENT OF FMCS PROTOTYPE DEVELOPMENT UNIT AND COMMUNICATION TECHNOLOGY TESTS

After choosing the communication technology (LoRa / LoRaWAN), and carrying out the analysis of the coverage area where the system is planned to be implemented, the design of the FMCS prototype development unit was carried out. Then its development and later, the functional tests of the proposed communications system, which is one of the main advantages of the proposal. The foregoing, to validate the efficiency of both the prototype and the selected communication technology, collect the data set of the tests performed, and compare the results obtained from the coverage area and the results of the tests.

Following, the first section (6.1.) presents the FMCS prototype development unit design and implementation, the second (6.2.) presents the FMCS Prototype communication tests, the third (6.3.) have an analysis of the results obtained in the tests, and finally, the fourth (6.4.) presents information on the generated data set.

6.1 FMCS prototype design and implementation

The design of the prototype development unit, in terms of hardware, initially took into account some of the basic functionalities of the “Transit vehicle OBE” module. Such as communication technology, GPS module for vehicle tracking, screen to display information to the driver, a microcontroller card for the connection of different sensors or modules and a sensor to measure humidity and temperature. The hardware for passenger counting was not developed because it provides relevant information to other modules of the ITS architecture, not selected for this research. However, some data was simulated in the database, to verify functionality of software development.

The prototype “Transit vehicle OBE” module was designed using a “HELTEC ESP32 WiFI (v2)” microcontroller card. Which has integrated: an ESP32 microprocessor, a 0.96' OLED screen, a Bluetooth module, a WiFi module, and a LoRa SX1276 chip [99]. To measure temperature and humidity, it was determined to use the “DHT 22” sensor, which has adequate characteristics of accuracy and measurement range. Finally, to capture the location of the card, it was added to the design, the module “GPS Neo 6M.” These elements were selected considering the budget available for the project, the required characteristics of the prototype (identified in previous chapters, e.g., in the ITS architecture), the context for which the FMCS was designed, the good performance of these components in solutions at an international level and the ease of acquiring them in the current market. In **Figure 24** the implemented prototype (of OBE hardware) is observed.

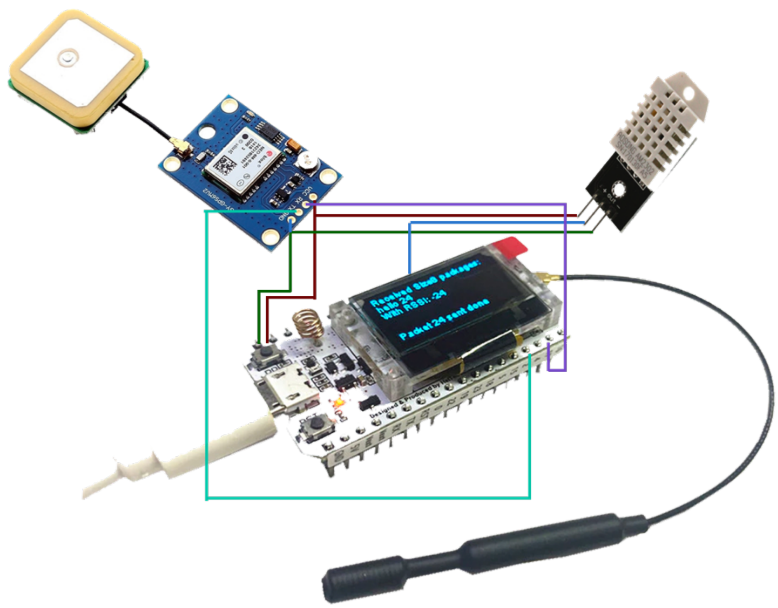


Figure 24. Prototype of OBE hardware

The development of this initial module (OBE) of the FMCS prototype development unit had no major drawbacks, the required connections were made, according to the manufacturers' specifications, and some initial functional tests of the components were made. These initial operational tests were carried out incrementally (initially connecting the DHT22 sensor, then the GPS), to show whether any component generated any inconvenience in the general functionality of the OBE module. Some minor adjustments were required (changing some of the connection pins) to prevent the GPS connection from causing problems with the presentation of the display integrated in the card. These initial tests were focused on fulfilling the third specific objective of this research ("Evaluate the working together of the different components of an FMCS within a laboratory environment using…").

Another important issue that had to be solved (in terms of HW) in the implementation of this module was the power supply of the card and the selected components, because, although the microcontroller card did not require much power, the module corresponding to the GPS did need a stable power supply with good power.

Regarding the programming of the code that was developed for the operation of the card, the IDE (Integrated Development Environment) Arduino was used with the

JAVA programming language and the use of the LoRaWAN, Heltec and TinyGPS libraries.

Once the “Transit vehicle OBE” module was implemented, the operation of such module was tested for the communication of the FMCS prototype development unit.

6.2 FMCS prototype network diagram and tests

For the communication tests of this “Transit vehicle OBE” module, it was necessary to previously design a prototype network diagram, which was based on the ITS architecture designed (presented in **Figure 18** of chapter 4). This diagram specifies the technology used in each module and the information flows exchanged between actors and modules, and between modules exclusively. The designed prototype network diagram is presented in the **Figure 25.** The diagram focuses on the three main modules of the aforementioned architecture, TMC, ITS Roadway Equipment, and Transit Vehicle OBE. Also, the four actors presented in the FMCS ITS architecture are included.

Once the prototype network diagram was made, 3 testing phases were proposed, each one with a specific objective to achieve the progressive improvement of the system.

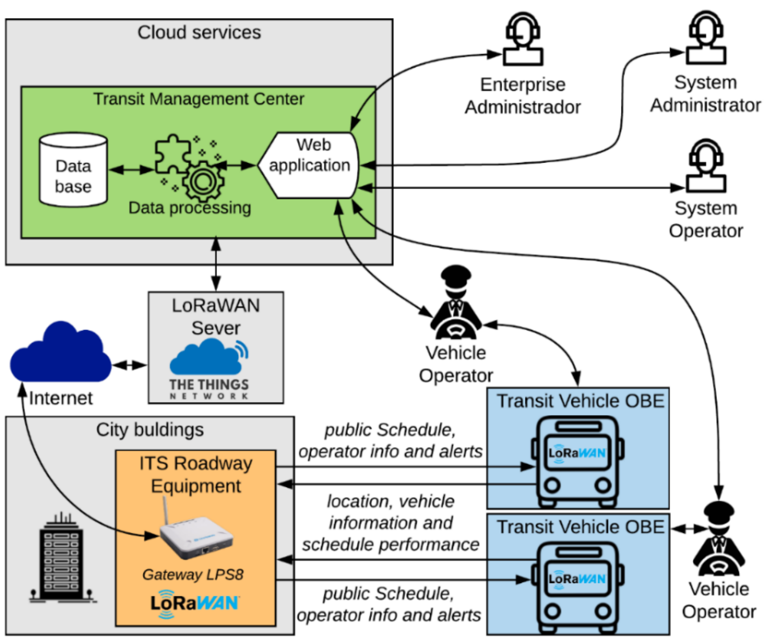


Figure 25. Prototype network diagram for the experiments of communication technology

Below are presented the prototype network diagram details (modules, selected technology, specific components used).

The **Figure 25** shows the path followed by the information between the different modules, and also shows where they are located. The OBE is located in each vehicle, which communicates with the ITS Roadway Equipment located in the city buildings, in which a Gateway is located. The use of the Heltec device (micro-controlled card) is a great advantage because it allows integration with other modules or devices to extend its operation.

The selected communication between Transit Vehicle OBE and ITS Roadway Equipment was the technology LoRa (in both ways), using the network protocol LoRaWAN (created by LoRa Alliance [100]). The preference of using LoRaWAN, rather than just LoRa messages, is given for two reasons. The first is that LoRaWAN provides an adequate security layer, the information is encrypted and the devices that are part of the network must join (when the activation method named Over-the-Air Activation or OTAA is used), in order to start sending messages, this joining has several authentication parameters. The second reason, is because the LoRa messages sent from several OBEs devices at the same time, with the same communication parameters (mainly the Spreading Factor, or SF) cause a considerable collision of packets in the Gateway and too much data is lost (this was verified with the systematic review performed [8], [101]–[105]). LoRaWAN network protocol facilitates dynamic change of LoRa communication parameters to minimize the probability of packet collision, this was checked in the first test and is discussed in the next item.

The selected Gateway (device located in the ITS Roadway Equipment) was the Dragino LPS8, which acts as LoRaWAN Gateway.

The programming of the Heltec devices, as mentioned earlier, was done through the Arduino IDE (Integrated Development Environment), using the examples of the card manufacturer (Heltec) and the help of its support staff. The configuration of the LPS8 Gateway was carried out with the help of the user manual of this device and the manufacturer's support staff (Dragino). The use of the LoRaWAN network protocol requires the use of a LoRaWAN server, which is in charge of all the upper layers of communication, in this project, it was decided to use the platform The Things Network named TTN [106]. The TTN platform (like other similar platforms) provides the possibility of sending the information that comes from the LoRaWAN devices to servers in the cloud; this functionality was used to store the data received from the OBEs in a database. This platform also facilitates the sending of Downlink-type messages, to send data from the TMC to the OBEs (alerts or changes in the routes).

The code used for the Heltec cards (which includes the integration with the GPS), and the configuration of the TTN platform (including the codification and de-codification of data, the integration with a cloud server for sending data and downlink messages) is presented in the Git repository presented in Annex G (“Git repository”).

A continuación son presentadas las tres fases de pruebas realizadas con el prototipo. Evaluate the working together of the different components of an FMCS within a laboratory environment using ITS services, LoRa communications technology, and the required information security.

6.2.1 First phase of tests

The first phase of testing included an initial stage performed in a laboratory environment, in which the operation of the communications technology (LoRA and LoRaWAN), the security in the access and sending of messages and the consumption of ITS services were tested. Fulfilling one of the specific objectives of the research (the third specific objective). This stage required several weeks of research, tests between the LoRA device and the Gateway, configuration of the LoRaWAN protocol, contact with support personnel of the manufacturers, tests at various distances, tests with different numbers of devices. Finally, the expected results were achieved, obtaining an adequate operation of the prototype, with some configuration of the LoRa devices, the Gateway and the information in the TTN Network.

This first phase included a second stage, where it was to evaluate the correct functioning of the FMCS prototype development unit in a semi-controlled environment (different of a laboratory environment) in order to validate all the configured parameters, in the OBE, Gateway and TTN Network (about security, reach, packet loss, and ITS service consumption). The prototype was tested using only LoRa technology for communication and then including the LoRaWAN network protocol.

This second stage of this first phase used four (4) OBE modules and two Gateways (one for each type of test, a LoRa Gateway, and a LoRaWAN Gateway). The location of the Gateway was fixed and the location of each of the OBEs was varying between 10 and 100 meters. All OBEs transmitted at the same time in the two types of tests.

In the LoRa tests, were verified the theoretical problems mentioned in the literature when sending messages (with the same communication parameters) at the same time by several OBEs [8], [101]–[105]). The LoRaWAN network protocol was tested to try to improve the operation with several nodes at the same time. LoRaWAN was essential for setting the parameters (spreading factor or SF, bandwidth or BW, and coding rate or CR) with which LoRa messages are sent and received. For the Gateway in the ITS Roadway Equipment module, two different devices were used. One of them, the Dragino LG01 which is a LoRa Gateway [107] works only with LoRa messages, without any network protocol. The second of these, the Dragino LPS8, which is a LoRaWAN Gateway [97], that in addition to using LoRa messages, uses LoRaWAN as a network protocol.

It is important to highlight that the tests were performed with a limited line of sight (LoS) between the Gateway and the LoRa devices (OBE) because there were some construction obstacles (this in order to correctly simulate the urban environment). In both tests, the Gateways were located inside a building, at the height of approximately 12 meters, near of position 1 indicated in **Figure 22** (it is named "*Bloques de moscopan"*).

Results of tests using LoRa

In these tests, the Dragino LG01 device was used as a Gateway with a LoRa communication technology. Four OBE devices were built and the tests were performed. The frequency band used was 915 MHz, the distance (between 10 and 100 meters) and the number of OBE devices transmitting simultaneously were modified.

The test performed with only one OBE module transmitting, showed positive results, for approximate distances between 10 and 100 meters in the places where there was direct LoS (Line of Sight) or with a low number of obstacles, neither lost packages were found. However, in the sites with considerable obstacles, the percentage of lost packages was high, close to 60%.

The central problem in this test occurred when transmitting with more than one OBE at the same time. Serious problems were found in the reception of packets, sometimes receiving only messages from one of the OBEs or a very low percentage of the others. This occurred when the Gateway receives LoRa packets with the same Spreading Factor (SF) parameter, there is a collision of these when they arrive in a close period of time [8], [101]–[105]. The SF used for the tests was 7, which is the recommended value.

It is possible to modify these parameters of the LoRa communication (such as SF, BW or CR) to help mitigate this problem, however, the same results are not obtained when varying the distance, these parameters would have to be varied continuously to achieve a correct reception of packets, additionally, energy consumption could increase.

Results of tests using LoRaWAN

The tests with LoRaWAN sought to validate if effectively using this network protocol the problems presented with several nodes are solved; by sending LoRa messages at the same time to a single Gateway; and to verify if the security scheme of devices joining was enough robust.

For this test, the LoRaWAN Gateway “Dragino LPS8” device was used, which has good radio parameters (**Table 7**).

This test was carried out in the same way as for LoRa, with the difference that here all the packets sent by the four OBE modules (simultaneously) were received correctly. The online data transmitted from the OBEs to the Gateway using LoRaWAN was possible to visualize them thanks to the TTN platform, which acts as LoRaWAN Server. Here the frequency managed by the devices was configured to work in sub-band 2 (channels 8 to 15) of the LoRaWAN 915 Mhz band, which is recommended for use in Latin America. This sub-band uses frequency values between 904.1 MHz and 905.3 MHz; also provides cross-device compatibility and support offered by the TTN platform.

The test performed shows that, when using this protocol, problems such as interference between packets is minimized, where four messages were transmitted simultaneously without any problem.

The LoRaWAN protocol has greater communication reliability because there is an acknowledgment of receipt (ACK) for each message; therefore, the loss of an ACK implies the retransmission of the message by the OBE. Although, this in large tests scale could be a problem managing to overload the system with messages that would not contain updated information.

The obtained results were satisfactory, receiving 100% of the packets transmitted in all the tests performed with LoS (Line of Sight) or minor obstacles, it is important to mention that the received signal level (RSSI) at a distance of approximately 80 meters was - 108 dB on average.

The security of the LoRaWAN protocol was also verified, the joining process that the devices must perform in order to start sending messages (with payload) has the adequate security parameters (which are configured both in the code of the micro-controlled card, as in the LoRaWAN Server platform, TTN).

In these tests, it was also possible to verify that the positioning of the antenna is of great importance, managing to improve the received signal level by up to 10 dB when it is in open space.

This test also allowed to study the behavior of the GPS (for vehicle tracing), here errors were found between a range of 1 to 5 meters, which is not a problem that could affect the operation of the system. It was found that the device used (GEO NEO 6M) consumes a considerable amount of electrical power because it did not establish a fast connection to the satellite with a portable battery, so it is suggested to evaluate the possibility of changing it for another reference of less consumption for future prototypes. Finally, the internet connection tests were completely successful, where each LoRaWAN packet received by the Gateway was successfully transmitted to the TTN platform via an Ethernet connection. **Figure 26** shows a diagram representing the tests with LoRaWAN.

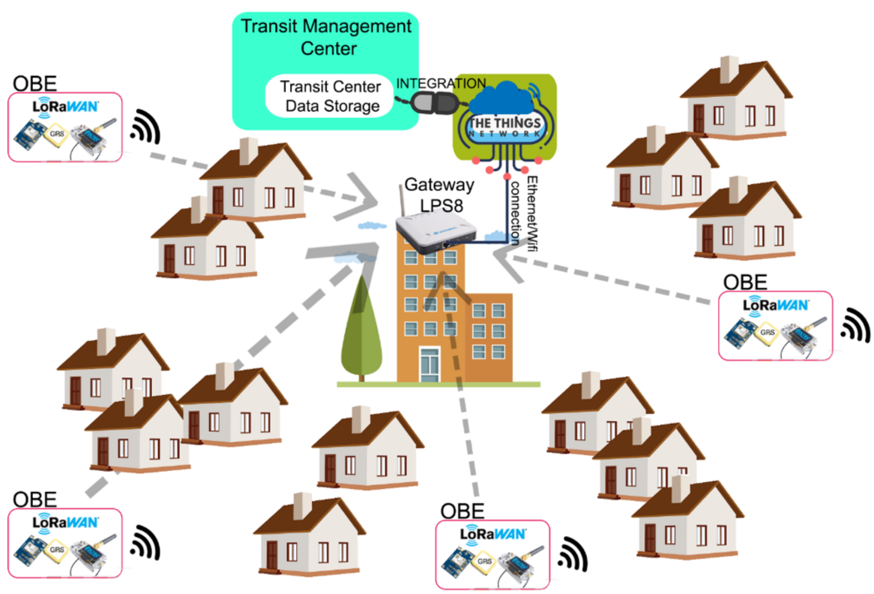


Figure 26: Sketch of the first LoRaWAN experiment

It is highlighted that by using the LoRaWAN network protocol it was possible to introduce the necessary security to the exchange of messages, which cannot be achieved only using LoRa communication technology. Additionally, to be able to make an adequate consumption of ITS services, LoRaWAN technology is ideal, because it allows the secure sending of messages in both directions (Up-link and Down-link).

6.2.2 Second phase of testing

This second phase of tests was carried out on October 16, 2020, the number of LoRaWAN Gateways devices (Dragino LPS8) was increased (using 2 devices), the first was located in the same position as the previous phase (Bloques de Moscopán building, location 1 of **Table 6**) and the second in the Faculty of Accounting Sciences of the Universidad del Cauca (location 2 of **Table 6**). Another difference with the previous phase was that the system was tested with two OBE devices transmitting through the LoRaWAN protocol, where one of them (device called Helctec_001) was left in a static position 2 meters away from a Gateway (with the objective of check the functionality of LoRaWAN and servers) and the other (device called Heltec_005) was located in a moving vehicle, which followed a route on the city roads. In this phase, all the necessary modules to store and observe the information had already been designed and implemented.

Route 1 was carried out with the device "Heltec_005", this is presented in **Figure 27** (in which the route is shown with red lines, black arrows indicate the direction of movement, green icons for each of the detected positions of the device and an equivalent scale 500 meters on the map for this case). This device began transmitting packets from 16:30:03 to 17:13:37, for a total of 2614 seconds transmitting, taking into account that a packet was transmitted every 11 seconds, in this period of time they should be received approximately 237 packages and a total of 146 were received, thus obtaining a total of 61.6% packages received. Device "heltec_001" began transmitting at 14:12:26 until 21:42:45 obtaining a total transmission time of 27019 seconds, in this period 2456 messages had to be received and 2403 were stored, for a total of 97.84% of packages received correctly (see **Table 9**).

#	Device	Status	Average speed (Km/h)	Txi time	Txf time	Tx time (seg)	Received packages	Expected packages	Percentage of received packages
1	Heltec_001	Static	0	14:12:26	21:42:45	27019	2403	2456	97,84%
2	Heltec_005	Movement (Route 1)	25	16:30:03	17:13:37	2614	146	237	61,6%

Table 9. Second phase tests results

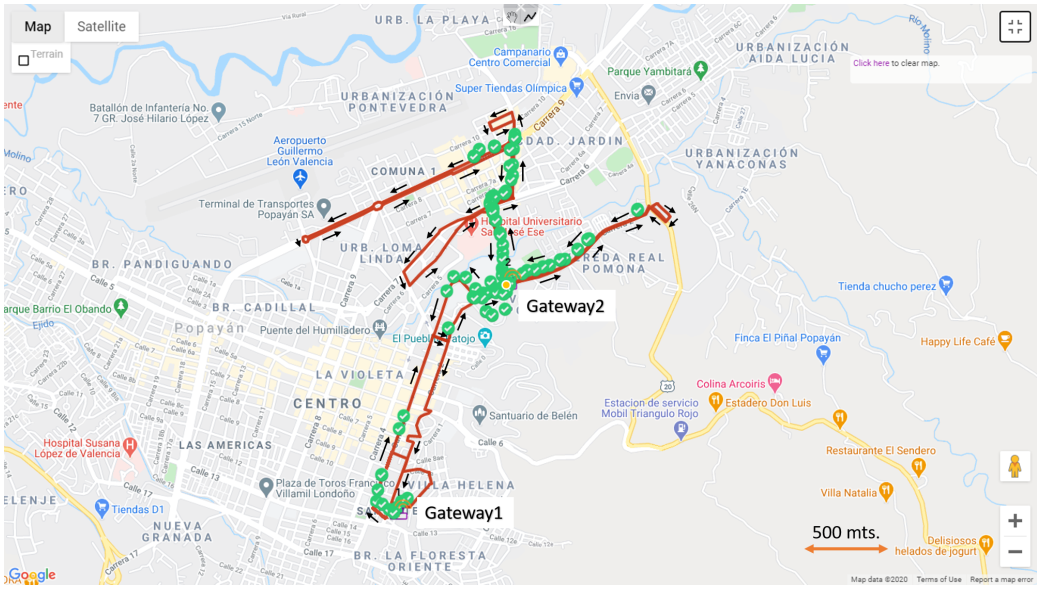


Figure 27. Route 1 - Second phase of the experiment

For the moving device (Heltec_005), most of the sent packets were obtained correctly, although a great loss of these was observed, mainly due to the losses that occurred by LoS. This can be seen in the right area of Gateway 2, where buildings are located, which affect transmission. Likewise, there are elevated areas, due to the geographical characteristics of the place, for this, it is observed that most of the packages received are located northeast of such Gateway. Close to Gateway 1 it is observed that fewer packages were received because it is an area with a greater number of buildings.

Of the packets received, the one with the greatest distance recorded was approximately 900 meters and was collected by Gateway 2. Likewise, the least received signal strength indicator (RSSI) corresponds to this same packet with a value of -131 RSSI.

It was identified that the LoS is a very important factor in this type of communication, however, more tests were needed to obtain better conclusions, so the third phase of tests was performed.

6.2.3 Third phase of testing

This final test phase was performed on October 27, 2020, the number of Gateways was maintained (2 devices), but the number of OBE devices was increased to five, where two remained static and three in motion, the results obtained in this phase are presented in **Table 10**.

#	Device	Status	Average speed (Km/h)	Txi time	Txf time	Tx time (seg)	Received packages	Expected packages	Percentage of received packages
1	Heltec_001	Movement (Route 2)	25	15:40:02	16:59:55	4793	234	435	53,79 %
2	Heltec_002	Static	0	15:22:46	17:00:28	5862	495	532	93%
3	Heltec_006	Static	0	13:49:20	23:59:53	3663	3190	3330	95,79%
4	Heltec_007_cubecell	Movement (Route 3)	20	15:31:30	16:59:13	5263	193	478	40,37 %
5	Heltec_008	Movement (Route 4)	25	16:02:34	17:00:52	3498	280	318	88 %

Table 10. Third phase of the experiment results

Figure 28 shows the route 2 and the locations registered for vehicles (in third phase tests). In this test, due to power problems the GPS did not connect correctly and the data was not sent to cloud server. The reception percentage obtained in this route (53,79%) was due, during a large part of the test, the device was close to the Gateways and the data was recorded at those points. Therefore, these records are superimposed (the green icons) on those zones. In the rest of the route, the location on the map was not obtained, as already mentioned, due to problems with the power supply.

Figure 29 and **Figure 30** show routes 3 and 4 respectively and the locations registered for vehicles. Of these tests, route 4 showed the best behavior, this was due, the device (OBE) was located in a vehicle with adequate power (provided through a USB port of the vehicle) and in a fixed way. In the vehicles used in the other routes it was not possible to do it that way.

As in the second test phase, it is observed in the third phase how most of the packets were received by Gateway 2 in the same geographical zones (north and northeast of the location of such Gateway) considering the structural conditions. Although, if route 1 is compared with route 4, a higher density of packets received towards the northwest is observed on route 4, this due to its more stable power supply that allows better transmission factors.

Figure 28. Route 2 - Third phase of the experiment

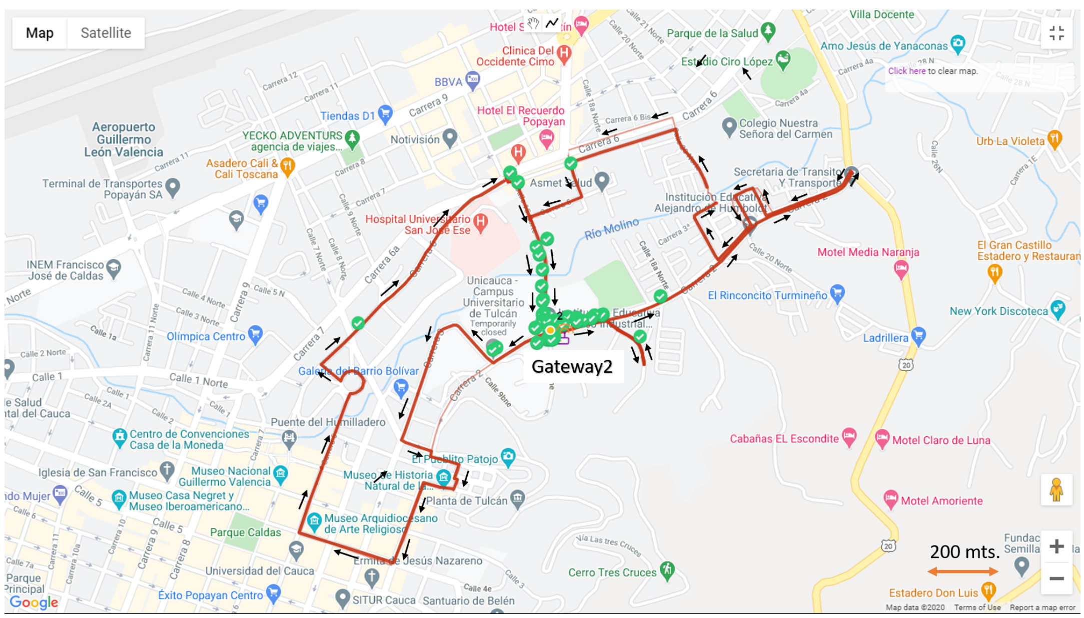


Figure 29. Route 3 - Third phase of the experiment

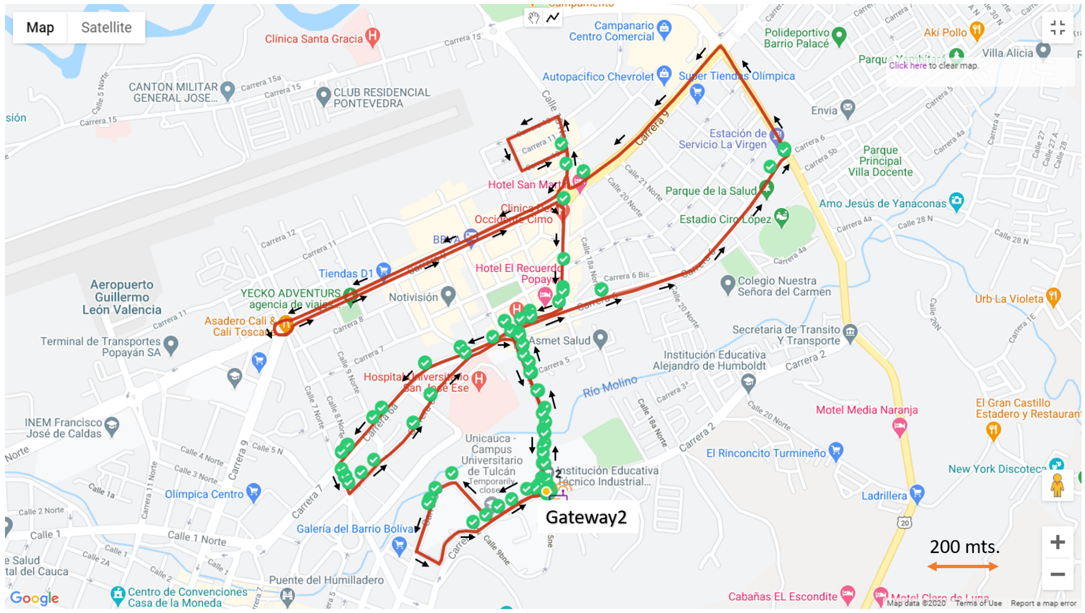


__Figure 30:__ Route 4 - Third phase of the experiment

6.3 Analysis of the results obtained in the tests

Analyzing, the three phases of tests performed, it was concluded that the LoS is a very important factor for the adequate operation of the communication system selected for the FMCS, additionally, the transmission power used by the devices is very low, which affects transmission when there are considerable obstacles. According to the four routes traveled, the greatest range of the received packet was obtained for route 4, with a distance of almost one kilometer reached approximately. Also, the difference in the percentage of packages received between moving devices powered by external batteries, and the device powered by the vehicle itself was considerable. Obtaining in the latter (powered by vehicle) 88%. This is a good issue, because the OBEs would be fed by the buses in an operating scenario (such as was done for route 4)

Analyzing the RSSI obtained, in route 2, there was an average level of -89.85, which was presented because most of the registered packets were very close to the receivers. For route 3 was obtained an average RSSI of -105.61, for route 4, -102.60 and for route 1, -106.15. Note how this value remains almost stable for the last three presented cases (routes 1,3 and 4), in these routes were obtained better results for the percentage of received packets too. Meanwhile, the lowest RSSI obtained corresponds to route 1, with -131 for the packet farthest from the Gateway registered in such route. Likewise, the highest RSSI was obtained in that same route (route 1), with a value of -45.

On the other hand, it can be observed that for static OBEs, the percentage of packets received is very high in all cases, which infers a good response from the LoRaWAN protocol in handling multiple simultaneous routing requests. This gives rise to evaluate their behavior with a considerably higher number of OBEs in future work. When making the comparison with the coverage obtained in chapter 5, it is evident that it would be appropriate to increase the value of miscellaneous losses in the coverage simulation performed. This adjustment would limit the range of each BS (Gateway), as occurred in the field tests performed. Which is identified the need to increase the number of Gateways in the city of Popayán, to achieve complete coverage. This increase in Gateways could be viable, considering that the budget required to develop it is not too high. The increase in the number of Gateways in the city would increase the number of packages received during a route and would allow adequate tracking of vehicles, without many areas where they cannot be located. Using the LoRaWAN protocol opens the doors to the internet of things, because many devices could connect to this network, creating an ecosystem of intelligent and intercommunicating devices without affecting the functionality of our system.

6.4 Data set generated from the tests performed

All measurements made in the phases 2 and 3 of tests were stored in a database, downloaded, and analyzed. In Annex H "Data set", the total of the 9511 registers obtained in the second and third phase are presented. These data are delivered in JSON and Excel (XLSX) formats. These documents contain relevant information on the different parameters of LoRa technology.

These records were analyzed using the Python programming language. Annex I ("Data set description") explains each variable and the analysis of these.

Following, the analysis of two variables considered important (in the data set) is presented. The first was the "data rate", this variable takes a higher value in devices located further away from the Gateway (**Figure 31**). In this way, the importance of the LoRaWAN protocol is validated, because the change of Spreading Factor (SF) and Bandwidth (BW) parameter is performed automatically depending on its SNR (Signal Noise Relation) and ACKs (Acknowledgment). This means that the transmission parameters (SF and BW) of the devices are automatically changed in LoRaWAN, so that the devices try to transmit packets in such a way that the Gateway receives them. The second variable analyzed was frequency, it is observed in **Figure 32** uniformity in the number of packets sent in the 8 frequency channels of sub band two, this with the aim of not saturating the medium. This is another important feature of LoRaWAN, the change of the transmission frequency automatically (within the configured range). The code for the analysis of these data is provided in Annex J ("Data set analysis").

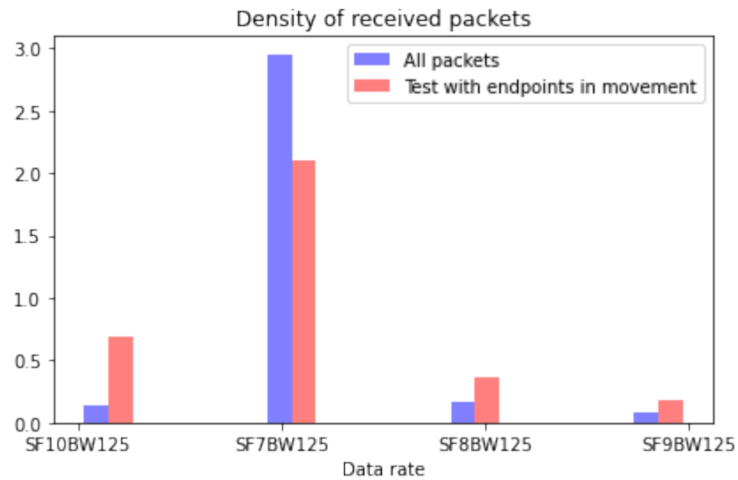


Figure 31. Density of received packets grouped by data rate

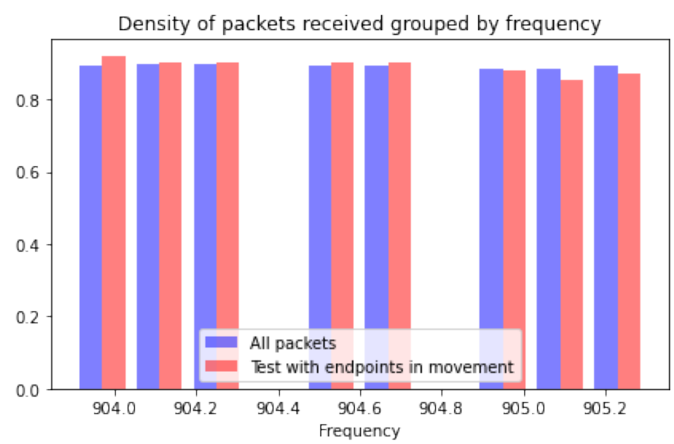


Figure 32. Density of packets received grouped by frequency

7 DESIGN AND DEVELOPMENT OF THE WEB APPLICATION AND DATABASE (OF FMCS PROTOTYPE DEVELOPMENT UNIT)

This chapter is focused on the design and implementation of the web application and the database of the FMCS prototype development unit.

For the development of the prototype, the Scrum methodology was used, in which the analysis of business case was make in the scrum start document. On the planning document the different actors of the FMCS (system administrator, system operator, enterprise administrator, and vehicle operator) were identified, also the functionality for each one of them. Thus, according to the development of the methodology, such functionality was first organized in epics and later in user stories. The total number of user stories obtained were subsequently organized into two Sprints. For each of the user stories of the Sprints, the necessary tasks were identified to develop them. According to the definition of these tasks, a schedule was established and its development was continuously monitored.

For each of the user stories, the tasks related to the design of the mockups and the design or adjustment of the database were identified, because they were considered necessary tasks for the design of the actors' functionalities. Some of the most relevant mockups are presented in this section, as well as the final design of the database. In order to clarify the actor-system functionality and make a design overview of the user stories, annex k (“Scrum”) contains a zip with all the documents of Scrum methodology.

7.1 Identified functionality of the web application

7.1.1 System Administrator

The system administrator is the user who manage all the parameters in the application, i.e., management of vehicles, users, companies, and routes. This user can track of all the vehicles registered in the system and observe statistics related to any company or vehicle registered.

7.1.2 System operator

The system operator is in charge of managing the routes based on the monitored traffic, this actor can also view statistics of any registered vehicle or company and can track any vehicle belonging to any company.

7.1.3 Enterprise administrator

This user is only linked to functionalities related to his transport company, i.e., he can only track the vehicles linked to his company, manage routes of his company and likewise, assign drivers to vehicles, and vehicles to routes of his company. The review of statistics also applies only to what is related to his company.

7.1.4 Transit vehicle operator

The transit vehicle operator can track his vehicle in the application, as well as see the route assigned to him, its functionalities are limited to the parameters that it handles (route and vehicle). The user can also receive notifications in the event of a change in a route that involves him.

7.2 Interface design

As previously mentioned, this section presents some of the most relevant mockups designed to fulfill the functionality of the identified “user stories”. This task was considered relevant to adequately develop the “user stories”. This in order to visualize ideas and concepts of design, navigation, structure, and elements. All mockups were developed with the Balsamiq cloud tool, which allows a friendlier interaction with the user. Annex L (“Mockups”) contains the mockup file that must be loaded into Balsamiq.

The first screen designed was the login screen, where users can log in with credentials defined at user creation, either by an administrator or the system operator. Password change is also included. The design is so simple, so the mockup is not presented.

The index screen (**Figure 33**) contains all the information related to monitoring or tracking. This interface can be inherited from any actor in the system because it is useful to locate vehicles and routes, such information can be observed on a map or in a table. Different series of filters can be made here.

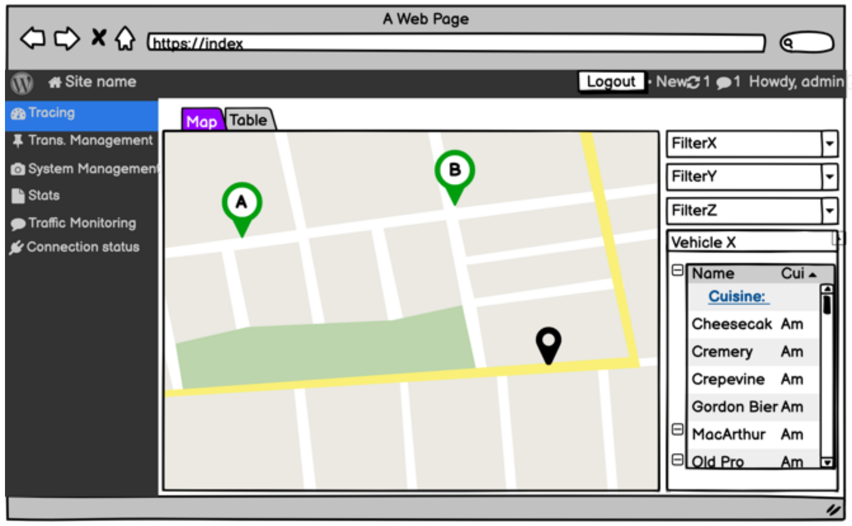


Figure 33: Index mockup

The transport management screen (**Figure 34**), allows to system administrator or the operator manage routes and vehicles. For route management, a name will be selected and each stop will be chosen using the map, thus forming a route. Vehicle management will also allow associating a route to a specific vehicle

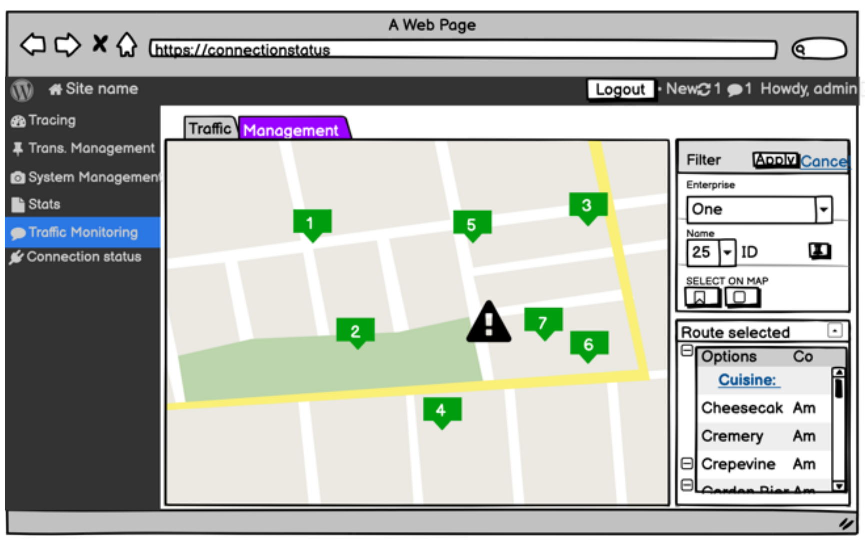


Figure 34: Transit management mockup

System management screen (**Figure 35**) allows the management of users, companies, and user groups. This screen is enabled for administrator users. The "user group" has the objective of controlling the functionalities of each user, this brings scalability to the system by allowing the integration of future new actors.

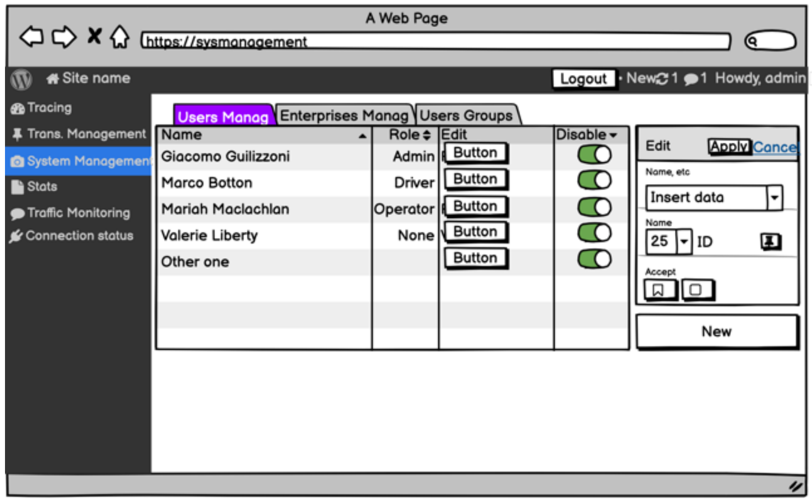


Figure 35: Mockup system management

In **Figure 36** the statistics screen is presented. This screen uses different filters, such as date ranges, companies, and vehicles. It is possible to see the number of passengers per vehicle, the number of vehicles per route, and the total routes for the defined range.

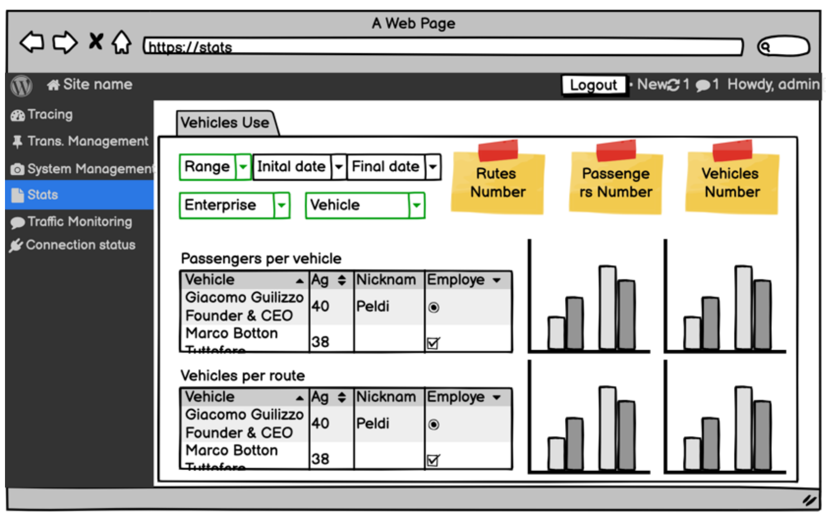


Figure 36: Stats mockup

The last screen (presented in this document) corresponds to traffic management (**Figure 37**), which is integrated with other modules that provide traffic monitoring information. This work is outside of the planned scope, so the data provided here was simulated.

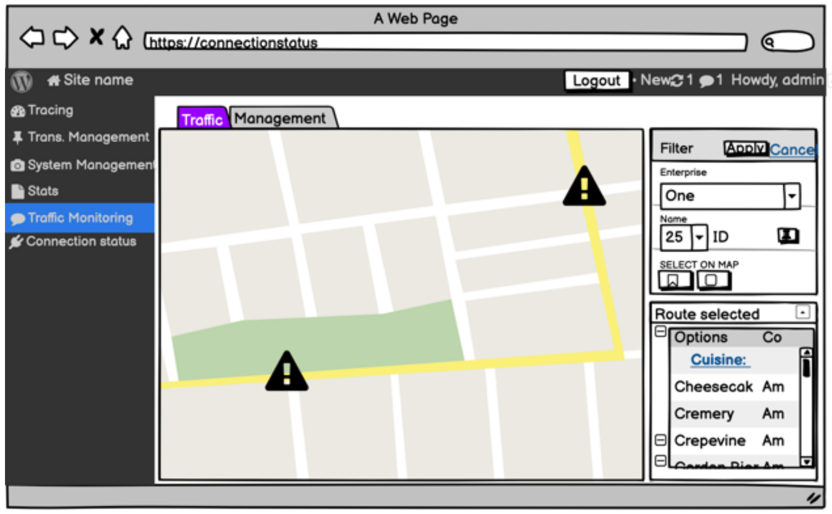


Figure 37: Traffic management mockup

7.3 Database

One of the most important parts of creating a system is designing the database. This assumes the task of storing the information that can later be consulted. Currently, Structured Query Language (SQL-relational) and Not only SQL (NoSQL-non-relational) are the two most used types of databases [108].

Although these databases have similar objectives, they have different characteristics [109]. In [110] It is mentioned that NoSQL is better for storing varied information and for a large data set, in addition, in [111] SQL databases are mentioned as having difficulties when it comes to scaling.

For these reasons, the FMCS database was designed and deployed with a NoSQL model, because a large amount of information would be handled and would allow easy scaling of the data to be stored without having to modify the rules of relationships and modeling.

After choosing a database type, the schema was designed. For the design of the database, it was followed the methodology proposed in [112], which is based on a NoAM (NoSQL Abstract Model) approach. NoAM exploits the similarities of the data modeling elements available in the various NoSQL systems, introduces abstractions to balance their differences and variations, and is used to specify an independent representation of data from the application. This methodology enables scalability, performance, and consistency in the database.

The design of the database took into account the conceptual data model where the various entities and necessary relationships are identified. The aggregate design to group related entities into aggregates. And the aggregate partitioning where aggregates are divided into data elements more smalls.

We also relied on [113], here the authors focus on query-based design. Where the first step is to study the application workflow and query patterns. Containers (collections) based on query patterns were then identified. The key was striking a balance between designing a container for each query and designing a container to satisfy multiple queries.

Finally, in **Figure 38** the complete design of the database for the developed system is observed.

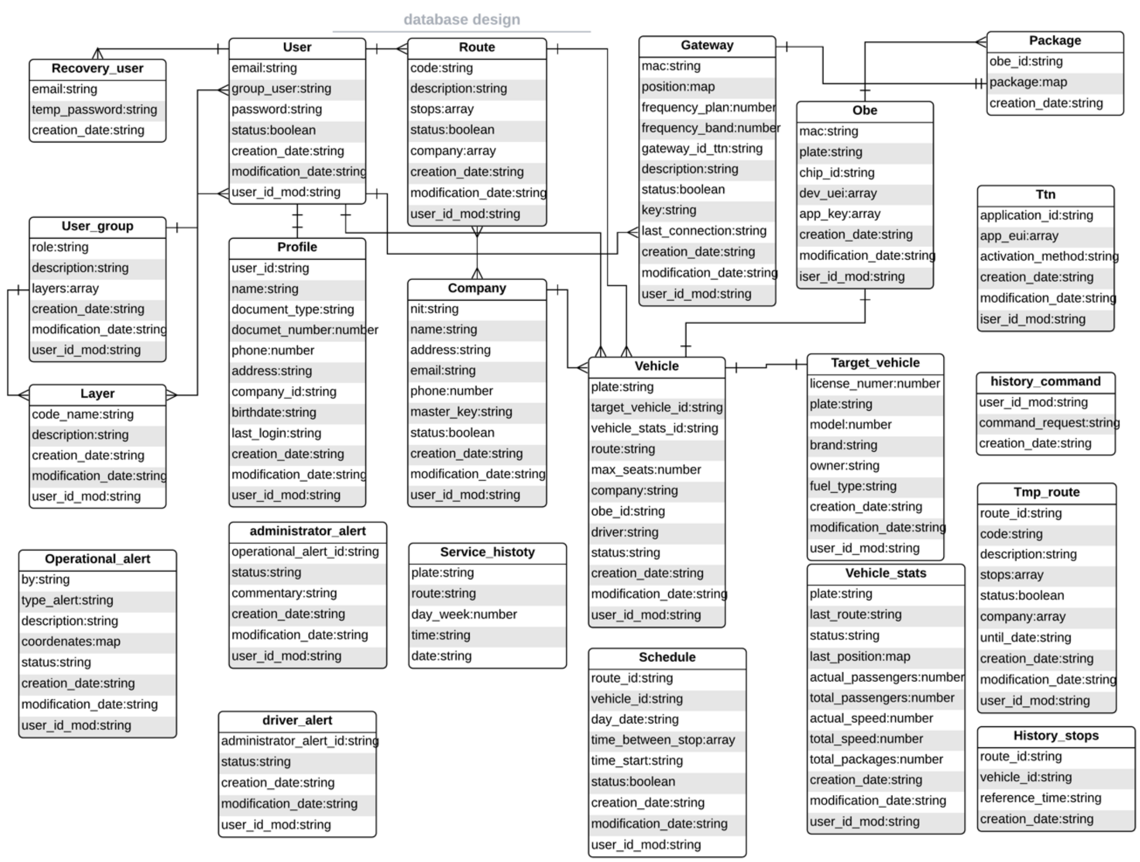


Figure 38: Database design

7.4 Development and architecture of the Web application

For the development of the application, it was decided to use Node.js as the framework and JavaScript as its programming language for the frontend. The choice of this framework is mainly due to the fact that it is designed to create scalable network applications, which is convenient for the type of application in context [114]. For the management and administration of the database, it was decided to use the NoSQL database Firebase's Cloud Firestore, because it offers certain advantages in data management and allows continuous “listenings”. It is ideal for vehicle tracking and some other features mentioned above. For the backend the named “micro-services” were developed with “Spring” framework and java as programming language. Meanwhile, for the entire issue related to route management, vehicle tracking, and traffic monitoring, it was decided to implement several of the services offers by Google Cloud platform offers, among them: maps JavaScript API, directions API, and roads API.

The implementation of ITS services (according to the specific objectives of the research) generates the need to distribute systems in micro-services in order to easily allow the addition of new modules and functionalities. The need to add other components such as a centralization of configuration for different deployment environments was identified. This was done with the dependency on “Spring” framework called 'config server'. In the same way, a “Eureka” server was implemented for load balancing, fault tolerance, registration and location of the different micro-services.

The FMCS system is expected to have a large number of modules or micro-services connected, for this reason, is necessary to add a dynamic router that allows monitoring and securing requests, this is achieved with the “ZUUL” edge service. With regard to security, each endpoint with Zuul has been protected with an authentication header.

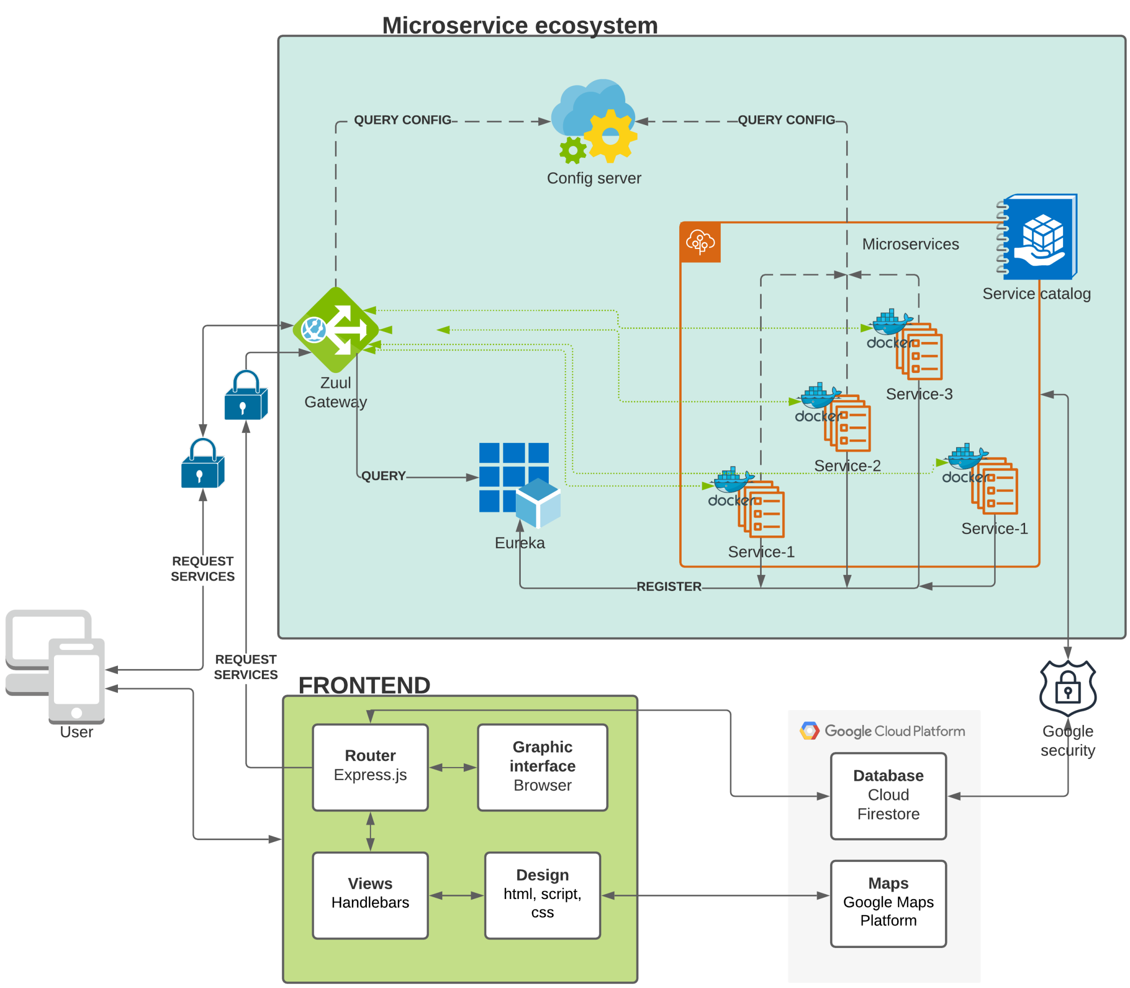
Each of the aforementioned services was Dockerized (implemented within a Docker container) with the aim of being easily deployed on any type of server without the need to worry about software version compatibility. Finally, these containers were deployed in an instance of Google Cloud.

With the main tools established, the architecture of the application's operation was designed (**Figure 39**). The module of google cloud contains the database, which according to the ITS architecture designed (Figure 18), correspond to the Transit Center Data Storage module, all the others functional objects as Transit Center Assignment, Transit Center Route and Schedule Management, and Transit Center Data Management were worked as micro-services.

In the frontend (**Figure 39**), the “router” module is in charge of all the addressing for the graphical interface. This routing is handled by the Node.js plugin named “Express.js”, which allows, in addition to directing, rendering the requested interface, this is made with handlebars template engine, which is used to generate HTML within JavaScript functions, which allows flexibility and more effective template execution.

The “design” module provides the styles and configuration to display in the “graphical interface” module. Additionally, it manages the requested from the Google Maps Platform module, which returns functionalities according to the APIs that are available.

Finally, the compiler will be in charge of processing all the information and creating a server where the entire application works, in this case, Node.js.



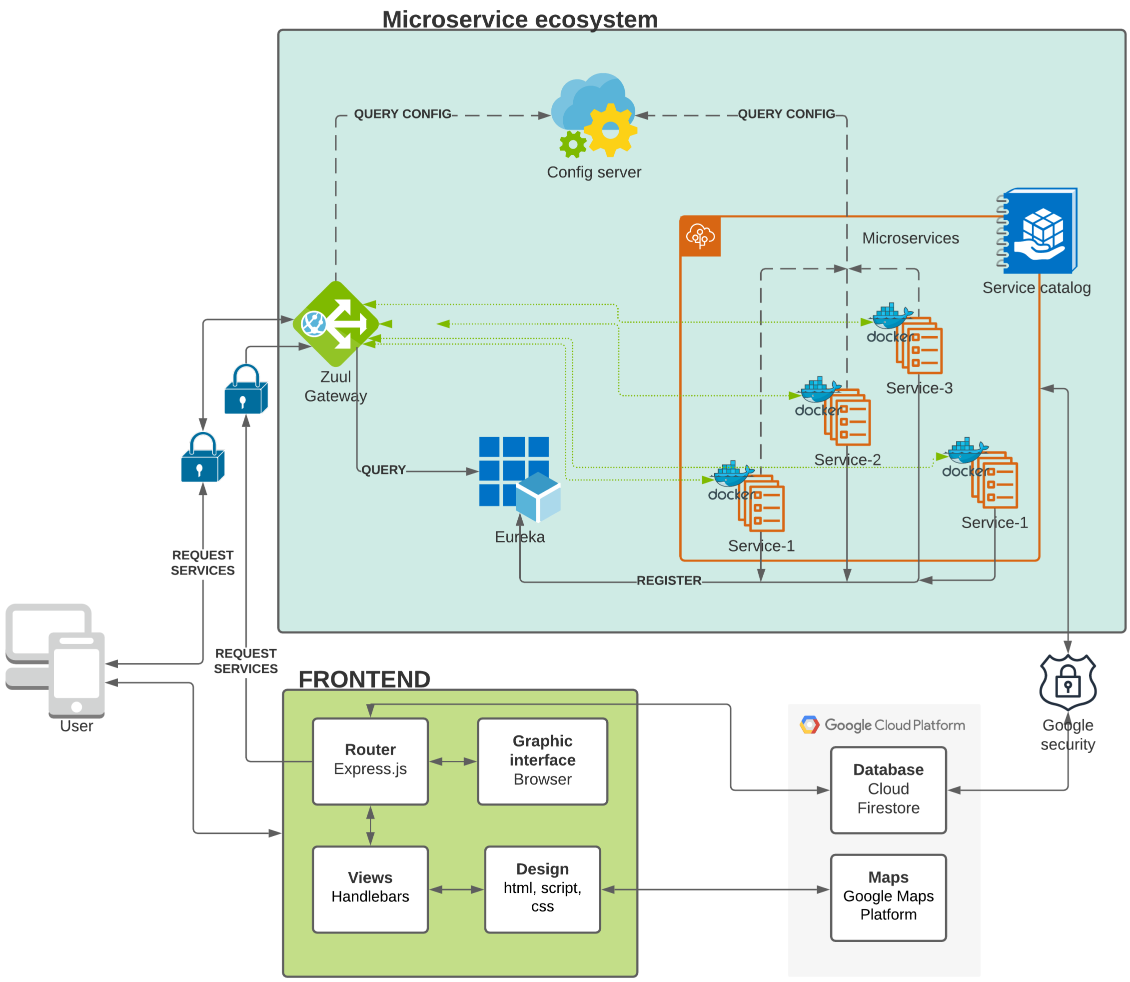


Figure 39: Web application architecture.

Once the architecture was established, the development of the application proceeded. According to the mockups presented in section 7.2, the respective interfaces were implemented. Some of the interfaces developed and their relationship with the functional modules proposed in the FMCS ITS architecture are presented below (Figure 18).

In the **Figure 40** is presented the interface for the index (which contains all the information related to monitoring or tracking).

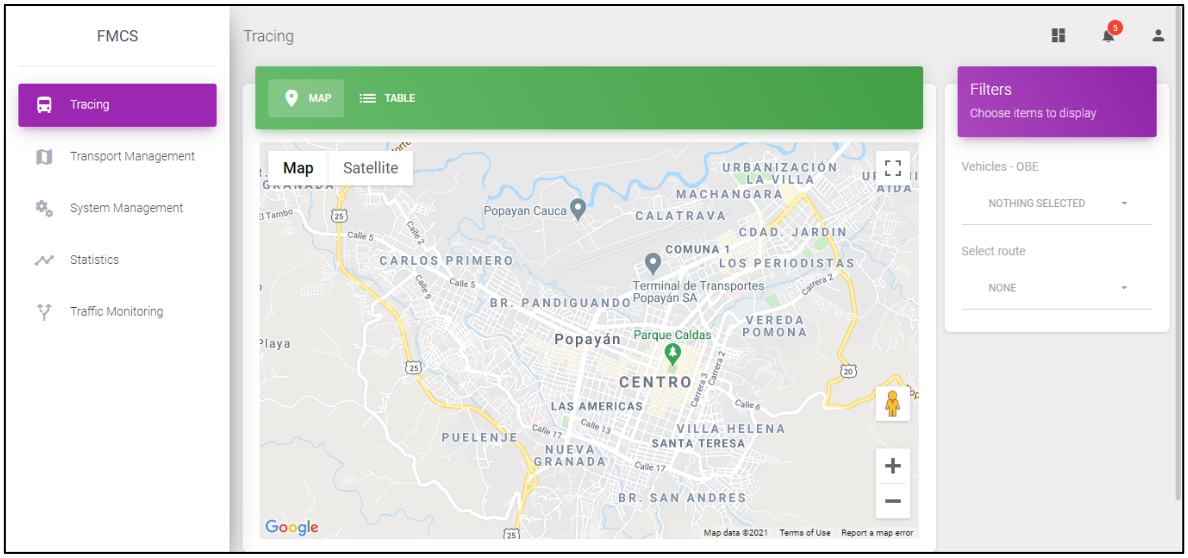


Figure 40: Web application - Index (developed interface)

In the ITS architecture, a module for route management called Transit Center Route and Schedule Management is proposed. The functionality of this module was implemented through two interfaces, Transport Management and Traffic Monitoring (**Figure 41** and **Figure 42** respectively). The first interface is responsible for manual route management, while the second is for automatic route management, depending on traffic problems.

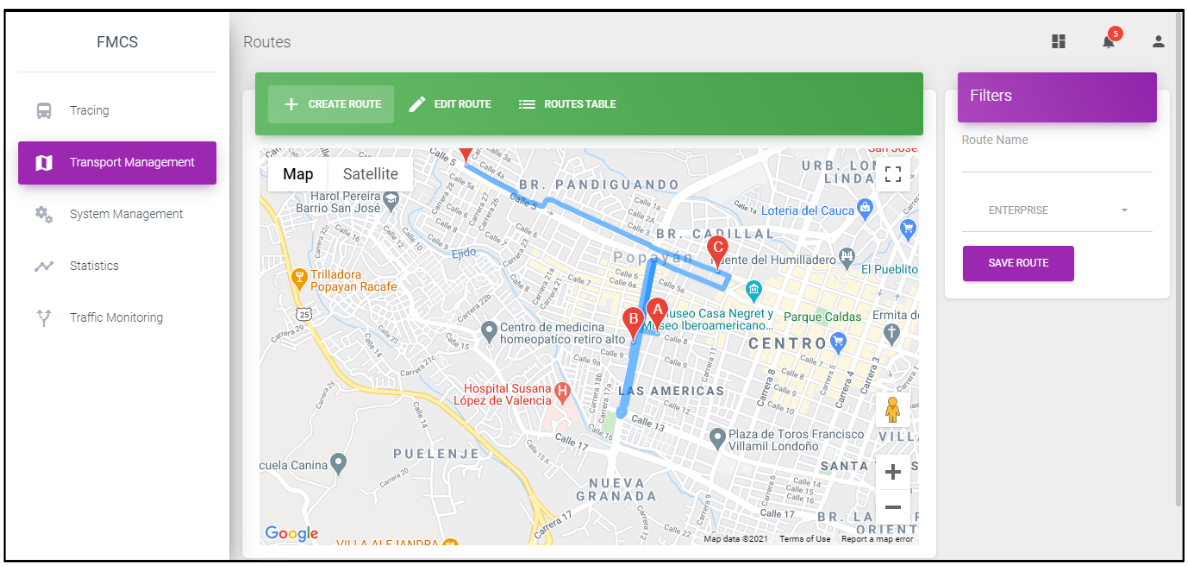


Figure 41: Web application - Transport management (developed interface)

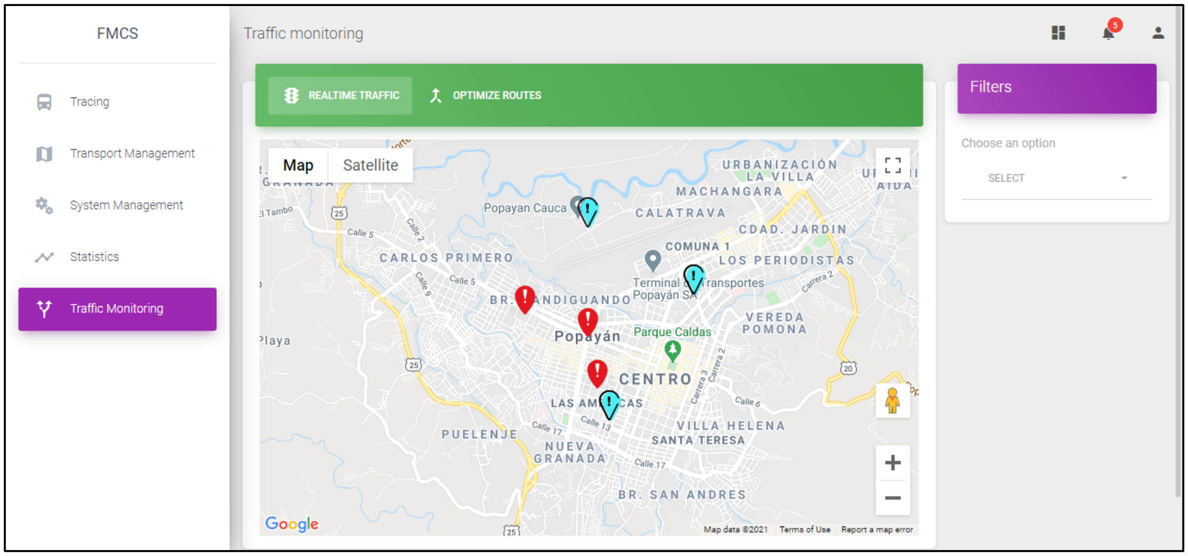


Figure 42: Web application - Traffic monitoring (developed interface)

According to the proposed ITS architecture, the interface called system management (**Figure 43**) was created for a part of the Transit Center Data Management functionalities. It manages various components of the system (users, vehicles, routes, and companies). This interface also fulfills the functionalities of the Transit Center Assignment Module, because it relates actors with system parameters (e.g., bus-driver, driver-enterprise, user-enterprise, etc.).

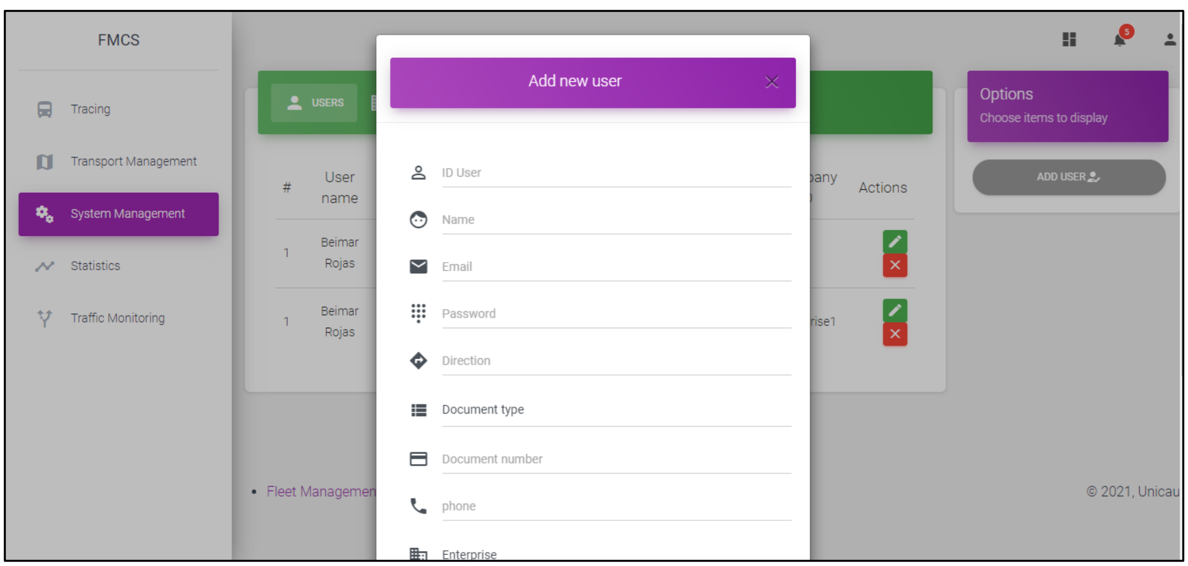


Figure 43: Web application - System management (developed interface)

7.5 Operation tests

The operation tests of the web application were developed integrating the functionality of the entire prototype development unit, for which the data set collected in the communications tests described in chapter 6 was used.

Initial tests were conducted for vehicle tracking and route graphing. For this, the data set of communication tests (phases 2 and 3) was stored in the respective tables of the database, as if the routes were being carried out by the vehicles in real time. Then, with the help of the Cloud Firestore listener, the change in vehicle positioning on the interface map is observed in real-time. In the case of routes, the API (Application Programming Interface) Directions Service of Google Maps was used, which allows graphing routes based on points or stops that are assigned in the form of a list of coordinates.

Figure 44 shows the result obtained. The orange markers correspond to the different OBEs that are operating, with their current location, while the red markers are the stops of the route. The route is presented in blue color.

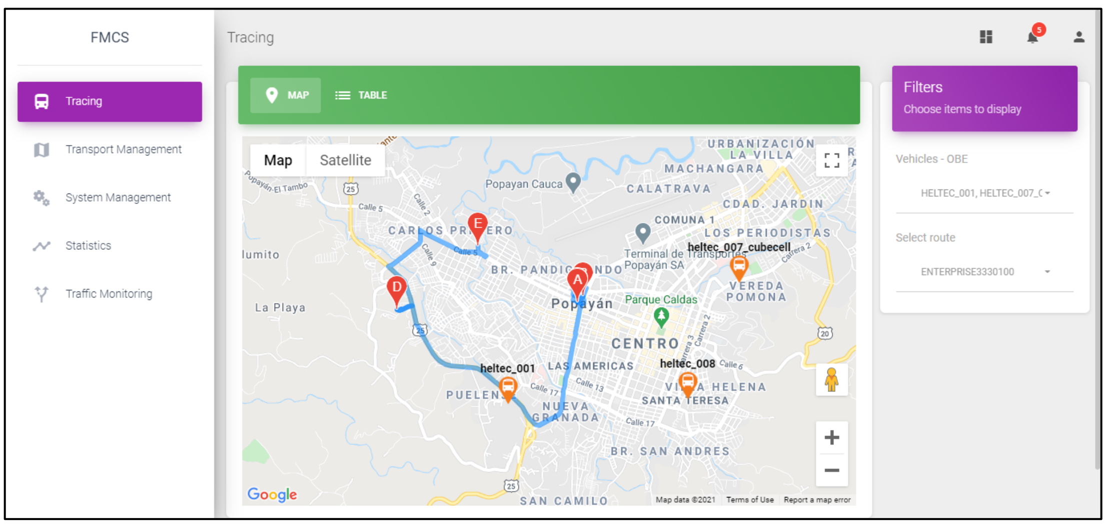


Figure 44: Web app testing – Tracing

For the creation and edition of routes, the API Directions Service was used again. In the Transport Management interface, the addition of points or markers on the map is allowed. The route is automatically generated and plotted by the service. For editing, the same API was used. In this case, the points can be moved at the user's freedom and more can be added as well. Then, the registered points are stored in the database and are graphed again. In **Figure 45** the result obtained for this functionality is shown.

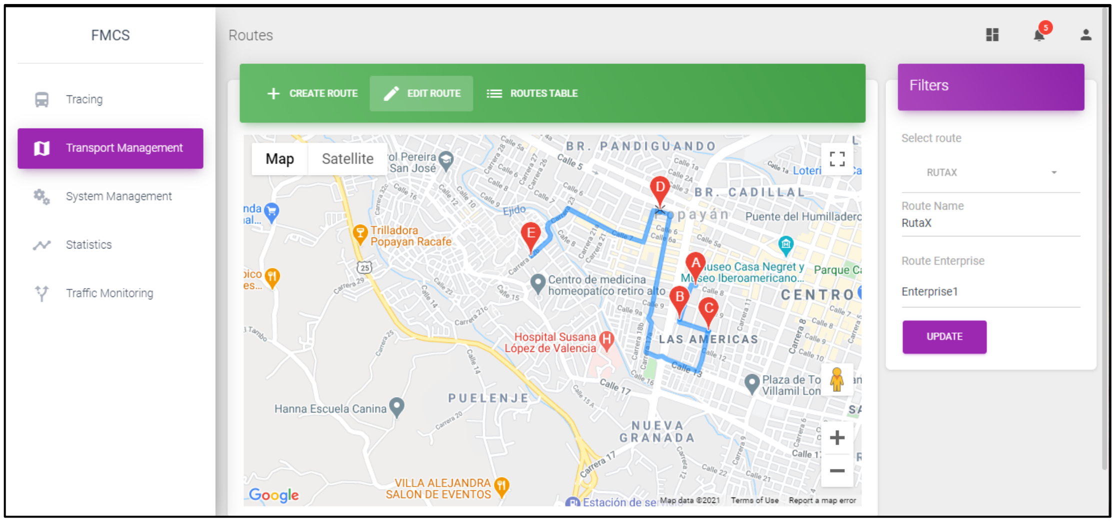


Figure 45: Web app testing - Transport management

Among the most relevant functionalities of the system, Traffic Monitoring is also included. This interface is divided into two operational tasks, the first is related to the real-time monitoring of traffic conditions (**Figure 46**), and the second is about the management of automatic route management based on current traffic (**Figure 47**).

The first operational task corresponds to markers differentiated by types of traffic alerts, which are provided by an external service (in this case, the alerts with POST requests are simulated and saved in the database).

The second operational task shows a list of the registered routes, from which it is possible select any, and later graph and manage with the help of Directions Service. In this case, an additional API functionality is requested (drivingOptions), which allows managing the route according to the monitoring of real-time traffic and the historical traffic that usually occurs between a certain range of hours of the day, this range of hours is sent to the API within the parameters of drivingOptions.

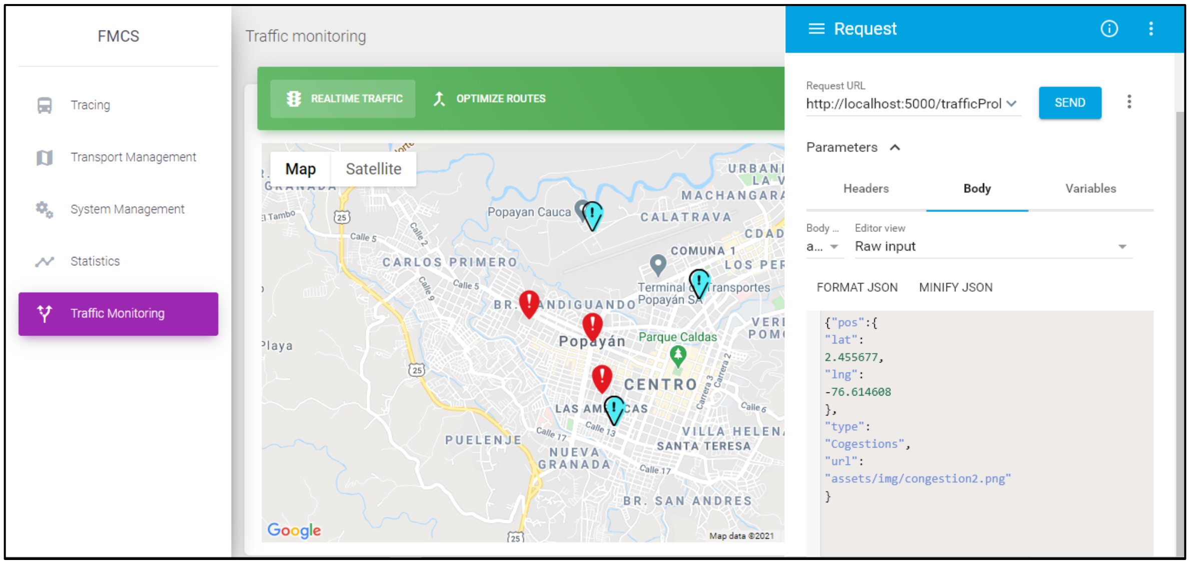


Figure 46: Web app testing – Real-time traffic

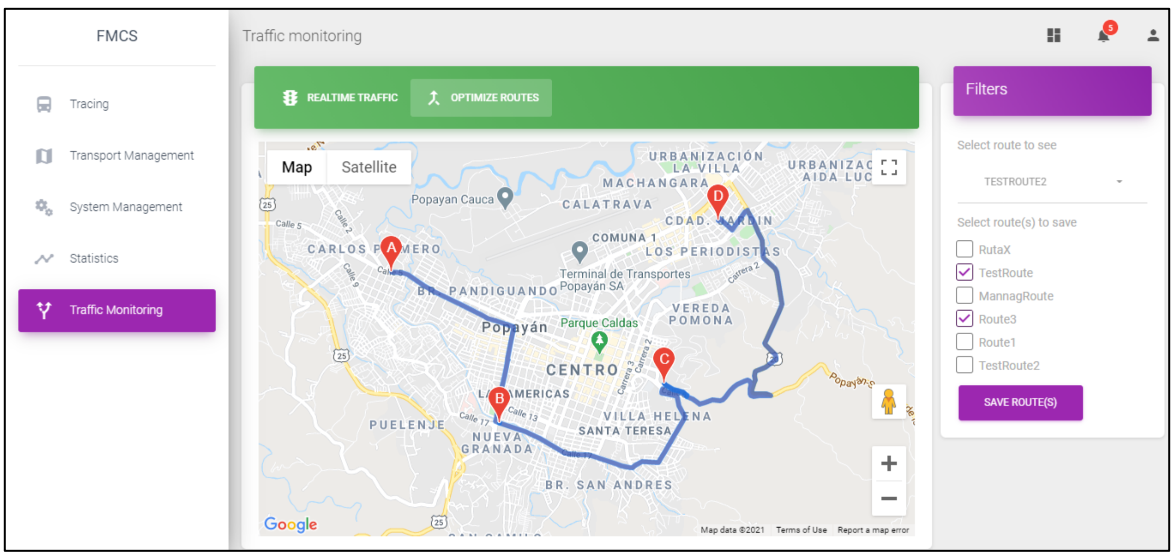


Figure 47: Web app testing - Optimizing routes

7.6 Conclusions

The Web application worked as expected, thanks to different tools integrated, for optimal visualization of the expected results. Firebase and Google Cloud Platform allow to detect changes in real-time and display them in the interface at the same time. However, there is a limitation with these two services, related to costs because their functionalities are limited to maximum number of daily requests.

The use of engines such as “Handlebars” can be very useful in terms of the performance and management of the application, because it allows working different parts of the application separately and also managing them according to the functions established with JavaScript. on the router.

The functionality integration of the prototype development unit was successful. It was possible to monitor and correctly graph the different OBEs, reproducing the behavior presented by the vehicles in the communication tests of the prototype (which was recorded in the data set).

8 CONCLUSIONS

In this final chapter, it is answered the research question posed in subsection 1.1.2, to later establish the main conclusions obtained from the study performed. Finally, some suggestions are made for future work.

So, to answer the research question: "How is it possible to improve the characteristics of the public transportation service called "collective" in cities such Popayán, regarding the management and control of vehicles, guaranteeing adequate standardization with other ITS services for the city?", initially, it was performed a review of the state of the art on the subject in question. For this review, a scientific mapping analysis was first performed, obtaining as relevant topics: security, ITS, public transport systems, wireless communication technologies, V2V communications, monitoring, and IoT.

Then, a systematic review was performed through the PRISMA methodology, taking in account the topics identified in the scientific mapping. According to this review, the principal characteristics for a development validation of an FMCS based on ITS services were identified. These characteristics include: low-cost and efficient communication technologies, use of services that allow interoperability with other mobility services, implementation of algorithms that guarantee confidence in the information that is handled and implementation of the proposal close to a prototype level.

Based on the characteristics identified, it was proposed an ITS architecture focused on an FMCS for a Colombian city of intermediate size, based on the American reference architecture ARC-IT. This architecture offers some advantages due to its characteristic of the distribution of obligations for different modules or entities of the system, which at the same time divides the workload and allows greater efficiency, likewise, facilitates the updating of various processes or technologies.

The designed ITS architecture proposed the use of LoRa technology and its LoRaWAN communication protocol, for which it was conducted a coverage study of this technology for the city of Popayán, from which it was obtained that the amount necessary of Gateways for total coverage of city was 13.

With the ITS architecture and the coverage study (of LoRa) it was designed a FMCS prototype unit development, including the OBE, the ITS roadway equipment, and TMC modules. Next, the prototype operation tests were performed (regarding communication system). These tests were performed in three stages; the first in a laboratory environment (with the majority of controlled variables); the last two stages in a semi-controlled environment using vehicles moving on the roads of the city of Popayán (selected as case of use). In good conditions of a stable feeding for the OBE, a high rate of reception of packages (88%), however, losses due to LoS should be considered, because they were very significant in areas where there is a lot of constructions. The records of the tests performed, in the final two stages, were collected in a data set, which was used to test the integration of the FMCS prototype and can be used in future work related to urban mobility.

Finally, it was designed and implemented the web application and database of the FMCS prototype development unit. A good response was obtained from the application made, due to the separation of functionalities and the use of micro-services, which allowed flexibility in processing and avoided overloading the application. To test the integration of the functionality of all the modules of the FMCS prototype development unit, as mentioned previously, the collected data set was used, which was allow the online simulation of vehicles operation. In this way, it was proven that the functionality developed (in the web application) met the requirements.

Thus, in this work, it was designed and implemented an FMCS based on an ITS architecture in the city of Popayán, with LoRa technology for communications, which offered an acceptable result in terms of vehicle monitoring and control and other factors that involve it, such as routes, users and public transport companies and that in terms of mobility, could contribute to improving it without high costs.

For future work, the prototype unit development could be tested on a larger scale, that is, with a greater number of Gateways and OBEs. Additionally, the proposed architecture could be used in the development of systems or services related to ITS in the city of Popayán or in cities with similar characteristics. Finally, the data set collected can be used by projects related to urban mobility (to simulate the routes made in the tests) or in projects related to the study of the use of LoRaWAN to analyze the results obtained and propose new tests and / or experiments.

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9 ANNEXES

This work has 12 annexes that allow a better understanding of the different topics presented, the following table presents a summary of each one of them together with a URL where the file can be accessed.

Annex	Name	Description	URL
A	Review article in Electronics Journal	This annex corresponds to the article published in the international journal "Electronics" (A1 in MinCiencias).	https://doi.org/10.3390/electronics9091383
B	SciMAT Analysis	It contains the information about all the steps performed to develop the scientific mapping analysis with the help of the SciMAT tool, it also contains the results obtained and their analysis.	https://drive.google.com/file/d/18cZIEESyrpBfTau3baUldasdRNjA8ulS/view?usp=sharing
C	SciMAT Configuration	It shows the configuration process for SciMAT.	https://drive.google.com/file/d/17_Wns1clL9wWXCmddR1rWyt9pw712V9c/view?usp=sharing
D	Systematic review	This annex presents the PRISMA methodology process, with a summary of all the documents obtained in each of the steps of the PRISMA flow.	https://drive.google.com/file/d/1hf75vuqT86vhBR1NvTlq7mCZ5FffK_y1/view?usp=sharing
E	Systematic Review - Synthesis - Description -	It is the main document obtained in the literary review. There is a summary of each of the articles that passed the	https://drive.google.com/file/d/1VjaQ4_EiAxIDtyoxUmxQZU3GF-

	Limitations - Revision tables	different filters, its limitations are analyzed and its revision tables are shown.	vfWul2/view?usp=sharing
F	Coverage zone analysis QGIS.rar	It contains all the necessaries files to build the coverage simulation.	https://drive.google.com/file/d/1KmwdRzPdM91IhyT5Wxe0a8X6YyP0vgPa/view?usp=sharing
G	Git repository	Presents the composition of the GitHub repository that contains all the software development information. Microservices, frontend and the programming files with Arduino for Heltec board.	https://drive.google.com/file/d/1r1Zv_c0WIzWQO7vd6k4GYD3CVdx83VmS/view?usp=sharing https://github.com/crissebasbol/fmcs.git
H	Dataset	It is the dataset obtained in the different tests performed. It is presented in json and csv formats.	https://drive.google.com/file/d/181FIsqer3f24jlSqTPk0_MG-w9kfJ8tf/view?usp=sharing
I	Dataset analysis	It presents the analysis performed with python to the dataset obtained in order to study the behavior of the prototype development unit.	https://drive.google.com/file/d/17ZjiCNb_31rPRuL94qCow6s5iZUdWqpa/view?usp=sharing
J	Dataset description	It contains a description of each of the variables found within the supplied Dataset. In the same way, a small analysis is performed on the data obtained with python.	https://drive.google.com/file/d/1poArUgcNXOYPwnkEDELPLn_3k2ryCNzx/view?usp=sharing
K	Scrum	This annex presents the different documents to carry	https://drive.google.com/file/d/1z1GwespJVJ8

		out this degree work using the Scrum methodology.	Atzk1l4WYT4IUqsf5UPtk/view?usp=sharing
L	Mockups	It is a file that must be imported into “Balsamiq Cloud” to be able to see all the interfaces in their initial design in a dynamic way.	https://drive.google.com/file/d/1IN_bZ-Qzw3PEXgB5m4ACSJm5YDQ3CD5G/view?usp=sharing