# Carsharing System for Urban Transport in Lima using Internet of Things

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Abstract: Carsharing has become a trend in the transport industry that has been growing exponentially in recent years and gaining popularity in large cities in Europe and Asia such as Madrid, Berlin, Amsterdam, among others. This work presents an implementation of a carsharing system that activates all the car's functionalities through an application without the need for additional elements such as cards, physical keys, etc. Likewise, being able to connect the car and mobile application through an IoT device and backed by a cloud infrastructure, it offers a new mobility modality that unites technology, in the city of Lima that is flexible, safe and affordable for most of the people; in addition to bringing to Peru the concepts of shared economy and uberization of things. We present that in Lima there is a very deplorable, disorderly and low-quality urban transport system generating many problems for users. The first alternative solution would be to acquire a private car, but for many people it is not accessible, especially for people between 20 and 45 years old, since it entails having a large budget that includes the cost of the car, maintenance, security permits, among others, that many people do not have in their entirety. We report such as Internet of Things, Cloud Computing and Applications Mobile, with an innovative technological architecture with new advances in the automotive field, such as electric cars.



## 1 INTRODUCTION

Nowadays, the traffic management systems in the world have struggled to keep pace with the relentless onslaught of vehicles that they have to deal with now and the disorganization of different types of public transportation, generating a big waste of time for citizens, especially in Latin-American cities like Lima.

According to a study by Universidad del Pacífico (Peru) and the Marketing Consulting firm for the peruvian newspaper "Gestion", the Lima citizens lose about 4 hours a day in transport and most of the trips in the capital are for work reasons[1]. Furthermore, according to a report by INRIX, published in the newspaper Gestión, 51% of Lima residents use public transport as a basic necessity. This is based on the fact that there is no flexible private transport alternative available in terms of usability, accessibility and price. In addition, in the same report it is mentioned that the taxi is a means of transport that is not very accessible for the majority of the population, being used by only 25% of the Lima population[2].

A solution to these problems could be the implementation of a new form of mobility such as carsharing, which is present in European cities such as Madrid, Paris, Rome, etc., but unfortunately these systems are not adapted to the reality and culture of a Latin American city like Lima. The implementation of a carsharing system in Lima takes on greater importance in the current context, since currently, according to the newspaper La Vanguardia, it is a flexible mobility tool. This is reflected in large cities, fitting in much better with new drivers who seek independence, autonomy and immediacy, but also savings, sustainability and comfort. In addition, having the smartphone as a connection through mobile applications and with an agile procedure, makes this type of mobility much more flexible for these drivers[3]. Implementing this in Lima means bringing new technologies and disruptive business models generating greater economic, social and technological development not only to the city but also to the country, futhermore managing to be a complement to the most modern transport systems such as the electric train, the Metropolitan or scattered road corridors in the city.

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[2] Gestión - https://bit.ly/2UlU0YM
[3] La Vanguardia - https://bit.ly/3iK5MVY



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Carsharing has a complex process for its implementation within a city due to two main factors: social and technological (Wang, 2018). On one hand, the social factor is fundamental since the place where it is implemented is required to be a developed or developing city. This is necessary due to the series of important accessories within the city such as parking lots, electric charging centers or gas stations, among others. Likewise, the reality of the city, its security level and the means of transport with which it would coexist must be taken into account. On the other hand, the technological factor is fundamental, since an advanced infrastructure and next-generation connections are necessary for this to work 100%.

This can include from wireless connection devices, mobile applications, 4G or 5G networks, among others, and above all, they provide highly reliable security to avoid risks.

Specifically, Lima is a complex city, but it is not impossible to implement a carsharing system, since there are more Internet of Things (IoT) developments in different aspects of the city. Nevertheless, the main problem is the current urban transport system due to its disorganization, informality, its non-integration among them and, above all, the little use of technology. Given this, a carsharing system would be a disruptor within Lima society, paving the way for the modernization of the city. However, this must be adapted to the reality of the city, which is totally different from large European cities, especially in terms of safety, operating processes, prices, and type of technology.

As mentioned above, implementing a carsharing system depends on different components. Taking European countries as a reference, this was implemented but with devices such as a key or a pin code. What is proposed now is the use of the cell phone, which through an application will be able to activate or block the selected car. For the implementation, a cell phone is required which is connected by Bluetooth to the IoT device in the car and a fast and stable connection to the internet.

Focusing on the application, it will be developed for the Android operating system. In addition, the language to use is Java with the Flutter programming framework. Regarding the connection with the car, an IoT device will be installed in the vehicle so that its mechanical and electrical system can be controlled in its entirety from the mobile device without the need for keys, cards, etc. The application is supported by the Amazon Web Services (AWS) cloud platform. For this paper, an Minimum Value Proposition (MVP) will be carried out to be able to test together with key users if this system becomes a viable alternative in Lima. Our contributions are as follows:

- We develop an Android carsharing application, which allows the user to reserve a car, show the user the fastest route to their destination and control the car wirelessly.
- We implement the technological infrastructure of the mobile application in the cloud using the services provided by AWS, applying the DevOps methodology and through an IoT device installed in the cars.
- We make experiments with the system through a series of tests with key users to be able to define through their experiences that this system could be an alternative in the urban transport system of Lima.

This paper is organized as follows. Section 2 discusses related work. Section 3 introduces the relevant concepts and defines the problem formally while Section 4 presents our approach and our development. This is evaluated in Section 5 after which we show the results of our experiments in Section 6, and we conclude in Section 7.

## 2 RELATED WORKS

In the first place, in (Boukhechba et al., 2017) the authors propose the development of a fleet electric vehicle system that works optimally and meets people's expectations, where according to different studies, different missing aspects were covered, such as the simulation of the cargo establishments and return policies, based on existing systems and in cities where this form of mobility is already established. In our case, we develop a carsharing system that meets different expectations, which differs from research, in a city where a similar or equal system has not been developed, taking into account the reality of a developing city such as Lima and the different deficiencies, all this through direct and focused investigations in the city in question.

Also, in (Lim et al., 2020), the authors presented a green logistics delivery framework with shared cars, based on IoT (Internet of Things) and using algorithms that allow travel optimization. The architecture included in the framework consists of a customer data layer, an information collection layer, a cloud optimization layer, and a delivery task execution layer. This shared delivery framework can provide customers with a more flexible delivery service. For our part, compared to what is proposed in this paper, we have implemented different algorithms that allow travel routes to be defined according to the current traffic collected by the API that we have integrated, seeking that the user can avoid wasting a lot of time in some unnecessary route; In addition, using a cloud architecture that ensures data consistency, high availability and where it gives us the possibility of monitoring cars in real time through Internet of Vehicles technology.

In (Min and Xing-Fu, 2020), the authors through a study of the theory in English ”Theory of Planed Behavior” or TPB (for its acronym in English) and in this the key factors required by a shared vehicle system were identified. The authors' study concluded with the series of steps to follow for the implementation of this system, because people do not usually opt for the carsharing system because they do not consider it a safe or convenient service. For this reason, the authors seek to change this idea by presenting a carsharing model that can be adapted to different needs. From this, we achieve this through the different social studies carried out in third-party works and generating a design at the user experience level very similar to the most used taxi applications in the country, generating greater users in tests confidence of use, also generating a simpler flow so that people who use it feel that it is a convenient mobility alternative to the traditional public transport system.

Finally, in (Wei et al., 2017), the authors presented a key exchange system for car rental or car sharing services based on the hierarchical signature, called HIBS-KSharing. This proposal is useful for company car rental services and also presents versatility to be adapted to the shared use of private owners vehicles. The proposal allows the electronic keys of invited users to be remotely issued, revoked and delegated by companies or owners. The end user will use their smartphones to access the vehicle using the NFC communication protocol. Compared to our research project, we use different keys that each device type and is unique, which are stored in our database and that allow that at the time of connection of our IoT device it can make a validation closer to the moment of access Likewise, the device that we use in cars makes use of the BLE communication protocol, which, compared to what was proposed by previous authors, usually takes a fraction of a second or more to identify and secure a connection, but it is considerably more versatile than NFC, thanks to its longer range; Furthermore, the data transmission speed is very different, as NFC barely reaches 424 kbit/s, while Bluetooth can exceed 20 MB/s. Finally, BLE is a technology that already exists in millions of smartphones, tablets and computers, so in that sense, BLE has already won a battle over NFC in the mobile market.

# 3 CONTEXT

Now we present a few concepts about our approach.

## 3.1 Internet of Things (IoT)

Internet of Things (IoT) (van Moergestel et al., 2016) refers to communication between the digital and physical world. It provides a wide infrastructure to provide services, such as the sending and receiving of information and interconnections through virtual elements. It consists of a set of sensors and radio frequency identification (RFID) technology that communicate over a network with various devices (Noori et al., 2020).

### 3.1.1 Bluetooth Low Energy (BLE)

Bluetooth Low Energy (BLE) also called Bluetooth 4.0 or Smart Bluetooth. BLE advertising beacons are particularly attractive because of the promise of long battery lives of many years, and so low maintenance requirements. Moreover, the low price of Bluetooth beacons (around 20$) represents an attractive solution for transmitting Smart Points of Interest data (SPOI) metadata. Beacons transmit a low-power signal that can be picked up by nearby Bluetooth-enabled mobile devices, including smartphones. They broadcast short-range signals that can be detected by apps on mobile devices in close proximity to a beacon (20–200 m) (Boukhechba et al., 2017).

### 3.1.2 Internet of Vehicles (IoV)

Internet of Vehicles (IoV) is a promising technology that can aid communication between vehicles on the road. IoV belongs to a special Mobile ad hoc Networks that enables communication between vehicles. Ad hoc network connectivity can be achieved through wireless communication devices installed in vehicles (Wang et al., 2020).

### 3.1.3 IoT World Forum Reference Model

This model can be considered as a multi-level system, which are detailed in Fig. 1 (Milenkovic, 2020).

This model is made up of 7 layers, each one with a different purpose:

- **Physical Devices and Controllers:** This layer refers to the sensors and devices that are managed by the IoT architecture
- **Connectivity:** This layer is the connection between the device and the Edge computing layer, this involves various communication alternatives and data transformation.


(a) IoT World Forum Reference Model (Milenkovic, 2020). (b) Our adaptation of IoT World Forum Reference Model.

Figure 1: Adapting the IoT World Forum Reference Model.

- **Edge Computing:** This is the computing layer where the conversion protocols will be implemented, the route for making latency decisions, among others.
- **Data Accumulation:** This layer where the incoming data is stored to be processed later.
- **Data Abstraction:** This layer where the information from the sensors or devices will be collected.
- **Application Layer:** This layer the application logic is executed.
- **Collaboration and Processes:** The last layer and where the processed data of the previous layers is presented to the end users.

As detailed, this layer-by-layer model achieves that both the IoT devices and the infrastructure with the services can take full advantage of it to achieve optimization together (Cocca et al., 2019).

## 3.2 Carsharing

To understand the carsharing, which you want to implement, you need to first understand two important terms:

### 3.2.1 Shared Economy

The collaborative economy called shared economy is a different way of acquiring goods and services. This alternative differs from the traditional business model of different corporations. In this, people rent goods such as homes or cars for a period of time. Once completed, someone else can use the same asset (Ruslan et al., 2020).

### 3.2.2 Uberization of Things

"Uberization" is known as the "killer" of intermediaries, since Internet technology platforms connect consumers with providers of goods and services. It allows you to perform several operations at the same time such as searching, ordering and paying. Today, "uberization" is spreading to various markets, such as financial and banking, medical, educational and commercial. It should be taken into account that the term appeared by the company Uber Technologies (Uber), known for developing a mobile application to call taxis faster and cheaper than the traditional one (Giniyatullin et al., 2019).

With both terms defined, you can better understand what Carsharing would be, is a form of shared mobility. Its system consists of a large number of vehicles distributed in a certain area that a person can access when making a payment. The cost depends on the duration of the trip and the distance traveled. Its main objective is to provide a service similar to that of a private transport (Sai et al., 2020).

# 4 CAR SHARING SYSTEM FOR URBAN TRANSPORT

In this section, we will take a total view of the entire development of the carsharing system, from the architecture to the development and commissioning of the application in connection with the IoT device.

In the first place, a research was made for the most appropriate technologies for the development of the systems such as Cloud Platforms to host the back-end and front-end of the application, as well as other resources such as databases, images, among others. Also, as the IoT device that will help us to carry out total control of the car. On one hand, a benchmarking (see Table 1) was generated with those that best suited the project requirements and, as mentioned in Section 1, the services of AWS will be used. On the other hand, for the IoT device, the Mobokey device from RoboArt, Inc. was used, which will allow us to have control of the mechanical and electrical system of the car.

For the creation of the benchmarkings, shown in Table 1, a search of 10 papers was carried out to obtain the alternatives and some characteristics of these platforms and two papers to carry out both the definition of the dimensions and the weighting of each of these. The 10 dimensions were defined, including: Scope, Storage, Mobile Applications, Certifications, Cost, Integration, Internet of Things (IoT), Migration and transfer, Networks and content delivery, Security, Usability. On the side of IoT Devices, in the same way, a search was carried out for 10 papers to obtain the alternatives and some characteristics of the devices and two papers to carry out both the definition of the dimensions and the weighting of each of these. The 8 dimensions were defined among them: Standards and protocols, Consumption, Compatibility, Connectivity, Usability, Cost, Security, Support. As mentioned above, the winning cloud platform was AWS and the case of the IoT Device is Mobokey.

Likewise, the Android application will be developed under the Google framework, Flutter, which will allow us to make the approval to iOS in the future. Based on this, the application architecture was designed under AWS services, which will help us, as mentioned in Section 1, to make the application serverless. In Fig. 2, the different AWS services that will be used in the development of the project are shown.

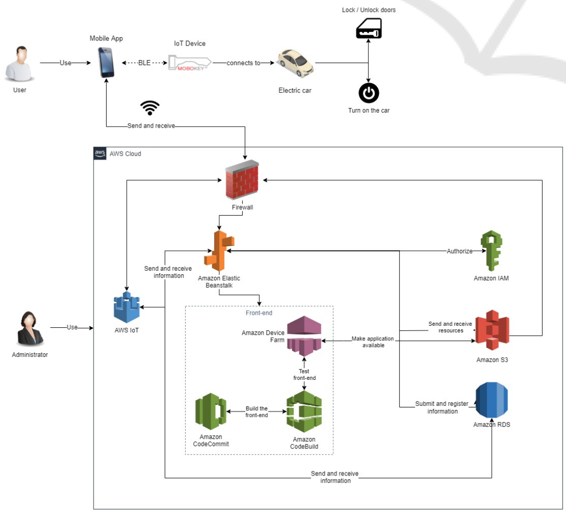


Figure 2: Application Architecture.

In the Fig. 2 we have Amazon RDS which will be where we will store our relational database and can be consulted by our back end. In the case of the Amazon ElasticBeanstalk service, it will be the one who executes our back end in a server-less manner with the API's necessary to obtain the information requested by our application. Likewise, Amazon S3 will be our storage for multimedia resources such as reference images of our cars, as well as images of driver's licenses. In addition to this, for our front-end deployments we will use the CodeCommit, CodeBuild and Device Farm services, to be able to bring from our repository, deploy, generate our APK and perform the tests. Finally, AWS IoT and Amazon DynamoDB will help us connect our IoT device to AWS and the collected data can be stored in a non-relational database in Amazon DynamoDB.

Followed by this, for the architecture to be considered as a mobile application architecture with IoT, it must comply with the layers stipulated in the IoT World Forum Reference Model, which is shown in more detail in Section 2. According to this, the architecture was modeled under the 7 layers of the reference model, complying with all the requirements. The adaptation of this model according to our proposed architecture is found in Fig. 1b.

As shown in Fig. 1b, in the Physical Devices and Controller layer is our IoT Device, in our Connectivity layer, there is the connectivity protocol of our device that as mentioned in Section 2 will be BLE, in the layer from Edge Computing and Data Accumulation is the AWS IoT service, in the Data Abstraction layer our two AWS services are positioned for each type of database, AWS DynamoDB and AWS RDS. In the Application layer, there are all the services that help our application run such as AWS Elastic Beanstalk, AWS S3, AWS CodeCommit, AWS CodeBuild, AWS DeviceFarm and AWS Cognito. Finally, in Collaboration and Processes you will find both the car and the Android smartphone. From this, we can confirm that the previously built architecture complies with the IoT World Forum reference model.

As previously mentioned, the mobile application was developed entirely under Flutter, where the user registration logic was generated, which allows that when the user registers, the specialized personnel of the application can verify that the income data is true and that it does not have serious or very serious traffic offenses, according to Peruvian legislation. In this way, an additional layer of security is generated so that traffic rules are not violated or there is a bad driver using our service.

In the case of the logic of the cost and the estimated time of the trip, the Google Maps Platform APIs were used where different variables traffic, time, route and places were obtained from the Maps, Routes and Places APIs, generating an algorithm that can give the shortest route to the destination, estimated

Table 1: Benchmarking (Cloud Platforms and IoT devices).

| Dimension | Weighting | AWS | Azure | Alibaba | GCP | SCP |
|---|---|---|---|---|---|---|
| Scope | 3% | 0.09 | 0.15 | 0.09 | 0.09 | 0.00 |
| Storage | 10% | 1.50 | 1.50 | 1.00 | 1.50 | 1.00 |
| Mobile apps | 4% | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 |
| Certifications | 3% | 0.60 | 1.05 | 1.20 | 0.45 | 0.75 |
| Cost | 5% | 0.65 | 0.55 | 0.50 | 0.65 | 0.25 |
| Integration | 10% | 0.50 | 0.50 | 0.50 | 0.50 | 0.00 |
| IoT | 20% | 12.00 | 11.00 | 8.00 | 12.00 | 8.00 |
| Migration and transfer | 15% | 2.25 | 2.25 | 1.50 | 2.25 | 1.50 |
| Networking and content delivery | 15% | 1.50 | 1.50 | 1.20 | 1.50 | 1.50 |
| Safety | 10% | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Usability | 5% | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| | Total | 20.94 | 20.35 | 15.84 | 20.79 | 14.85 |

time and cost of the service.

In the case of our IoT device, the Support team gave us access to their SDK and the respective documentation, where they mentioned that the SDK and API's were in Native Android, being more specific in Java, so the development team performed a Method channel in both Android and Flutter to link the Android activities and they can be executed through the app in Flutter, linking each of the activities or functions in Android with an asynchronous activity or function in Flutter, that is, the Flutter function waits for the response of the function on Android. In Fig. 3 the final version of the application is shown.

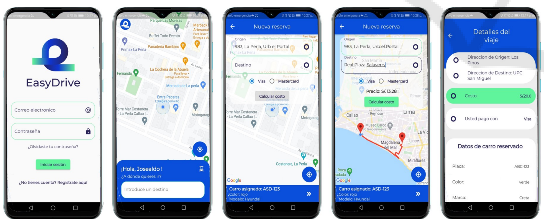


Figure 3: Application Interface.

As can be seen in Fig. 3, there is the final front-end of the application where the client can register in the application with a simple form to fill out with information such as name, surname, cell phone, identity document, driver's license, date of birth, email and password. After that, they register and go to an evaluation stage that should not take more than 3 hours, at that time the application administrator is alerted through an email, evaluates that the user meets the requirements described above, After evaluation, the user is accepted or rejected. If the user is accepted, they can log in to the application, where they can make a reservation to any part of Metropolitan Lima and choose the car closest to their location, showing the route, the cost and the estimated time of the trip and making the reservation. After that, the user must approach the car and be able to connect with the car, unlock the car or unlock the latches, start the trip where the vehicle will turn on and when the destination is reached the car will turn off and after a few seconds the carriage will lock completely. Followed by this, users will be able to view the details of their trip. Finally, users can also modify their profile, reset their password and view their travel history, as well as the administrator can register, activate and block users, and add new cars to the fleet.



## 5 EXPERIMENTS

In this section, the experiments carried out in this paper will be explained, starting from the experimental protocol and the results, as well as its discussion.

### 5.1 Experimental Protocol

For the development of the application, we used a laptop with a 64-bit Windows operating system, a seventh-generation core Intel i5 processor, with 8 GB ram (expanded to 24GB) and 2 TB storage was used. Also, on the side of the programs we use Android Studio with version 4.2.1, Flutter 2.0.1 as an SDK, Java 8 and Spring Boot 4.12.

The APK for our app is available at https://bit.ly/3iKLjRa

Table 2: EasyDrive VS. Current situation.

| | Variables | Now | EasyDrive | Reduction (%) |
|---|---|---|---|---|
| **Public Transport** | Average Waiting Time (min) | 12.00 | 1.30 | -89.17% |
| | Travel Time per single trip (min) | 59.00 | 37.00 | -37.29% |
| | Travel Time round trip (min) | 171.00 | 97.00 | -43.27% |
| **Taxi** | Average price per trip by taxi ($) | 5.05 | 4.00 | -20.83% |
| | Average price weekly taxi rides ($) | 50.51 | 40.10 | -20.77% |
| | Average price monthly taxi rides ($) | 204.29 | 151.14 | -26.02% |

*A trip is aroung 8.3km

## 5.2 Results

In this section, we will show the results of the two experiments developed in this investigation. In the first place, we will take into account the time and cost savings with respect to the two most used means of transport in Lima Metropolitana, which are buses or popularly called "micros o combis" and taxis. On the one hand, in the case of buses, only the saving in time will be taken into account, because in Lima bus transport is considerably cheaper than other means of transport, but the time that is invested is much greater in comparison to other means of transport. On the other hand, in the case of taxis, the economic savings will be taken into account, since the time is equal to or slightly greater than it would be in carsharing.

In principle, the annual report of the consulting firm Moovit Insights in the city of Lima[4] will be taken as base information for the case of buses, taking different variables such as: average waiting time in minutes, travel time per 8.3 km in minutes. Likewise, an own study was carried out to obtain travel time per 16.2 km in minutes. On the side of the experiment with taxis, the real prices obtained from the Cabify app were taken into account, one of the most used taxi applications in Lima, and the one generated by our application with the aforementioned algorithms, having a destination point same. As can be seen in Table 2, in the case of buses there is an 89.17% or 10.7 minute reduction in waiting time for the vehicle or at a bus stop. Likewise, the travel time for a single trip (8.3 km) has been reduced by 37.29% or 22 minutes using EasyDrive carsharing compared to buses. It has also been reduced by 43.27% or 74 minutes in travel time by 16.2 km. A dditionally, in the case of the comparison between carsharing and taxis, a reduction of 20.83% about 1.5$ was obtained in the average price of a trip of approximately 8.3 km using carsharing compared to taxi. There is also a reduction of 20.77% or 10.41 dollars in the weekly cost that is currently had by using taxi versus what would be spent weekly using carsharing. Finally, it was obtained with simulated data, based on the information previously extracted, that monthly there would be a reduction of 26.02% or 53.14 dollars in the cost of using a taxi twice a day versus the cost of using carsharing.

Second, functional tests were carried out with Lima citizens within 20 and 55 years of different districts of Lima, who tested the application and responded to a survey taking into account the user experience they had in this test, taking into account different variables such as:

- For the question "Do you think that carsharing could help you to move to your workplace, your study center or some other private place?". 8 people responded that carsharing can help them to move in their daily activities. Therefore, it is concluded that the service would be consumed by the vast majority of inhabitants of Metropolitan Lima belonging to our target audience.
- For the question "If the service were available today, would the carsharing system be a primary or complementary transportation alternative to other modes of transportation?". 6 people responded that if the service were available today it would be the main one they would use compared to other means of transport and 2 that it would be complementary to these. Therefore, it is concluded that the use of the service would be mostly used as the main means of transportation.
- For the question "Based on your experience and the Peruvian reality, do you consider that carsharing could be a viable alternative for the Urban Transport System of Metropolitan Lima?". 8 people responded that according to the current reality, carsharing would be a viable alternative to the urban transport system of Metropolitan Lima. Therefore, it is concluded that the proposed service would have great viability in the Lima population of the proposed age range.

[4]Moovit Insights - https://moovitapp.com/insights/en/Moovit_Insights_Public_Transit_Index_Peru_Lima-1102

### 5.3 Discussion

As could be seen in the previous section, the results presented in the first experiment (See Table II) show that with the use of the application, a person can save up to 43.37% of the time in trips through public transport in Metropolitan Lima, this being a great contribution to users since it is the transport where people waste more time. Additionally, compared to one of the most used alternatives to the well-known buses in Lima, taxis, users would save an average of 20.77% on the monthly cost that they currently use taxis for trips of approximately 8km.

On the side of the experiment with end users (See Fig. 5-9), the results show that the application has as its main attribute functionality and development innovation, obtaining 75% approval by the respondents. Likewise, end users agree that the carsharing application could become the main means of transport, succeeding in completely replacing it, and to a lesser extent complementing it with some means of transport. Finally, the results obtained show that users consider that the carsharing application has a clear viability in the city of Lima Metropolitana.

## 6 CONCLUSIONS

Based on the research, it is concluded that a carsharing system is feasible to be implemented in the city of Lima Metropolitana, becoming an alternative to the city's Urban Transport System, based on the experiments both with Lima citizens and through the comparative with studies carried out in the city. Likewise, one of the main attractions for the use of the application by the users who participated in the experiment is the cost, since with the algorithm developed the saving in time and money is considerable compared to other transport alternatives.

Finally, it is proposed that in future research, an integration of the project is carried out in conjunction with artificial intelligence, helping to further enrich the different algorithms that provide more optimal routes and suggestions to the needs of users. In addition, the implementation of a security model aimed at carsharing applications is proposed where the components of this will be analyzed both at the application, data and technology level involved (Bangui et al., 2018) and similarly to health applications (Jorge-Lévano et al., 2021). Finally, this type of service could be expanded to other means of transport and not focus only on cars. For example, join motorcycles, bicycles in conjunction with cars to meet the needs of a larger group of users.

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