ISBN: 978-628-95207-8-1. ISSN: 2414-6390. Digital Object Identifier: 10.18687/LACCEI2024.1.1.105

Improvement of the Public Transport Route for Line 7103 in Lima: Reduction of Travel Time

Marcelo Fabian Garay Naveros
(0000-0002-1688-2197)
Facultad de Ingeniería Civil
Universidad Peruana de Ciencias Aplicadas
Lima, Perú
u201819073@upc.edu.pe

Renzo Daniel Jiménez Ramírez
(0000-0002-8303-8869)
Facultad de Ingeniería Civil
Universidad Peruana de Ciencias Aplicadas
Lima, Perú
u201619530@upc.edu.pe

Fernando Mauricio Tarquino Torres
(0000-0002-6635-8406)
Facultad de Ingeniería Civil
Universidad Peruana de Ciencias Aplicadas
Lima, Perú
pcciftar@upc.edu.pe

***Abstract*— The primary objective of this research wasto propose a modification to the current route of bus 7103, in order to decrease the total travel time for the users. The methodology employed was based on the application of the Bureau of Public Roads (BPR) function to calculate travel times for both the original route and the segments proposed by this study. These proposed sections are chosen with criteria based on their proximity to potential commercial areas, minimizing deviation from the original route, avoiding significant impacts on the circulation of other vehicles, among others. The main results revealed that the current total travel time is 245minutes, whereas the proposed route would have an estimated time of 228 minutes, representing a reduction of 17 minutes, equivalent to a 7% decrease.**

***Keywords*—Urban public transportation; Line 7103; Travel time; Bureau of Public Roads; Route redesign**

I. Introduction

Starting from the 1960s, the landscape of public transportation in Lima underwent a transformation marked by the prevalence of informal actors offering services with notably low quality standards. This situation was strongly influenced by the drastic demographic growth of the city which, from the period of 1960 to 1990, witnessed a population increase from less than two million to over six million inhabitants. The demand generated by this significant population growth encouraged the proliferationof mini buses from the 60s onwards, initially operating in peripheral areas neglected by the formal public transportation system, represented by Empresa Nacional de Transporte Urbano (ENATRU) and a small group of authorized companies. These mini buses eventually encroached upon routes in the urban center, directly competing against the formal system. To carry out these operations, mini buses organized into committees of transporters, maintaining operational costs considerably lower than those of ENATRU and formal private companies, as their workers were not registered and evaded the established regulations for the activity [1].

Currently in Lima, the capital of Peru, it is commonfor citizens to face a significant loss of time when using the bus public transportation system, both formal and in formal. This inefficiency translates into delays at stops as well asduring journeys, causing a widespread problem. In fact, 38% of Lima's inhabitants lose around 1.5 hours daily stuck in traffic, resulting in a significant economic loss estimated at 3.02 billion dollars annually, according to the Peruvian Automotive Association [2]. Nowadays, ENATRU no longer exists, and public transportation in Lima and Peruis predominantly characterized by informality.

The negative impact is reflected in the time Lima citizens dedicate to public transportation, with an average of 59 minutes daily, a high figure compared to other Latin American cities [3]. Even more concerning is that 34% of citizens spend more than 2 hours a day using these means of transportation. This traffic congestion, with its resulting delays, substantially affects the quality of life of Lima's inhabitants, identified as one oftheprimaryproblemsinthe city according to a survey conducted by the "Cómo Vamos" observatory [4, 5].

In this context, the public transportation line 7103 operated by E.T. Machu Picchu S.A. stands outasasubject of study due to being one of the longest with the highest duration of travel [6]. The proposal addresses this issue, considering the operational schedule of the line and its current route, with the objective of suggesting modifications and/or stops that would enhance users' time utilization and thus improve the efficiency of the public transportation system in Metropolitan Lima.

II. FRAMEWORKANDMETHODOLOGY

A. Framework

A.1. ServiceRestructuring

The restructuring of the transportation infrastructure focuses on ensuring efficient mobility for those who depend on this service, considering the analysis of availability and necessity, ease of access, interconnection, among other aspects. [7]

To address the current issues and delays on the selected route in a technical manner, it is essential to conduct a detailed analysis of the situation. This includes identifying in-depth the factors contributing to the delays and the technical aspects that can be corrected to enhance the system's performance. This approach aligns with the other recommendations of the Transportation Cooperative Research Board (TCRP) [8], which advocates for a holistic approach to addressing challenges in public transportation.

A concrete example of successful restructuring is evident in the city of Riobamba [9], as shown in Figure 1, where significant changes were implemented in the public transportation service. The primary goal of this restructuring was to enhance accessibility and the quality of public transportation in the city. Through route optimization and the implementation of more efficient services,aremarkable transformation in user experience was achieved, reducing delays and improving mobility throughout the city.

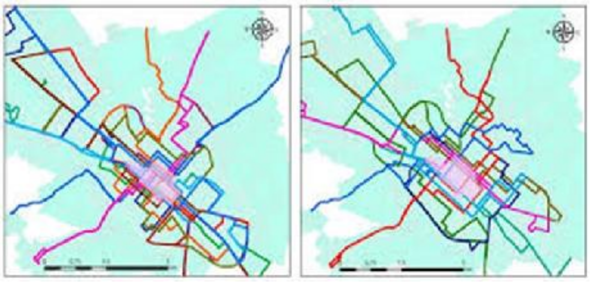

Fig 1. Restructuring of a Public Transportation Network. Adapted from "Rediseño de rutas de transporte urbano aplicando sistemas de información geográfica caso: Riobamba"

A.2 TravelTime

The complete time interval of a journey encompasses the moment when one departs from the origin point until the moment of arrival at the destination point. In the case of public transportation systems, this journey can be considered in various phases: the time spent walking to the boarding point or station, the waiting period, the duration of the actual transit, and the time used for walking to the final destination. [10]

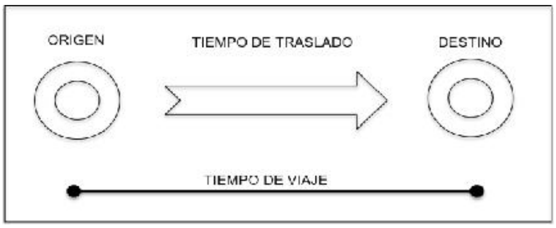

Fig 2. Total Travel Time

A.3 Stops and Spacing

Establishing stopping points, also known as busstops, within a transportation system plays an essential role in providing this essential public service. For this reason, it is imperative to consistently define variables such as the quantity of these stops and their strategic placement. From a certain perspective, having a large number of stops can be certainly beneficial for users, as it enhances accessibility, there by attracting new passengers and meeting current needs [11]. However, this circumstance also entails a greater time investment in public transportation due to the involved waiting periods.

It is worth mentioning that, according to the TCRP-Report 19 [12], it is also noted that the arrangement and spacing between stops will be conditioned by their specific conditions, and it is estimated that, forurbanareas,a separation of 500 to 1200 feet between stops remains viable, with an average of 750 feet.

A.4 BPR Function

The Bureau of Public Roads (BPR) function is a widely employed mathematical model in the field of transportation, known for its balance between simplicity and utility [13].It yields the travel time as a result, which is influenced by a series of variables and factors, presented as follows.

Therefore, the calculation of travel time for a segment of the network (T_f) is established using the Equation 1:

$$T_f = T_0 \left[1 + \propto \left(\frac{v}{c} \right)^{\beta} \right] \quad (1)$$

Where:

- T_f refers to the time required to traverse the segment in question.
- t_o denotes the time required to travel the segment under optimal traffic flow conditions.
- v corresponds to the volume of vehicles passing through the segment in an hour.
- c represents the maximum capacity of the road, i.e., the number of vehicles it can accommodate.
- α is defined as the ratio f the flow rate at optimal conditions to the flow rate at congested situations.
- β reflects the rate at which vehicle speed decreases as the volume-to-capacity ratio increases.

In relation to the specific values of $\alpha$and β, these are parameters that can theoretically be adjusted to suit each particular case. Based on the characteristics and type of road under analysis, it is possible to determine the appropriate values for α and β. However, in practice, standard numerical data exist for these parameters that over time have proven reliable in terms of accuracy. In this context, the values proposed in the "Plan maestro de transporte urbano para el area metropolitana de Lima y Callao en la República del Perú" in 2005 will be used, as they closely resemble our current local reality [14]. These values are presented in Table 1.

Table1

Values of α and β for the BPR Function

Road	Capacity	α	β
Arterial	1200	3.75	3.35
Collector	960	1.1	3.2
Metropolitan Expressways	1400	2.55	2.65
Regional Expressways	1400	2.55	2.55
Local Roads	940	1.38	2.35

B. Case study

The study route is Line 7103, which is currently operated by E.T. Machu Picchu S.A. This line starts in the Chorrillos district and reaches its final point in the Carabayllo district, crossing 13 districts in total. It has 158 stops [6] and covers a total length of 56.4 km. This is illustrated in Figure 3.

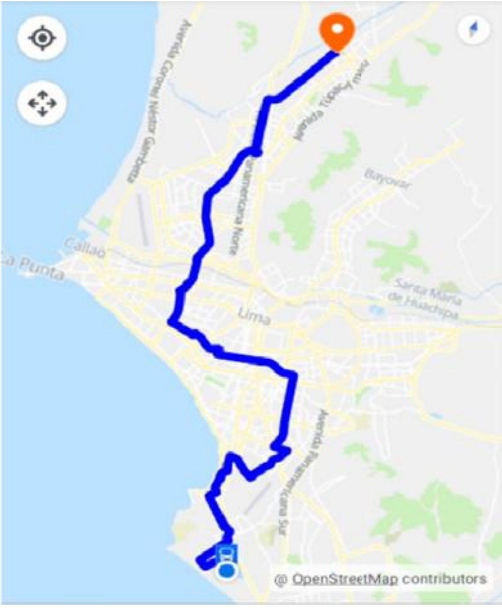

Fig 3. Route of line 7103.

This is one of the longest urban bus routes in the entire Lima department, resulting in extended travel times for passengers and, in turn, creating the perception among users that they are spending more time than necessary in their transportation from one place to another. Table 2 presents the main characteristics of the mentioned line, with data gathered in November 2022.

Table2

Characteristics of Line7103

Characteristics	Line 7103
Operating Schedule	6:00 am-11:0 0pm
Fleet of Buses in Service	30
Route Length (mi)	35.1
Total Travel Time (min)	245
Commercial Speed (km/h)	8.6
Frequency (min)	16
Price Range ($)	0.28 cent - 2.1 dollars
Average Passengers per Trip	410

C. Methodology

First, multiple trips were conductedonLine7103buses, from the starting point to the final destination, to collect relevant field information, with the key data outlined in Table 2. After this, the most significant segments will be selected, primarily where there's notable passenger demand, either due to high or low values. Following this selection, route modifications will be executed in the chosen segments. This will also involve determining the location of new stops, considering factors such as proximity to local businesses, utility services, among others, as suggested by [15].

Subsequently, after the proposed changes are defined, the BPR function will be applied to estimate travel times, enabling a comparison between existing and proposed segment times. For obtaining the necessary values tousein formula (1), the following data sources will be utilized: The value of travel time for the link at free-flow speed will be obtained through field measurements and corroborated with theoretical information. The value of the road capacity will be derived from existing theoretical data, and vehicle volume will be measured in the field. For the values of α and β, the data from Table 1 will be employed.

III. IMPLEMENTATION OF THE STUDY PROCESS

It's important to high light that both the outbound and return routes are practically the same. For the return trip, the bus has to make minor detours in a couple of sections, since those roads do not allow vehicular traffic in both directions. These small changes do not occur in the same sections that will be detailed below, which is why the outbound and return routes are considered as a single entity to be addressed. Therefore, the most significant segments have been identified in order to propose modifications. Specifically, five sections have been selected along the entire route, which are of particular importance.

Section 1:

Based on the collected data, it can be observed that in the stretch between stops number 3 (Aruba station) and number 7 (Alameda Sur Ave.), none of the conducted trips recorded a passenger flow of more than 2 passengers boarding or alighting from the bus at these points. Due to this marked reduction in passenger presence, this segment has been identified as the primary candidate for modification, as passenger demand is minimal. Figure 4 illustrates the current situation of this initial part of the route, showcasing the present scenario as well as the proposed changes.

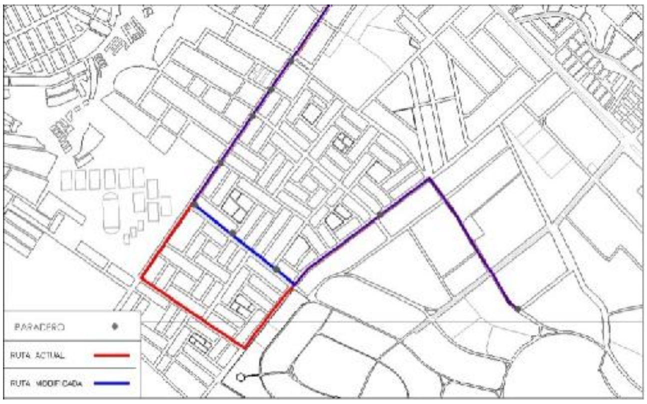

Fig 4. Redesign Proposal: Section 1.

Section 2:

Similarly, the process is repeated throughout the route, leading us to identify the second segment susceptible to modification. This stretch spans from stop number 54 (Estación Ayacucho) to number 57 (Óvalo Higuereta). In this scenario, there is a considerable passenger flow disembarking at stop 54 in all trips, thus this stop will remain unchanged. However, the subsequent stops in this section show low demand both for boarding and alighting passengers. Figure 5 depicts both the current and proposed routes.

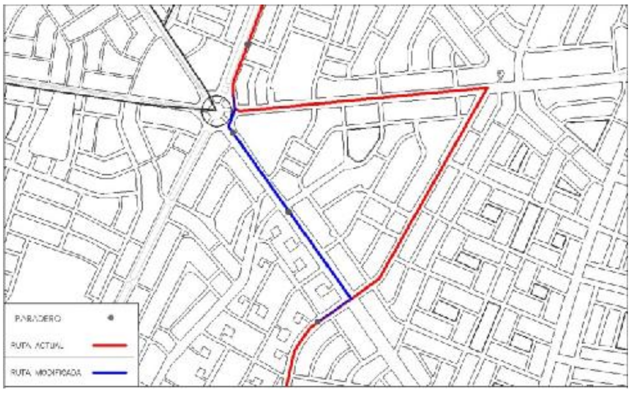

Fig 5. Redesign Proposal: Section 2.

Section 3:

The third segment with modification potential has been evaluated along Juan Pardo de Zela Avenue, spanning from its intersection with Paseo de la República Avenue to its intersection with Arenales Avenue; this continues along Cesar Canevaro Avenue, ranging from its intersection with Arenales Avenue to its intersection with Guillermo Prescott Avenue. In this case, the intention is to carry out adjustments to the stops, as in most of them, the passenger flow has been fewer than 4 individuals. Figure 6 provides a current visualization of this selected third portion, highlighting the stops to be removed in order to achieve a more even distribution and avoid inconvenience to users.

Fig 6. Redesign Proposal: Section 3.

Section 4:

The next segment to consider for adjustments spans from stop number 127 (Antúnez de Mayolo) to number 133 (Marañón). This stretch ontherouteappearsasasignificant detour, as the passenger flow, both for boarding and alighting, is relatively low. Additionally, it's note worthy that the 4.1 km distance is covered in a 20-minute interval, resulting in a commercial speed of 12.3 km/h, a relatively low figure.

In line with the methodology employed in the analysis of previous sections, it has been decided to replace the segment that traverses Antúnez de Mayolo Avenue with a route that continues along Universitaria Avenue. Figure 7 provides a visual representation of this selected fourth section.

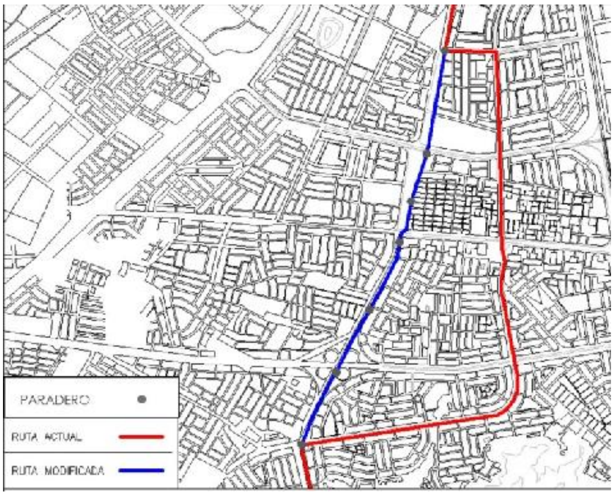

Fig 7. Redesign Proposal: Section 4.

Section 5:

Analogously to the third segment, following the pattern of low passenger traffic both boarding and alighting at stops towards the end of the route on the Trapiche highway, the decision has been made to eliminate the last two stopping points. This choice is supported by the consistent observation, in all conducted trips, that fewer than 2 individuals disembark at these stops. Figure8 illustrates the implemented change.

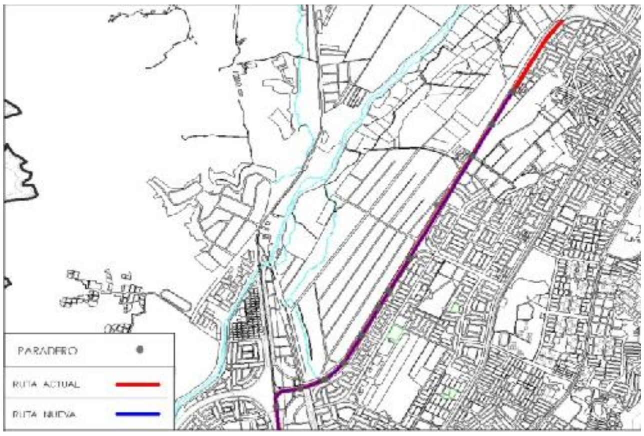

Fig 8. Redesign Proposal:Section 5.

IV. CALCULATIONS AND RESULTS

Once the modified segments have been defined, the next step involves evaluating the travel time that each of them provides, thereby assessing whether the proposed changes indeed offer lower values. Based on this, the BPR formula is applied to each of the 5 proposed segments.

Before using the formula to analyze travel time in the selected segments, two key considerations are taken into account. Firstly, the formula cannot be directly applied tothe entirety of the proposed segment; instead, for more accurate precision, it will be used for each individual arcthat makes up the segment, where arcs correspond to distances between stops. Secondly, the formula will be initially applied to the current conditions of the route, allowing a comparison between actual travel times and calculated theoretical times.

Section 1:

Then, substituting the data into the BPR function described in equation (1), between stop 1 and stop 2 of the current route, the following is obtained:

$$T_f = 1.98 \text{ x } [1 + 3.75 \left(\frac{368}{1200}\right)^{3.3}]$$

$$T_f = 2.1216 min$$

Applying the function between stop 2 and stop 3 of the current route:

$$T_f = 1.30 \text{ x } [1 + 3.75 \left(\frac{368}{1200}\right)^{3.3}]$$

$$T_f = 1.3930 min$$

Applying the function between stop 3 and stop4 of the current route:

$$T_f = 0.54 \text{ x } [1 + 3.75 \left(\frac{368}{1200}\right)^{3.3}]$$

$$T_f = 0.5786 \, min$$

The same process is followed to cover all the arcs that constitute the respective segment. Subsequently, in Table 3, the data summarizing these results numerically for the entire first segment of the current route a represented. In this case, the road in question is an arterial type, therefore the values of alpha and beta for the BPR function are 3.75 and 3.35, respectively.

Table3

Application of the BPR function for the first segment of the current route

Segment between stops	Arc length	τo (min)	V	C	Calculated travel time (min)
1-2	990	1.98	368	1200	2.12
2-3	650	1.30	368	1200	1.39
3-4	270	0.54	368	1200	0.58
4-5	450	0.90	368	1200	0.96
5-6	160	0.32	368	1200	0.34
6-7	230	0.46	368	1200	0.49
7-8	160	0.32	368	1200	0.34
TOTAL	2910				6.24

The theoretical travel time value is 6.24 minutes. Regarding the actual value, the average value of the completed trips indicates that the time taken to traverse this segment is 6.67 minutes. The percentage variation is 6.88%, suggesting that the margin of error is relatively small. The application of the BPR function continues, but this time for the proposed route, with results shown in Table 4.

Table4

Application of the BPR function for the first segment of the current route

Segment between stops	Length (m)	τo (min)	V	C	Calculated traveltime (min)
1-2	990	1.98	368	1200	2.12
2-3	610	1.20	368	1200	1.31
3-4	260	0.52	368	1200	0.56
4-5	220	0.44	368	1200	0.51
TOTAL	2080				4.50

The resulting value indicates that the proposed first segment would be completed in 4.50 minutes, instead of the 6.24 minutes obtained through the formulation.

Regarding distances, applying the proposed changes reveals the variation in lengths, as shown in Table 5.

Table5

Comparison of lengths with the proposed changes

	Current route distance(m)	Proposed route distance (m)	Reduction (m)
Change 1	2910	2080	830
Change 2	1960	800	1160
Change 3	2833	2833	0
Change 4	4052	2925	1127
Change 5	5575	4895	680
Total	17330	13533	3797

Regarding travel times, the variations in times with the proposed changes are shown in Table 6.

Table 6.

Comparison of times with the proposed changes, rounded to the nearest integer.

	Current route distance(m)	Proposed route distance (m)	Reduction (m)
Change1	6	5	1
Change2	4	2	2
Change3	14	9	5
Change4	15	9	6
Change5	23	20	3
Total	62	45	17

The same procedure was performed for the following 4 segments. Upon completion of this process, significant improvements are observed in three main factors: distance, travel time and bus frequency.

Finally, we have the bus frequency, in other words, the time a user waits at the bus stop for the next bus to arrive. From the field data, it is known that the route in questionhas a total fleet of 30 buses; at the beginning of theworkday, 15 buses depart from Chorrillos towards Carabayllo. So, by applying Equation (2), the current frequency of bus service is obtained.

$$C \quad b \quad f = \frac{T \quad ti \quad (m \quad)}{n \quad o \quad b} \qquad (2)$$

$$C \quad b \quad f = \frac{2 \quad (m \quad)}{1 \quad b} = a \quad 16\, m \quad / b$$

In accordance with the proposed changes and thereduced travel time indicator mentioned earlier, a new calculation can be made to determine the new busfrequency, which would be found as follows (Equation 3)

$$N \quad b \quad f = \frac{T \quad ti \quad - ti \quad s \quad (m \quad)}{n \quad o \quad b} \qquad (3)$$

$$N \quad b \quad f = \frac{2 \quad -1 \quad (m \quad)}{1 \quad b} = a \quad 15\, m \quad / b$$

Table 7 provides a comparative analysis of these three primary attributes between the current route and the proposed redesign.

Table7

Comparative data of the current situation versus the proposed changes.

	Current Route	Proposed Route	Difference (Δ)
Travel time (min)	245	228	17
Route distance (km)	56.4	52.6	3.8
Bus Frequency	16	15	1

V. CONCLUSIONS

The proposed redesign for bus line 7103 promises a significant reduction in travel time, marking a notable 6.94% improvement in public transportation efficiency per trip; this is equivalent to a savings of 206.8 hours per year for the user. Through strategic adjustments to the route, such as the elimination of unnecessary stops and distance reduction, not only do direct users benefit, but it also has a positive impact on the city's overall mobility. However, when applying the BPR function, it is revealed that on longer stretches, the theoretical travel time result diverges from real values, indicating the need to consider additional factors in the modeling.

Furthermore, the number of stops has been reduced from 158 to 148. This certainly represents a key factor in the pursuit of reducing travel times, as fewer stops equate toless time spent decelerating and stopping. Additionally, another consequential advantage is the improvement in the vehicle's average speed, resulting in greater efficiency in the journey. The reduction of stops is a useful technique that, however, should not be overused, as a balance needs to be struck between it and passenger demand.

An additional consideration points to common practices in Peruvian cities, where bus drivers often do not respect official stops. This bad habit increases the total travel time and leads to traffic congestion. Hence, the importance of enforcement and control measures is emphasized to ensure the effectiveness of any route improvement and the optimization of the transportation system as a whole.

Lastly, there are external factors that also play a crucial role in users' travel times. These external factors en compass aspects such as the quality of road infrastructure, the level of congestion on roads, and inappropriate driving practices by company drivers. These elements have a significant impact on each user's travel experience and, therefore, also influence the perception of value in relation to travel costs.

VI. REFERENCES

[1] Poole-Fuller, E. (2017). ¿Hacia unamovilidadsustentable?Desafíosde las políticas de reordenamiento del transporte público enLatinoamérica. El caso de Lima. Letras Verdes, Revista Latinoamericana de Estudios Socio ambientales, (21), 4-31. Doi:http://dx.doi.org/10.17141/letrasverdes.21.2017.2445

[2] Asociación Automotriz del Perú, (2022). Costo económico causadopor la congestión vehicular. Retrieved fromhttps://aap.org.pe/observatorio-aap/costo-economico/CostoEconomico-caudo-por-la-congestion-vehicular.pdf

[3] Moovit Insights, (2020). Estadísticas de transporte público en Lima.Retrieved from: https://moovitapp.com/insights/es/Moovit_Insights_%C3%8Dndice_de_Transporte_P%C3%BAblico_Per%C3%BA_Lima-1102#commute-time

[4] Bravo, A. (2019). La congestión vehicular de Lima: Cuando y donde menos lo esperas. Económica. Retrieved from https://economica.pe/la-congestion-vehicular-de-limacuando-y-donde-menos-lo-esperas/

[5] Lima Cómo Vamos (2018). IX Informe de percepciónsobrecalidadde vida en Lima y Callao. Retrieved fromhttps://www.limacomovamos.org/wp-content/uploads/2018/12/EncuestaLimaComoVamos2018.pdf

[6] Moovit (S.f.). Línea 7103. Retrieved from: https://moovitapp.com/index/es-419/transporte_p%C3%BAblico-line-7103-Lima-1102-1102744-681209-1#:~:text=La%20primera%20parada%20de%20la,es%20de%20aproximadamente%20150%20minutos.

[7] Palaguachi J., Arellano M., Villa R., & Paucar G. (2020).Rediseñode la red de transporte público urbano de la ciudad de Riobamba,provincia de Chimborazo. Mkt Descubre, 2019, 207-218. Doi:10.36779/mktdescubre/v%23.%23

[8] Transit Cooperative Research Programme (2004). Bus routing andcoverage. The national academies press. Doi :https://doi.org/10.17226/23330

[9] Espindola, O., Londo, F., & Sánchez, N. (2019). Rediseño de rutasde transporte urbano aplicando sistemas de información geográficacaso: Riobamba. *Explorador digital*, 3(3.1), 19-29. DOI:https://doi.org/10.33262/exploradordigital.v3i3.1.862

[10] García-Schilardi, M.,(2013).Transporte público colectivo: su rol en los procesos de inclusión social. Bitácora 24, 2014(1), 35-200

[11] Schobel,A.(2006).Optimization in public transportation. Springer.

[12] Transit Cooperative Research Programme (2019).Guidelines for the Location and Design of Bus Stops. Retrievedfrom:https://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_19-b.pdf?fbclid=IwAR1wGMHzk6PyIpyU_yJHjY7FYtu53a9M2DeE52SuFk0z8VWTQl6mBHcqUlc

[13] Carbonel, E. & García, Sa. (2020). Calibración de la función bpr en vías colectoras de lima metropolitana, basada en el caso de laAvenida San Luis [Thesis]. Universidad Peruana de CienciasAplicadas.

[14] JICA (2005). Agencia de Cooperación Internacional de Japón.*Planmaestro de transporte urbano para el área Metropolitana de Lima y Callao*. Ministerio de Transportes y Comunicaciones de la República del Perú.

[15] Verma, A. & Ramanayya, T. (2015). Public transport planning and management in developing countries.CRC Press.