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Design Of A Circular Express Route With Limited Stops Derived From A Conventional Route For The BRS System

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Abstract **-** Urban public transport congestion reduces user quality of life and system efficiency, posing a major challenge for growing cities. This study designs an express route in a Bus Rapid Service (BRS) system using TransCAD macro-simulation. A model based on origin-destination (OD) data reflects current conditions. The proposal introduces a mid-route turn to optimize West-East trips, where demand is higher, and distance is shorter. Simulation results show a 13.98% reduction in West-East travel time and a 20.19% reduction in East-West travel time. Express routes supported by advanced tools can improve operational efficiency and user experience in public transport.

Keywords**:** express bus route, rapid bus service, mid-route turn, public transport, transport demand.

1. Introduction

A Bus Rapid Service (BRS) route faces major challenges related to traffic congestion and high passenger demand, especially during peak hours. These conditions cause long waiting times and extended travel times for users, reducing service efficiency, user satisfaction, and competitiveness against other transport options.

Public transport (PT) optimization is a key focus in recent research, particularly regarding system efficiency and adaptability to demand changes. One of the main challenges involves bottlenecks, such as traffic light cycles, which cause significant delays. In Santiago, Chile, adjusting traffic signal timings proved effective in reducing bus delays [1]. Strategies aimed at improving travel time reliability are critical to making PT more competitive against private vehicles. Enhancing punctuality and reducing waiting times are essential factors for attracting more users to public transport [2].

Express routes, which skip selected stops to reduce travel times and improve service efficiency, have proven effective in areas with high passenger demand. Implementing express services significantly reduces travel times, improves user satisfaction, and alleviates congestion at heavily used stops [3]. However, designing an express route requires careful selection of which stops to skip, based on demand and waiting time analysis [4]. While express routes can improve travel times, access equity can become an issue, as higher-income users often benefit more from express services, while lower-income populations may not [5]. Additionally, there are challenges in balancing efficiency and accessibility, since users of skipped stops can be negatively impacted [6]. Careful planning of express route stops and frequencies, along with the integration of micro-mobility solutions (shared bicycles and electric scooters), can help mitigate these impacts and improve connectivity for users without direct access to express lines [7].

In transport system evaluation and improvement, simulations play a key role by allowing the analysis of operational strategies and infrastructure measures. Macroscopic simulations have validated strategies such as "bus-splitting" (redistributing buses along a route to prevent bunching and balance service flow) and "bus-holding" (strategically delaying buses at stops to adjust schedules or headways), showing their effectiveness in adapting to travel time variability and improving operational efficiency under real demand conditions [8]. Transport network simulations, using tools such as AIMSUN, have also modeled large-scale user behavior and traffic flows under road pricing policies, demonstrating how such measures can enhance public transport efficiency and reduce congestion in dense urban areas [9]. Furthermore, macro-simulation traffic analysis evaluates the interaction of multiple network components, including vehicle flows, public transport, and traffic lights, offering insight into how infrastructure interventions affect overall system performance [10].

This study proposes the design of a circular express route operating on an existing trunk route to improve urban mobility in a metropolitan area. Unlike conventional routes, the express service does not cover the entire line. Instead, it operates only along segments with the highest passenger flow and makes a strategic mid-route turn, such as at a roundabout or major intersection, to return to its starting point. It stops only at high-demand stations, enabling faster circulation. This proposal aims to significantly reduce travel times by minimizing low-demand stops and decreasing waiting times at bottleneck locations. The main contribution of this research lies in the detailed analysis and design of a circular express route based on an existing service, utilizing macro-simulation tools like TransCAD. It is expected that the findings will support urban mobility improvements and promote public transport usage, aligning with principles of urban sustainability and accessibility.

2. Materials and Tools

2.1. Information Gathering Tools

Due to the lack of specific data on passenger drop-offs, it was necessary to conduct user surveys using Google Forms to gather information directly from passengers regarding their most frequent drop-off points and other factors affecting route circulation.

Additionally, official data on passenger boardings was requested from the Urban Transport Authority for Lima and Callao (ATU), providing a solid basis for understanding passenger flow patterns.

Field measurements were also conducted using mobile applications to record delays and travel times in real time, enabling a more detailed assessment of route conditions.

2.2. Data Analysis Tools

Excel was used for the analysis and processing of the collected data. This tool facilitated the organization and statistical analysis of survey responses, travel times, speeds, stop demand, and bus capacity. Descriptive statistics, such as averages and frequencies, were calculated to identify user behavior patterns. Additionally, charts and tables were generated to visualize results and provide a solid foundation for evaluating the efficiency of the proposed express service.

2.3. Traffic Modeling and Simulation Software

TransCAD, a specialized macro-simulation software, was used to simulate the impact of the new express service. The software enabled modeling of passenger demand and evaluation of how the express service would affect travel times and congestion at selected stops. TransCAD allowed for a comparison of pre- and post-implementation scenarios, supporting data-driven decision-making to optimize the route.

3. Methodology

This study was developed in several stages to implement an express route within a BRS trunk line.

The first stage focused on comprehensive data collection, including passenger boardings, bus operating frequencies, vehicle capacities, and speeds. Additionally, origin-destination (OD) surveys were conducted at the busiest stops to determine passenger alighting patterns.

In the second stage, the survey sample was expanded by applying an expansion factor. This factor was calculated by dividing the total recorded boardings (from smartcard validations) by the number of boardings observed in the survey sample. The expanded data provided reliable passenger behavior estimates. The third stage involved developing the simulation model of Route 204 using TransCAD. The macroscopic model incorporated the road network, bus stops, route segments, and public transport assignment parameters such as frequencies and capacities. Origin and destination data were loaded to generate the OD matrix. Additional parameters like speed, travel times, and delays were integrated. The model was calibrated iteratively to match observed real-world data.

In the fourth stage, a circular express route was proposed based on passenger flow analysis conducted in TransCAD. The segment with the highest demand was identified to define the express route path. A suitable turning point, such as a roundabout, was selected, and high-demand stops were chosen to optimize travel times and operational efficiency while maintaining user accessibility.

In the fifth stage, the circular express route was simulated within the existing Route 204 model. The OD matrix was updated to include only the selected express stops, and travel time data were adjusted by removing delays from skipped stops. This simulation assessed the express route’s performance, optimizing travel times and passenger flow, with model parameters adjusted based on results.

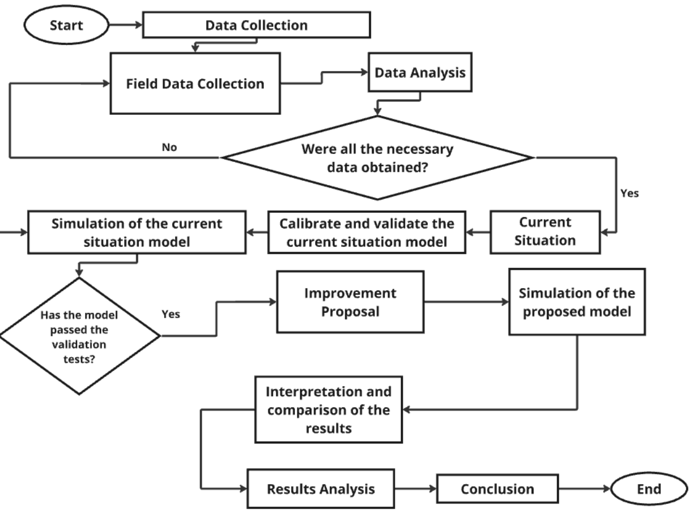

Fig. 1: Procedure Flowchart.

4. Results

4.1. Passenger demand and operating patterns

The data collected along Route 204 revealed clear demand patterns throughout the day. As shown in Fig. 2, demand peaks occurred mainly during the morning and afternoon rush hours, with a notable concentration of passengers between 6:00 a.m. and 9:00 a.m., and between 4:00 p.m. and 7:00 p.m. These periods align with typical work and school schedules, explaining the increased passenger volumes. Therefore, the analysis period was set during the morning peak hours.

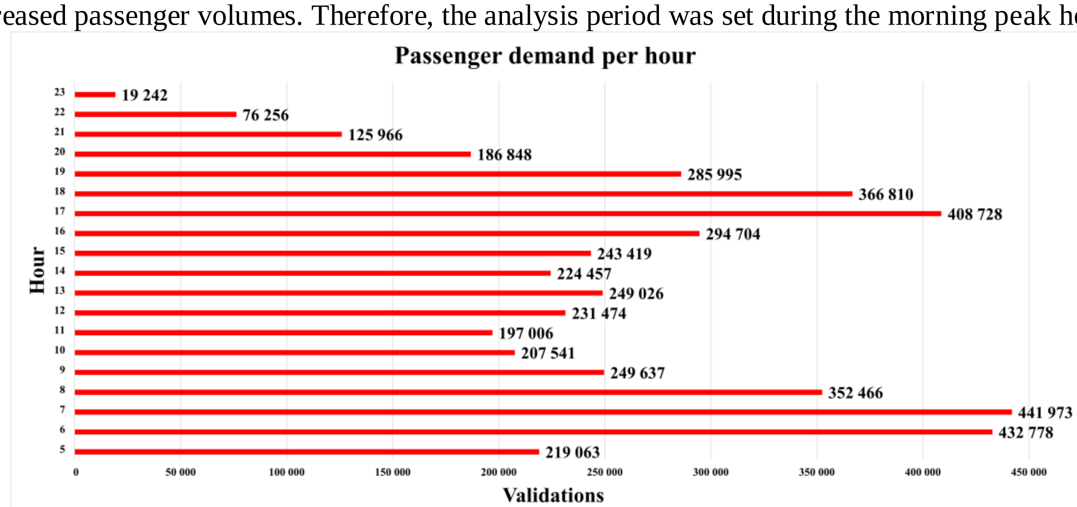

Fig. 2: Passenger Demand by Hour from January to June.

Additionally, several stops with high passenger concentrations were identified, as highlighted in Fig. 3. These graphs emphasize key points along the route where the highest number of users were recorded, indicating critical areas for operational efficiency analysis and potential intervention planning.

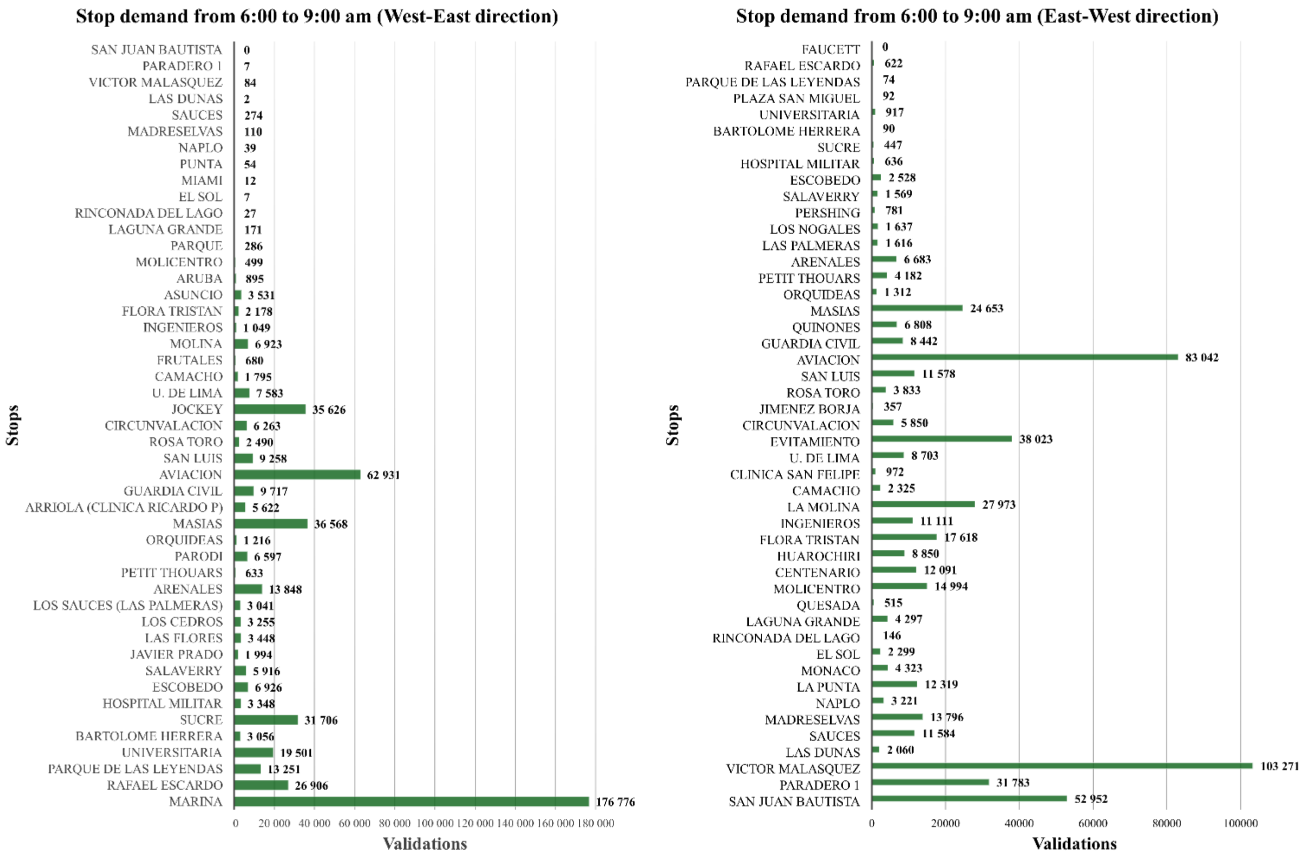

Fig. 3: Passenger Demand by Stop during Morning Peak Hours for the East-West and West-East Directions.

Table 1 presents a summary of the operating frequencies and vehicle capacities during the morning peak hours. The data show that, during peak hours, the bus frequency is insufficient to meet demand, leading to congestion and high waiting times at certain stops.

Table 1: Summary of Operating Frequencies and Capacities

Time slot	Headway (EW)	Headway (WE)	Capacity (WE)	Capacity (EW)
06:00-07:00	00:03:13	00:04:16	1360	1125
07:00-08:00	00:05:20	00:05:00	800	960
08:00-09:00	00:05:41	00:06:00	720	800

4.2. Passenger flow OD

The application of the expansion factor to the OD surveys allowed for a more accurate and representative estimate of passenger behavior along the entire Route 204. This adjustment significantly improved the reliability of the data, as it extrapolated the information obtained from the sample to the total number of passengers on the route.

Table 2 show a comparison between the original survey data and the adjusted data using the expansion factor, highlighting the improvement in estimation accuracy. As seen, the application of the factor provided a representation more in line with the total passenger demand, which is crucial for route planning and optimization.

Table 2: Expansion factor West – East and East – West direction

Route 204 de Oeste-Este				Route 204 de Este-Oeste			
Stop	Trips	Expansion Factor	Adjusted Trips	Stop	Trips	Expansion Factor	Adjusted Trips
Marina	427	3.19	1360	San Juan Bautista	134	3.04	407
Rafael Escardo	29	7.14	207	Paradero 1	40	6.10	244
Parque de Las Leyendas	15	6.80	102	Víctor Malásquez	253	3.14	794
Universitaria	22	6.82	150	Sauces	19	4.68	89

Sucre	27	9.04	244	Madreselvas	30	3.53	106
Escobedo	12	4.50	54	La Punta	31	3.06	95
Salaverry	22	2.09	46	Molicentro	27	4.26	115
Arenales	20	5.35	107	Centenario	32	2.78	89
Parodi	12	4.25	51	Huarochirí	21	3.24	68
Masías	27	10.41	281	Flora Tristán	45	3.02	136
Arriola	12	3.67	44	Ingenieros	16	5.31	85
Guardia Civil	17	4.41	75	La Molina	30	4.53	136
aviación	203	2.38	484	U. de Lima	19	3.53	67
San Luis	29	2.45	71	Evitamiento	76	3.84	292
Circunvalación	16	3.06	49	San Luis	43	2.07	89
Jockey	47	5.83	274	Aviación	229	2.79	639
U. de Lima	19	3.05	58	Guardia Civil	22	2.95	65
Molina	7	7.71	54	Masías	59	3.22	190

To visualize the passenger distribution at the stops along Route 204, Fig. 5 and Fig. 6 are presented, illustrating passenger flows from origin stops to the most frequent destinations along the route. These graphs allow for the identification of mobility patterns and areas with higher user concentration.

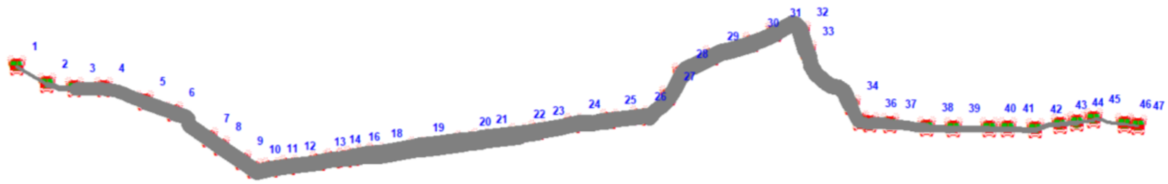

Fig. 5: Passenger flow West to East

Fig. 6: Passenger flow East – West

4.3. Simulation results of the Circular Express Route

The results of the simulation for the circular express route on Route 204 show an optimized distribution of stops based on the demand flows from the current situation. For the West-East direction, 11 stops were identified, while for the East-West direction, 12 stops were selected, including both origin and destination stops.

Additionally, the turning point for the express route was determined at the Huáscar Monitor Oval, chosen for its strategic location and its capacity to allow efficient bus turns, facilitating smooth traffic flow.

Fig. 7 shows the route of the express route, highlighting the selected stops and the turning point at the Huáscar Monitor Oval, while Fig. 8 and Fig. 9 present the passenger flow along the route, emphasizing the areas of higher user concentration covered by the new express route.

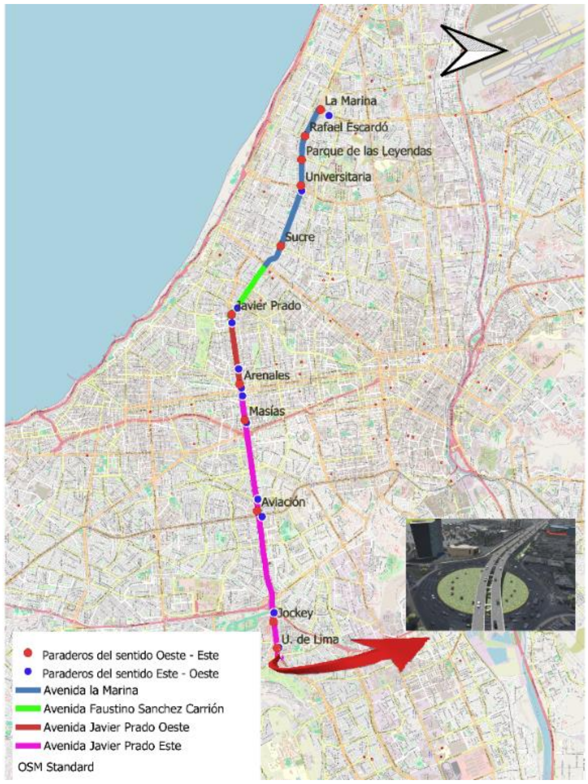

Fig. 7: Express route route indicating West-East stops

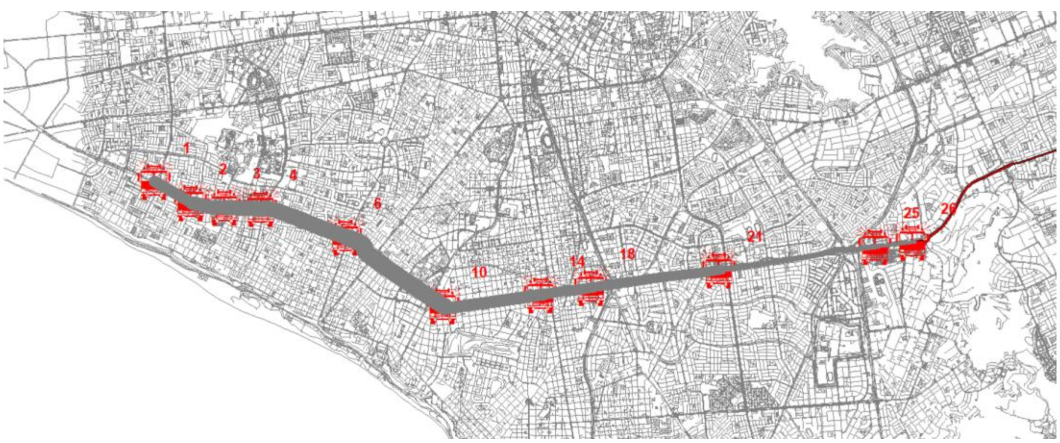

Fig. 8: West-East demand flow of the express route

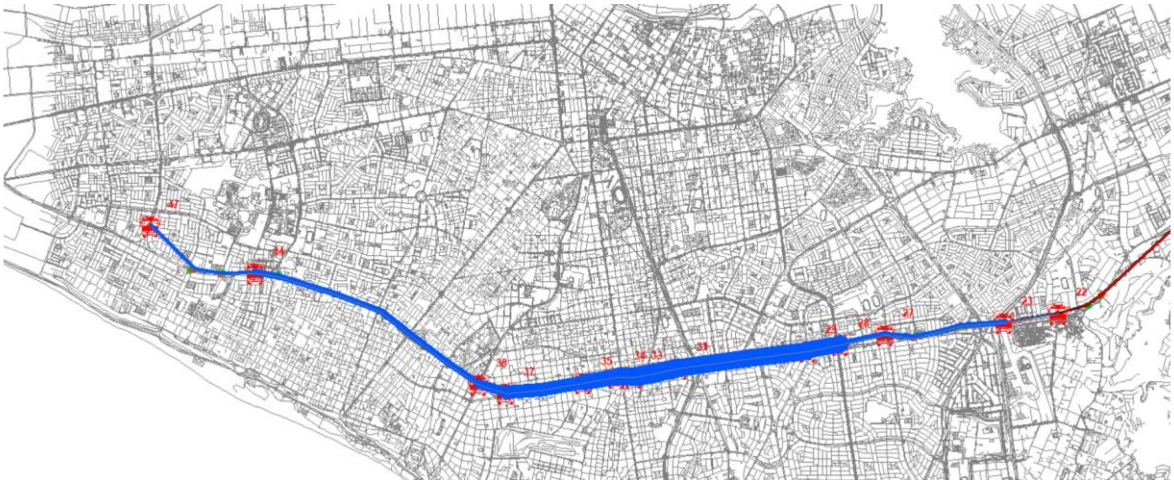

Fig. 9: East-West demand flow of the express route

The results obtained from the simulation of the circular express route in the Route 204 model are presented, showing the differences in travel times before and after its implementation. Table 4 display the travel times for each segment, comparing the current situation with the express route, allowing for the observation of variations along the route. On the other hand, Fig. 10 provide a visual representation, through bar graphs, of the travel times for each segment before and after the incorporation of the express route.

Table 4: Reduction in sections of the West – East and East - West direction

Link West - East	**Current Travel Time**	**Express Route Travel Time**	**Time Saved**	**Travel Time Reduction (%)**	**Link East - West**	**Current Travel Time**	**Express Route Travel Time**	**Time Saved**	**Travel Time Reduction (%)**
Marina - Rafael Escardo	00:05:35	00:05:35	00:00:00	0.00%	U. de Lima - Evitamiento	00:02:02	00:02:02	00:00:00	0.00%
Rafael Escardo - Parque de Las Leyendas	00:01:48	00:01:48	00:00:00	0.00%	Evitamiento - Aviación	00:10:53	00:07:18	00:03:35	32.94%
Parque de Las Leyendas - Universitaria	00:03:33	00:03:33	00:00:00	0.00%	Aviación - Guardia Civil	00:03:49	00:03:49	00:00:00	0.00%
Universitaria - Sucre	00:05:16	00:04:46	00:00:30	9.51%	Guardia Civil - Masías	00:06:49	00:05:49	00:01:00	14.66%
Sucre - Javier Prado	00:10:13	00:07:53	00:02:20	22.86%	Masías - Petit Thouars	00:04:37	00:03:07	00:01:30	32.54%
Javier Prado - Arenales	00:10:42	00:09:02	00:01:40	15.59%	Petit Thouars - Arenales	00:01:18	00:01:18	00:00:00	0.00%
Arenales - Masías	00:07:44	00:05:59	00:01:45	22.63%	Arenales - Las Palmeras	00:02:14	00:02:14	00:00:00	0.00%
Masías - Aviación	00:11:10	00:09:50	00:01:20	11.93%	Las Palmeras - Pershing	00:04:52	00:03:52	00:01:00	20.57%
Aviación - Jockey	00:10:19	00:08:19	00:02:00	19.38%	Pershing - Salaverry	00:03:37	00:03:37	00:00:00	0.00%
Jockey - U. de Lima	00:02:13	00:02:13	00:00:00	0.00%	Salaverry - Plaza San Miguel	00:16:38	00:12:15	00:04:23	26.34%
Total	01:08:32	00:58:57	00:09:35	13.98%	**Total**	00:07:15	00:05:47	00:01:28	20.22%

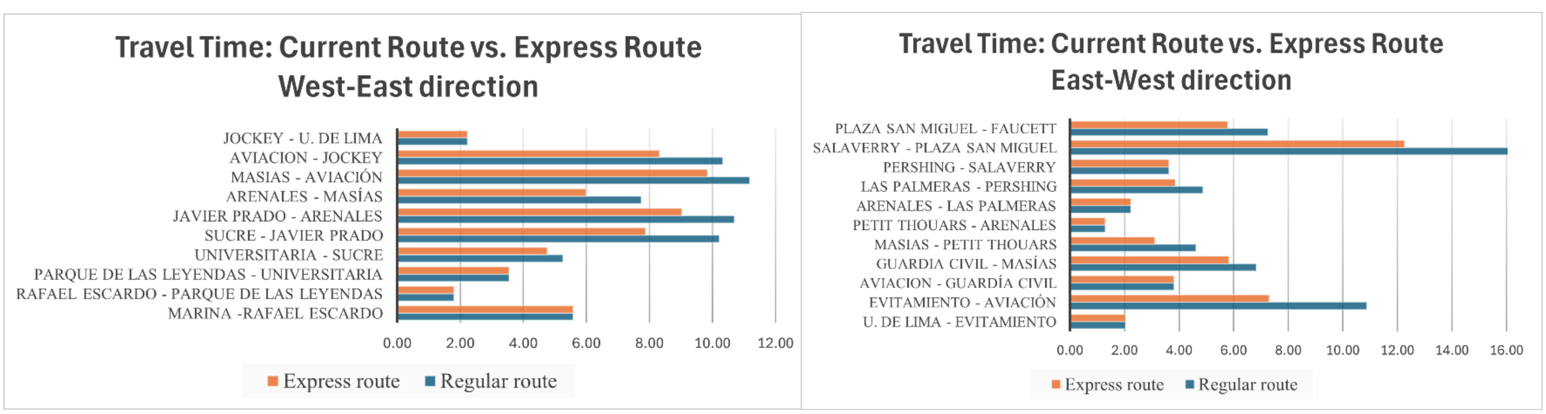

Fig. 10: Travel time by section in the West-East and East - Westdirection

5. Conclusions

The design of a circular express route based on a simulation model has proven to be an effective tool for reducing travel times in BRT systems. By proposing an express route with fewer stops, there is an improvement in bus circulation, resulting in a faster and more convenient service for users.

The results obtained from the simulation in TransCAD show a significant reduction in travel times, with a 13.98% reduction in the West-East direction and a 20.19% reduction in the East-West direction. This improvement in travel times is essential for increasing the competitiveness of public transportation compared to other modes, such as private cars.

By reducing travel times, the proposal for a circular express route could encourage greater use of public transportation. This change may also contribute to the sustainability of the system, reducing vehicular congestion and the carbon footprint.

The strategic planning of stops on the circular express route allows for better use of available resources by focusing on high-demand areas. However, it is essential to balance efficiency with accessibility, as some less-demanded stops may be left out of the express service coverage.

The strategic choice of a turning point is crucial to ensuring smooth circulation. If turning points are not correctly selected, issues such as congestion or interruptions in vehicle flow may arise. In this case, an oval was chosen as the turning point due to its design, which facilitates a safer and smoother turn, reducing the risk of complications in traffic flow. This decision aims to ensure that the circular express routes can operate adequately, thereby improving the overall functionality of the transport system.

This study demonstrates that the use of simulation tools, such as TransCAD, to model and assess the impact of changes in public transport routes can be replicated in other cities or transport lines. The methodologies employed allow for informed, data-driven decision-making to improve the quality and efficiency of public transport systems in urban environments.

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