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# Analysis of the Interaction between Passengers and Buses at a Congested Bus Stop through Simulation to Reduce Congestion Rate

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***Abstract*** - This article addresses the issue of user congestion at a high-demand public transportation stop in Lima, caused by prolonged waiting times and the perceived low quality of service. Microsimulation was conducted using VISSIM software to model ideal scenarios based on empirical data. The analysis considered key indicators such as service demand, congestion levels, and operational frequency of transportation lines. The study simulated the anticipated behavior of users who, upon having access to real-time bus arrival information, arrive at the stop just in time, thereby reducing waiting times. The results showed a 12.22% reduction in user congestion during peak hours and a more uniform redistribution of service demand during the same period. This optimization improved passenger flow and user experience without the need to alter the current bus frequencies, validating the economic and operational feasibility of the proposal. The research highlights the use of micro-simulation as an effective tool for designing sustainable solutions in urban environments, contributing to improved mobility and perceived reliability of public transportation.

***Keywords*:** Microsimulation, public transportation, congestion, VISSIM, urban mobility

## 1. Introduction

The rapid growth of cities and the increasing demand for public transportation have created significant challenges of congestion at high-demand bus stops, affecting both the user experience and the overall efficiency of the system. This issue is evident in prolonged waiting times, exacerbated by poor planning and inefficient infrastructure management, particularly in improvised cities like Lima.

In this context, it is crucial to develop methods that allow for understanding and managing the flow of users and vehicles at these critical points. Simulation in virtual environments, such as those offered by VISSIM, has become a valuable tool for analyzing and modeling these interactions.

The main contribution of this research lies in the comprehensive methodology developed to analyze the interaction between passengers and the public transportation system at a heavily congested bus stop. Specifically, it integrates user surveys, field data collection, and VISSIM simulation. This approach facilitated a robust evaluation of the impact of time information provision on congestion levels and service demand at the bus stop.

## 2. State Of The Art

The use of analytical modelling to optimize public transportation in high-demand scenarios is a cornerstone of current research. Vismara et al. demonstrate how analytical modelling reduce congestion and enhance efficiency at crowded bus stops, highlighting the impact of bus grouping and synchronization on minimizing waiting times and optimizing capacity. Their quantitative results show waiting time reductions between 12% and 32%, supporting the relevance of analytical modelling in optimizing critical bus stops [1].

Visual analytics and spatiotemporal data are vital tools for improving transportation efficiency. Mariotto et al. demonstrate the value of these methods in identifying high-demand stops and optimizing routes and schedules. Their findings, including a 15% reduction in congestion and a 12% decrease in waiting times, validate the integration of these techniques in this research [2].

Analyzing bus frequency variability and its impact on public transportation demand is key to evaluating system efficiency, especially in cities like Lima. Deepa et al. show that irregular intervals affect demand and that reducing variability could increase it by up to 19%. Given Lima's structural constraints, this research highlights the importance of service predictability to help users plan trips, reduce wait times, and improve satisfaction. [3].

Liu and Miller indicated that having only precise scheduled bus arrival information can be as effective as real-time transit information, as both strategies demonstrated comparable waiting times, and in some cases, scheduled information provided equivalent or better results by reducing uncertainty and enabling efficient trip planning [4].

User accumulation analysis is a key metric for evaluating efficiency at congested stops. Ansari et al. propose differentiating user profiles based on accumulation patterns, achieving a 15% reduction in congestion. Their findings underline the significance of tailoring strategies to passenger characteristics, which aligns with this research [5].

Behavioral pattern analysis provides a basis for designing strategies to reduce congestion at critical bus stops. Achar et al. demonstrate that identifying structural and scheduling influences on user accumulation allows for targeted adjustments, achieving a 16% reduction in congestion. This underscores the importance of behavioral dynamics in optimizing passenger flow at busy stops [6].

## 3. Proposal And Contribution

### 3.1. Objectives

- Measure service demand and the level of congestion at the UPC Monterrico bus stop using data on entries, exits, and the usage of bus lines.
- Conduct a survey to understand user preferences and their perception of the proposed solution.
- Analyze the service frequency of bus lines during peak hours, identifying patterns and issues in distribution.
- Develop, calibrate, and validate a VISSIM model that accurately represents the current conditions of the study area.
- Simulate an ideal behavior scenario with a schedule-adapted flow of users to reduce congestion.
- Evaluate the effectiveness of the simulation in reducing congestion at the bus stop.

### 3.2. Procedure

This research was conducted in six phases, enabling the analysis and development of solutions to address congestion at the UPC Monterrico bus stop. Initially, field data and recordings were collected to study the current situation, identify peak hours, and calculate key indicators such as service demand and congestion levels. Next, service frequencies of selected bus lines were analyzed using KMeans clustering to identify arrival patterns. Surveys captured user preferences and perceptions, informing the design of a VISSIM model calibrated to real conditions. Based on this, an ideal model was proposed by adjusting frequencies and parameters to optimize user flow. A comparative analysis between the current and ideal scenarios validated the proposed strategies, highlighting their impact on congestion reduction. Figure 1 illustrates a flowchart summarizing these phases, providing a clear overview of the methodology.

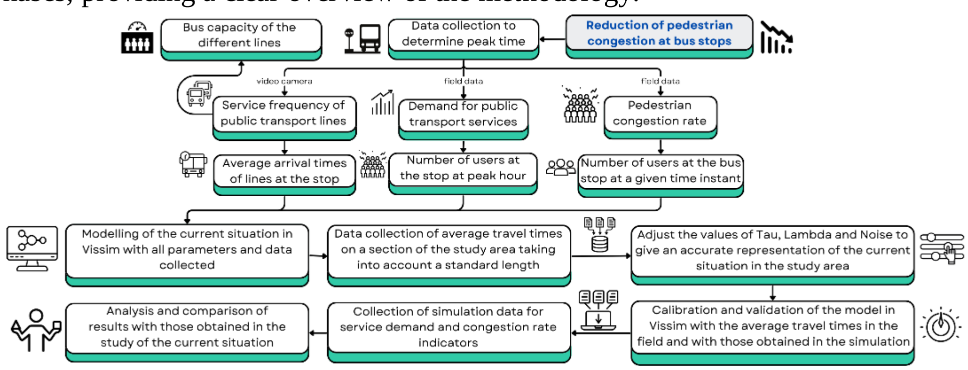

Fig. 1: Flowchart.

## 4. Materials And Method

In this research, documents, surveys, and field data were collected to analyze the current situation and establish evaluation indicators. Video surveillance recordings, obtained through formal requests to the local municipality, were employed to assess service demand and congestion levels. However, due to the technical limitations of the cameras, additional data was gathered through fieldwork, during which a team of five individuals recorded the flow of pedestrians entering and exiting the bus stop and measured user accumulation at specified time intervals. Figure 2 delineates the pedestrian counting zone at the studied bus stop, where entry points are marked in green and exit points in red. Furthermore, surveys were conducted to evaluate user satisfaction and perceptions of waiting times, providing critical inputs for the simulation and the development of the proposed solution.

Fig. 2.: Established boundaries for pedestrian data collection

To understand user preferences and their perception of the proposed solution, a survey was conducted among 35 users. In response to whether they would arrive at the stop just in time if they knew the exact bus arrival time, 65.7% strongly agreed (rating 7 out of 7), 25.7% agreed (rating 6), and 8.6% moderately agreed (rating 5). These responses suggest that most users are willing to adjust their arrival time based on accurate scheduling, supporting the strategy to reduce crowding at peak hours. Additionally, when asked about the importance of receiving information on the exact arrival time of their bus, 82.9% rated it as very important (7 out of 7), while 11.4% rated it as important (6) and 5.7% as moderately important (5). These results reflect a highly positive perception of the proposed solution and confirm that real-time schedule information is not only valued by users but also has the potential to influence their behavior, making it a key component in improving the system's operational efficiency. While the simulation assumes full compliance with scheduled arrivals for modeling purposes, it is recognized that real-world behavior may vary due to individual or contextual factors. However, the strong tendency observed in the survey responses supports the plausibility of the assumed behavior, reinforcing the proposed strategy's relevance and potential for real-life application.

Figure 3 illustrates bus line demand at different time intervals. The CR71 line showed the highest demand during most of the analyzed time ranges, absorbing passenger flow when other lines were unavailable, highlighting its key role within the transportation system.

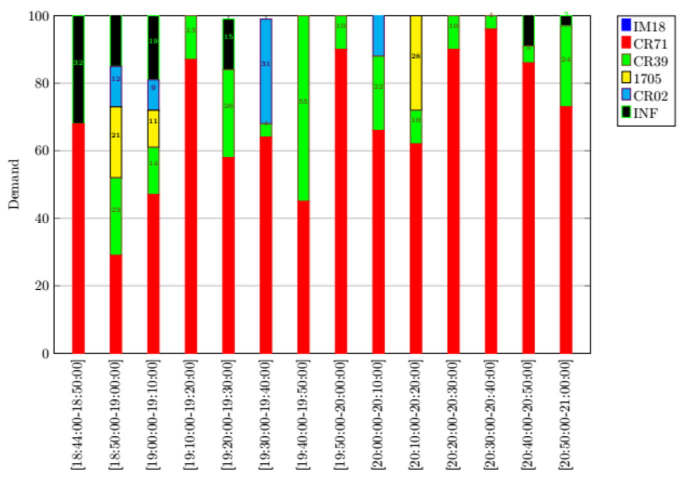


Fig. 3.: Demand by time range for each bus line

Figure 4 shows the fluctuation in the number of people present at the bus stop overtime. This analysis helped identify peak periods and the progressive accumulation of people during rush hours, evidencing the current system's insufficiency to manage demand during these periods.

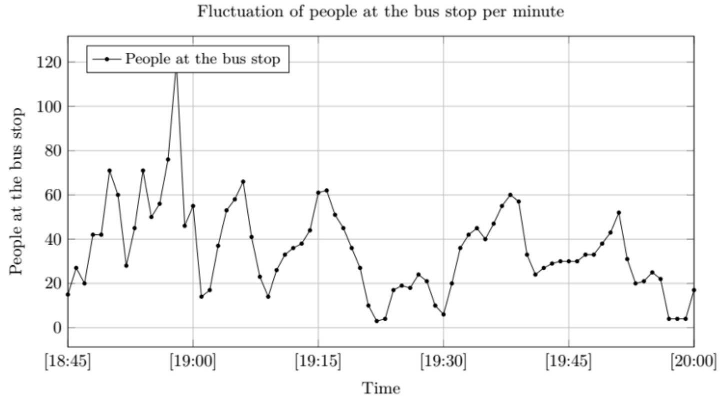


Fig. 4.: Variation in the number of people waiting at the bus stop per minute

Figure 5 details the time period with the highest congestion rate, showing the number of people remaining at the bus stop without boarding any bus. This analysis determined that the 6:45–7:45 p.m. time range was the most critical, allowing for frequency analysis and simulation model adjustments to work with more representative data.

Between
6:45 and 7:45

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | 27 | 20 | 42 | 42 | 71 | 60 | 28 | 45 | 71 | 50 | 56 | 76 | 120 | 46 | 55 | 14 |
| 17 | 37 | 53 | 58 | 66 | 41 | 23 | 14 | 26 | 33 | 36 | 38 | 44 | 61 | 62 | 51 | 45 |
| 36 | 27 | 10 | 3 | 4 | 17 | 19 | 18 | 24 | 21 | 10 | 6 | 20 | 36 | 42 | 45 | 40 |
| 47 | 55 | 60 | 57 | 33 | 24 | 27 | 29 | 30 | 30 | 30 | 33 | 33 | 38 | 43 | 52 | 31 |
| 20 | 21 | 25 | 22 | 4 | 4 | 4 | 17 | 9 | 12 | 19 | 19 | 11 | 9 | 8 | 16 | 23 |
| 33 | 42 | 32 | 21 | 0 | 8 | 13 | 0 | 4 | 0 | 2 | 12 | 30 | 22 | 14 | 16 | 19 |
| 26 | 21 | 24 | 23 | 22 | 23 | 29 | 15 | 18 | 15 | 20 | 24 | 29 | 20 | 28 | 20 | 26 |
| 17 | 33 | 18 | 26 | 22 | 31 | 34 | 39 | 49 | 41 | 26 | 29 | 27 | 28 | 36 | 43 | 29 |

Fig. 5.: Established boundaries for data collection

After completing the data collection, the analysis was carried out using VISSIM, the main simulation tool of the research. The collected data and conducted surveys provided a solid basis for simulating users' ideal behavior to evaluate potential improvements in service efficiency and congestion reduction at the bus stop.

The simulation modeled the proposed solution and analyzed the impact of providing information to users, contributing to the optimization of passenger flow.

## 5. Results

The following graph examines how the implemented strategies influenced the number of people entering the bus stop during key intervals. This analysis is essential for identifying moments when the greatest impact on demand reduction was achieved and how these changes align with variations in vehicular dynamics.

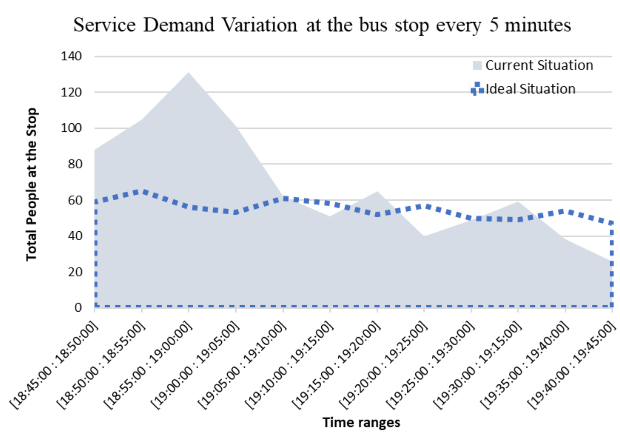


Fig. 6.: Comparison of Demand at the Bus Stop

As observed in Figure 6, in terms of service demand—which refers to the total number of people entering the bus stop in each 5-minute interval—the greatest reduction occurred during the 6:55–7:00 p.m. time range. During this period, the number of people entering decreased by 55 compared to the scenario without intervention, representing a 49.55% reduction.

This time range coincided with a period of high vehicular frequency, suggesting a change in user behavior when approaching the bus stop.

The next graph evaluates the effect of the proposed measures on user accumulation at the bus stop. This approach highlights the effectiveness of flow redistribution in mitigating crowding, particularly during periods of high pedestrian traffic.

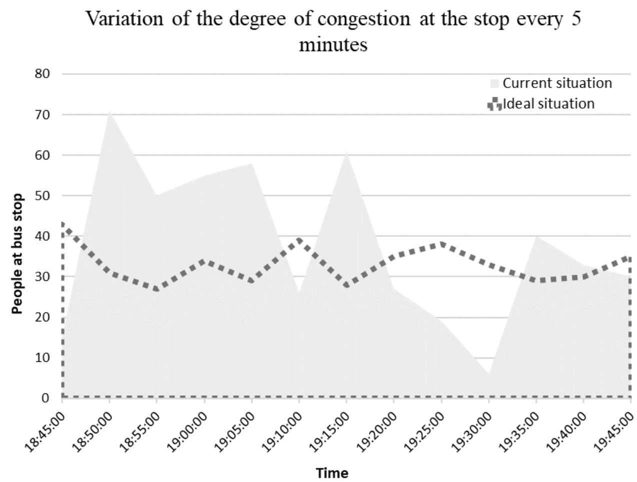


Fig. 7.: Comparison of Congestion Levels at the Bus Stop

As presented in Figure 7, the most significant reduction in congestion levels at the bus stop occurred at 6:50 p.m. This indicator, which represents the number of people waiting at the bus stop at the specified moment, decreased from 71 to 31, reflecting a reduction of 40 people—a 56.34% decrease in the number of individuals simultaneously waiting at the bus stop. This time range showed the most significant change compared to other analyzed intervals.

## 6. Analysis And Validation

### 6.1. Comparison of Service Demand at the Bus Stop

Between 6:45 PM and 7:10 PM, significant differences were observed between the service demand from the Vissim simulation and the field data. The simulation showed relatively constant demand with minor fluctuations, while field data revealed abrupt peaks, reaching up to 111 people.

This discrepancy indicates that the Vissim model, adjusted with induced parameters, represents an idealized scenario where demand can be reduced and distributed more evenly between 6:45 PM and 7:45 PM. Field-recorded accumulated demand decreased from 406 to 294 people in the simulation, representing a reduction of approximately 30% during the most critical time window (from 6:45 to 7:10). This reduction did not occur in the total demand, but rather reflects a redistribution of users over time, easing congestion during peak moments and spreading arrivals more evenly throughout the simulation period.

The results demonstrate that the calibrated Vissim microsimulation model effectively replicates observed service demand while offering a more balanced temporal distribution. This approach reduces congestion at public transport stops, enhancing bus line operational efficiency and ensuring smoother, safer flows for pedestrians.

### 6.2. Comparison of Congestion Levels at the Bus Stop

This study evaluated congestion levels at a public transport stop between 6:45 PM and 7:05 PM, comparing field data with Vissim simulation results. Field data revealed a cumulative congestion level of 249 people, driven by high service demand and low bus frequencies, whereas the simulation showed a maximum of 85 people and a cumulative level of 164, representing a 35.14% reduction.

The 35% reduction suggests that passenger flow management strategies, such as schedule synchronization and planned temporal user distribution, can effectively mitigate congestion peaks. Over the full peak study hour, the overall congestion reduction was 12.22%, less pronounced but still significant for improving service quality.

This 12.22% reduction reflects an improvement in operational efficiency, primarily supported by a redistribution of service demand and a lower level of congestion at the bus stop during peak periods. While total demand remained constant, its temporal spread contributed to easing crowding at critical moments, which is essential for improving user experience and service regularity. Future research should incorporate more variables and simulate diverse scenarios to strengthen results and enhance model applicability.

The analysis confirms that the calibrated Vissim model, combined with passenger flow management strategies, can significantly reduce congestion at public transport stops. These improvements enhance system operation, user experience, and urban sustainability, supporting more efficient and organized development.

## 7. Validation

To validate the design of the model in VISSIM, a null hypothesis test was carried out, comparing the travel times observed in the field with those obtained through simulation. This validation consisted of two stages: initial calibration and model validation. Both stages were supported by statistical tests that allowed evaluating the accuracy and representativeness of the model in relation to real-world conditions.

### 7.1. Model Calibration

The calibration of the model was essential to ensure that it accurately reproduced the conditions observed at the UPC Monterrico bus stop. In particular, the evaluation focused on the time it takes a pedestrian to cross the crosswalk located within the simulated area. For this, key parameters such as Tau, Lambda, and Noise, which directly affect simulated pedestrian behavior, were adjusted. This process was carried out in 7 iterations, comparing the results obtained in VISSIM with the data collected in the field. Table 1 summarizes the results of these iterations and shows how the progressive adjustments helped reduce the differences between the simulated model and the real-world conditions.

Table 1: Analysis of 7 Iterations in VISSIM and Comparison with Field Data for the Calibration of Tau, Lambda, and Noise Parameters in Pedestrian Modeling

| Attempt | Viswalk parameters | | | Average Travel Time |
|---|---|---|---|---|
| ID | Tau | Lambda | Noise | (s) |
| 1 | 0.050 | 0.900 | 0.250 | 11.267 |
| 2 | 0.175 | 0.600 | 0.300 | 11.534 |
| 3 | 0.300 | 0.400 | 0.310 | 11.681 |
| 4 | 0.450 | 0.200 | 0.350 | 11.833 |
| 5 | 0.460 | 0.195 | 0.335 | 11.854 |
| 6 | 0.455 | 0.197 | 0.335 | 11.836 |
| 7 | 0.453 | 0.197 | 0.335 | **11.839** |
| **Field data average** | - | - | - | **11.840** |

The table demonstrates the improvement in the model's accuracy as the parameters are optimized, reducing discrepancies with field data.

Subsequently, a null hypothesis test was conducted to evaluate the equality of the average travel times measured in the field and simulated, using the StatKey tool for randomization tests through permutations. As shown in Figure 8, the mean differences fall within the defined acceptance range, thereby validating the model's calibration.

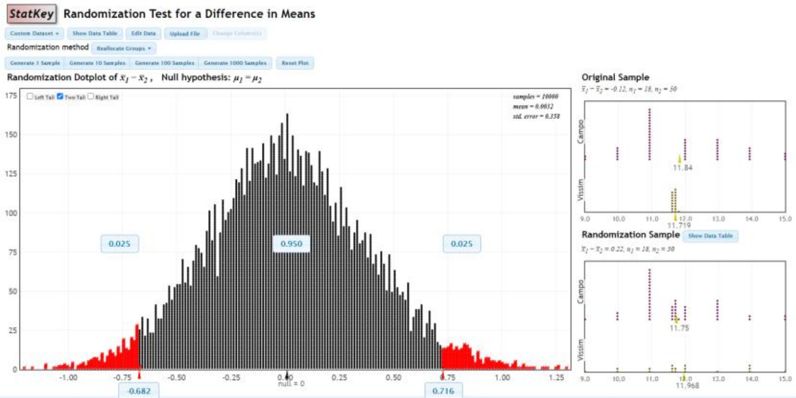

Fig. 8.: Null Hypothesis Test for Calibration – Pedestrian Crossing at UPC Monterrico Bus Stop

### 7.2. Model Validation

In the second stage, the model was validated by collecting new field data to ensure the effectiveness of the calibration and verify its ability to faithfully reproduce the observed pedestrian behavior. The averages of the simulated travel times were compared with those measured, following the same statistical procedure. The results, presented in Figure 9, confirm that the mean differences remain within the acceptance interval, thus supporting the reliability of the model to represent real conditions at the UPC Monterrico bus stop.

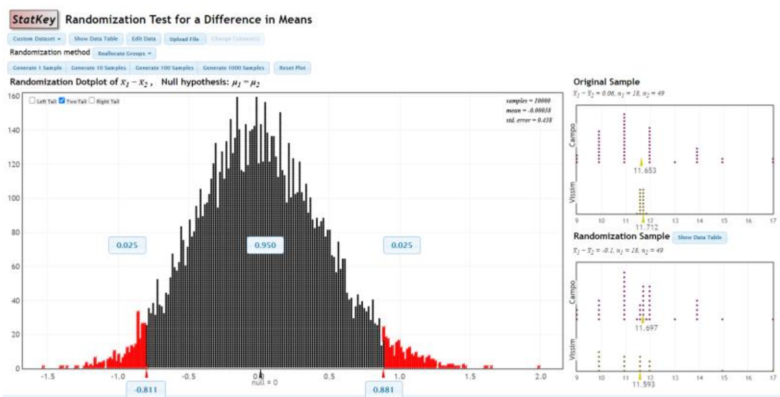

Fig. 9.: Null Hypothesis Test for Validation – Pedestrian Crossing at UPC Monterrico Bus Stop

This figure shows that the validated model accurately reflects pedestrian behavior, as the differences between simulated and observed averages are not statistically significant. Both stages of validation—calibration and verification—confirm that the model developed in VISSIM accurately represents pedestrian flow dynamics and the specific conditions at the UPC Monterrico bus stop. This guarantees the model's reliability as a tool for analyzing and proposing effective solutions to congestion.

## 8. Conclusions

This research emphasizes evaluating service demand and congestion levels as key indicators for optimizing pedestrian behavior at public transport stops. Analysis of the UPC Monterrico bus stop, which accommodates more than seven formal bus lines alongside informal operators, revealed that this coexistence disrupts the steady flow of formal buses and private traffic, resulting in congestion that affects punctuality and regularity. The presence of informal operators further complicates traffic management and urban planning, diminishing operational efficiency and service quality.

A six-question survey captured users' preferences and behaviors, including waiting times, bus line usage, and willingness to utilize schedule information. Notably, 65.7% of respondents strongly agreed they would arrive just before the bus if accurate schedules were available, with an additional 34.3% expressing moderate to high agreement. This supports the effectiveness of the proposed congestion-reduction strategy by confirming users' willingness to adjust their arrival behavior.

Furthermore, 82.9% of users rated real-time arrival information as very important, highlighting a strong preference for reliable scheduling. These insights not only validated the need for organized and accessible bus schedules but also guided simulation adjustments, reinforcing the proposal's potential to improve user flow and operational efficiency.

Service frequency analysis for bus lines IM18, CR71, 1701, and 1705—based on five weeks of video-recorded data—highlighted varying arrival patterns. While CR71 was consistent, IM18 exhibited wider intervals, 1701 showed variability, and 1705 maintained stable frequency. Using the KMeans algorithm, representative patterns were established as inputs for simulations, reinforcing the importance of optimizing service distribution. This technical framework provided a robust basis for modeling current and ideal scenarios, improving user experience.

A high-precision VISSIM model was developed to replicate the study area's current conditions, capturing pedestrian behavior accurately. Calibration included field data from 50 pedestrians crossing a 15.83-meter road, with adjustments to social force parameters (Lambda Tao and Noise). Validation through additional data collection confirmed the model's accuracy, as simulated travel times closely matched observed times. This rigorous process establishes the model as a reliable tool for future transport optimizations.

The adjusted VISSIM model demonstrated reduced congestion at the bus stop by simulating scenarios with real-time bus arrival information. Synchronizing passenger departures with schedules evenly distributed flow during peak hours (18:45–19:45), reducing crowding and improving traffic flow. Comparative analysis showed that cumulative demand in the simulation (294 people) decreased by 30% compared to field data (406 users).

Congestion analysis revealed a 34.14% reduction during the 18:45–19:05 interval, with global congestion declining by 12.22% throughout the peak hour. These improvements stem from strategies like schedule synchronization and temporal distribution of departures, balancing flow and alleviating crowding during high-demand periods. The findings underscore the effectiveness of real-time information systems in reducing congestion and enhancing operational efficiency and service quality.

Future research should integrate additional variables, such as user behavior and environmental conditions, to further refine simulation models, promoting sustainable urban development and improved user satisfaction.

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## References

[1] Vismara, L., Saw, V.-L., &. Chew, L. Y. (2021). Optimal assignment of buses to bus stops in a loop by reinforcement learning. arXiv preprint arXiv:2101.06464.

[2] Mariotto, F. T., Santos, R. A., &. Silva, L. H. (2023). A visual analytics approach for inferring passenger demand in public transport system based on bus trajectory. Transportation Research Procedia, 55, 123 135. https://doi.org/10.1016/j.trpro.2023.06.014

[3] Deepa, L., Pinjari, A. R., Nirmale, S. K., Biswas, M., &. Srinivasan, K. K. (2023). The adverse impact of headway variability on bus transit ridership: Evidence from Bengaluru, India. Transport Policy, 141, 343-356. https://doi.org/10.1016/j.tranpol.2023.07.006

[4] Liu, L., &. Miller, H. J. (2020). Does real-time transit information reduce waiting time? An empirical analysis. Transportation Research Part A: Policy and Practice, 141, 167-179. https://doi.org/10.1016/j.tra.2020.09.014

[5] Ansari Esfeh, M., Wirasinghe, S. C., Saidi, S., &. Kattan, L. (2021). Waiting time and headway modelling for urban transit systems–a critical review and proposed approach. Transport Reviews, 41(2), 141–163. https://doi.org/10.1080/01441647.2020.1806942

[6] Achar, A., Bharathi, D., Kumar, B. A., &. Vana jakshi, L. (2020). Bus arrival time prediction: A spa tial kalman filter approach. IEEE Transactions on Intelligent Transportation Systems, 21(3), 1298–1307. https://doi.org/10.1109/TITS.2019.2909314