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Optimizing Transit Operations and Passenger Experience: A Simulation-based Study of Bus Interarrival and Passenger Load Scenarios at a Major Transfer Point

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A B S T R A C T

This study employs simulation-based analysis of passenger flow and bus operations at the Adam Malik transfer point within the TransJakarta BRT system. The findings from the analysis of the current system indicate that the average number of total passenger exits in corridors 13, 13B, 13C, and L13E were 618, 509, 1143, and 790, respectively. Additionally, the average time spent by passengers within the system for each corridor was 4.48 minutes, 6.12 minutes, 5.94 minutes, and 5.46 minutes, respectively. Through the development of 15 scenarios, the study demonstrates the impact of adjusting passenger boarding procedures and reducing interarrival time on waiting times and passenger processing efficiency, particularly during peak hours. The results emphasize the substantial influence of these variables on waiting times, total exits, and system duration for passengers and buses.

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1. INTRODUCTION

Commuter transportation is of utmost importance in Jakarta, particularly for residents in neighboring areas (Tjahjono et al., 2020). In Jakarta, the commuterline and TransJakarta Bus Rapid Transit (BRT) services have emerged as highly favored transportation choices among commuters. The TransJakarta BRT system, in particular, holds a significant edge over the commuterline due to its exclusive lanes, a larger fleet, and improved accessibility. The provision of dedicated lanes guarantees more seamless and effective transportation, while the greater fleet size of TransJakarta buses enables them to accommodate a larger number of passengers. Furthermore, the TransJakarta BRT system boasts an extensive network of transit points, with the Adam Malik transfer point serving as a prominent location strategically located on the border of South Jakarta and Tangerang provinces. These transit points effectively cater to the transportation needs of commuters in the surrounding areas, thereby enhancing the convenience and appeal of the TransJakarta BRT system in Jakarta. The Adam Malik transfer point presents substantial challenges attributed primarily to traffic congestion and concerns in relation to passenger comfort related to boarding capacity. The congestion experienced at this transfer point results in delays and disruptions, significantly impeding the seamless functioning of TransJakarta buses. Furthermore, as customer satisfaction is crucial (Trimarjoko et al., 2020), prioritizing passenger comfort during the boarding process assumes critical importance since prolonged waiting times possess the potential to impact satisfaction levels and influence public interest in utilizing TransJakarta services. Effectively addressing these challenges entails a concentrated effort toward congestion mitigation and the implementation of strategies aimed at optimizing boarding capacity. By adopting such measures, the overall efficiency and dependability of TransJakarta bus services can be heightened, thus enhancing the overall commuting experience for individuals utilizing the Adam Malik transfer point.

This study employs discrete simulation modeling as a methodology to comprehensively address the waiting time issue at the Adam Malik transfer point. This approach offers several advantages as it involves creating a model that accurately mimics the behavior of real-world systems without disrupting the actual system (George-Williams et al., 2022). By simulating the processes of the entities through a series of activities at the Adam Malik transfer point, this study intends to analyze the efficacy of the current system. Subsequently, the study develops scenarios that take into account passenger comfort, which will involve adjustments to bus interarrival time and maximum allowable load of passengers. Ultimately, this study provides valuable insights to the stakeholders in optimizing the system's efficiency.

2. LITERATURE REVIEW

Discrete event simulation has been utilized in various studies to address waiting time-related issues. For instance, (Lusiani & Chandra, 2018) applied a discrete simulation approach to analyze commuter line arrivals and determine the number of passengers transported. Studies focusing on TransJakarta generally assess service quality, such as Savitri et al. (2018) who evaluated passenger satisfaction on TransJakarta Corridors 13 buses, and Kusumawardani et al. (2020) who identified four prioritized service attributes. Research by (Sriwana et al., 2019) examined nine issues faced by passengers in TransJakarta Bus Corridor 8, and after simulating multiple scenarios, observed an increase in passenger numbers ranging from 6.83% to 44.38%. Lusiani & William (2020), conducted a study using discrete event simulation to determine the headway time of TransJakarta buses during rush hour in Corridor 1. Research by Winandanto & Narendra (2021), investigated passenger arrival patterns at the Simpang Lima and Kampung Pelangi bus stops to optimize service levels. Rachmawati & Dianisa (2022) focused on reducing the average queue time for trucks through their discrete simulation research. Research by Liperda et al., (2022), developed a simulation-optimization model to minimize the average loading time of grocery trucks within the system. A study proposing the utilization of a discrete event simulation approach to analyze the patient queues and to improve the efficiency of patient service management was conducted by (Krisnawati et al., 2022). Research by Hasanuddin et al. (2023), employed a discrete simulation approach in 2023 to analyze the queuing system for ferry ticket purchases. The work of (Liperda & Rahmadanti, 2023) analyzes the performance efficiency of container loading and unloading at JO. BUMIKALOG terminal using discrete event simulation. The existing system exceeds the target loading and unloading time of the company. To meet the target time of 2.47 hours with 85.65% reach stacker utilization, the addition of 2 units is proposed. In this research, the discrete event simulation approach is utilized to address the existing research gaps by comprehensively examining the waiting time challenges and concerns associated with passenger comfort in relation to boarding capacity at the Adam Malik transfer point.

3. RESEARCH METHOD

Case Study

The activities taking place at the Adam Malik transit point involve two main entities: passengers and buses. The flow of entities within the system begins with the arrival of passengers. Upon arrival, passengers proceed to the tapping gate for initiation. Passengers who have successfully tapped in will then form queues and wait for the bus to arrive at the designated boarding platform. Once the bus arrives at the transfer point, its doors open, allowing passengers to board. The departure of the bus from the boarding platform marks the end of the system process. To assess the performance of TransJakarta, it is crucial to adhere to the standard bus waiting time of 5 minutes during peak hours since it represents the most challenging operational conditions rather than off-peak hours. This standard time serves as a benchmark for evaluation.

Conceptual Model

As stated by (Robinson, 2013), a conceptual model is a depiction of a simulated model that represents a real system. The conceptual model holds significant influence over various aspects of simulation models (Liperda et al., 2021), such as data identification, model development, model validity, and confidence in the obtained results. By employing a conceptual model, the system being simulated becomes more comprehensible and easier to understand. Fig. 1 presented of illustrates the conceptual model of the system

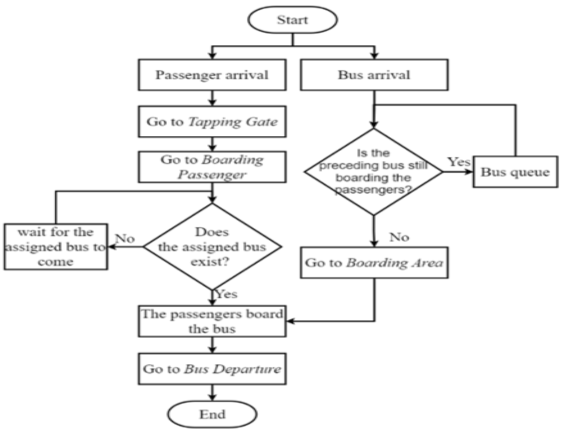

Fig. 1. Study flowchart

Discrete Event Simulation Model

This section focuses on the identification of the components comprising the simulation model, as presented in Table 1. The system encompasses two primary elements: entities and locations. The model's entities include passengers and buses, while the locations encompass passenger arrival, tapping gate, boarding platform, bus arrival, and bus

Developing Simulation Scenarios

This study focuses on the development and

departure. Upon arrival, the passengers are categorized into two types according to the number of available stations at the Adam Malik transfer point. The passengers are further classified based on the specific corridor they belong to, which includes corridor 13, 13B, 13C, and L13E. Additionally, the type of bus operating within each corridor is taken into consideration during the classification process. For the purpose of model design, this study utilizes ProModel 10.5.0.3688 software, running on a computer equipped with a Core i3 processor and 4 GB RAM.

Table 1. Model elements

Element	Type
Passenger Adam Malik 1	Entity
Passenger Adam Malik 2	Entity
Passenger 13	Entity
Passenger 13B	Entity
Passenger 13C	Entity
Passenger L13E	Entity
Bus 13	Entity
Bus 13B	Entity
Bus 13C	Entity
Bus L13E	Entity
Passenger Arrival Adam Malik 1	Location
Tapping Gate Adam Malik 1	Location
Boarding Platform Adam Malik 1	Location
Passenger Arrival Adam Malik 2	Location
Tapping Gate Adam Malik 2	Location
Boarding Platform Adam Malik 2	Location
Bus Arrival	Location
Bus Departure	Location

Verification and Validation

Model verification is a crucial step in assessing the fidelity of a simulation model in relation to its conceptual model, as outlined by (Harrell et al., 2004; Suharko, 2020). To conduct the model verification process, the trace and debug feature within the ProModel software is utilized. Following the verification stage, the next step involves model validation. In this study, model validation is performed by carefully observing the animation of the simulation model and subjecting it to testing in extreme conditions (Swider et al., 1994).

analysis of two pivotal elements: the interarrival time of buses and passenger comfort. The accurate determination of bus interarrival time plays a crucial role in maintaining compliance with established standards. Simultaneously, emphasizing passenger comfort aims to mitigate overcrowding issues and elevate overall passenger satisfaction levels. To thoroughly investigate these factors, this study presents a comprehensive framework consisting of 15 distinct scenarios. These scenarios encompass a broad spectrum of combinations, incorporating variations in bus interarrival time and passenger load capacity. By implementing this diverse set of scenarios, the study aims to conduct a comprehensive analysis of the variables under scrutiny, thereby contributing to a more profound comprehension of the intricate relationship between bus interarrival time, passenger comfort, and system performance.

4. RESULT AND DISCUSSION

To conduct the simulation, it is necessary to develop a mathematical formulation. The input for this formulation is derived from raw data obtained through observations. However, before inputting the data into ProModel, it must undergo a distribution fitting process to minimize any deviations and ensure accurate representation. To facilitate this process, the Stat::Fit program within the ProMo distribution fitting for the Adam Malik transit del application is employed. The outcomes of the point simulation model are presented in Table 2

Table 2. Distribution fitting results

Element	Data	Unit	Data Distribution
Passenger Adam Malik 1	Passenger interarrival time	minutes	-0.0342+(1./2.89)*(-LN(U(0.5,0.5)))**(-1./2.36)
	Number of passengers for each arrival	person	GEO(0.239)
	Duration of the tapping process	seconds	-35.7+G(740, 0.0537)
Passenger Adam Malik 2	Passenger interarrival time	minutes	0.07+P6(1.73, 5.35, 0.798)
	Number of passengers for each arrival	person	GEO(0.188)
	Duration of the tapping process	seconds	0.863+W(1.8, 2.73)
Bus 13	Number of passengers board the bus 13	person	P(18.7)
	Bus 13 interarrival time	minutes	0.195+W(1.42, 4.35)
	Duration of arrival-to-open	seconds	0.682+IG(42.9, 15.5)
	Duration of open-to-close	seconds	-23.6+P5(19.5, 963)
	Duration of close-to-depart	seconds	-4.01+(1./0.0933)*(-LN(U(0.5,0.5)))**(-1./3.55)
Bus 13B	Number of passengers board the bus 13B	person	P(21.8)
	Bus 13B interarrival time	minutes	-10.6+P5(47.5, 876)
	Duration of arrival-to-open	seconds	6.56+IG(9.9, 7.57)
	Duration of open-to-close	seconds	13.7+35.4*(1./(1.+EXP(-(N(0.,1.)-0.49)/0.581)))
	Duration of close-to-depart	seconds	-1.05+10.8*(1./((1./U(0.5,0.5))-1.))**(1./4.73)
Bus 13C	Number of passengers board the bus 13C	person	17+TRUNC(U(0.5,0.5)*(50-17+1.))
	Bus 13C interarrival time	minutes	2.53+18.4*(1./(1.+EXP(-(N(0.,1.)-1.05)/0.659)))
	Duration of arrival-to-open	seconds	16+(1./0.195)*(-LN(U(0.5,0.5)))**(-1./1.63)
	Duration of open-to-close	seconds	-3.43+P5(7.62, 203)
	Duration of close-to-depart	seconds	1.6+5.39*(1./((1./U(0.5,0.5))-1.))**(1./3.2)

Element	Data	Unit	Data Distribution
Bus L13E	Number of passengers board the bus L13E	person	12+TRUNC(U(0.5,0.5)*(42-12+1.))
	Bus L13E interarrival time	minutes	-8.36+(1./0.0831)*(-LN(U(0.5,0.5)))**(-1./5.32)
	Duration of arrival-to-open	seconds	16.2+(1./0.22)*(-LN(U(0.5,0.5)))**(-1./1.85)
	Duration of open-to-close	seconds	7.1+L(25.6, 8.25)
	Duration of close-to-depart	seconds	3+P6(28.1, 2.43, 0.352)

The layout of the simulation model used in this study is visually depicted in Fig. 2. The model's structure and components are accurately represented, ensuring its fidelity to the intended conceptual framework. To verify the effectiveness of the simulation model, a validation process was conducted, as outlined in Fig. 3. The simulation results indicate that the model runs smoothly and the syntax aligns with the conceptual model's specifications. To test the model under extreme conditions, the absence of bus 13 in the system was simulated. As a result, the simulation revealed that no passengers were able to board bus 13. According to the data, out of the 577 passengers who intended to board bus 13, none exited the system (total exits = 0), as bus 13 itself was absent. The reason behind the inability of passengers on bus 13 to exit the system lies in the model's design, where a passenger entity of a specific route can only leave the system after successfully boarding a bus with the same route. In the absence of the Bus 13 entity, passengers were unable to board any buses, thus preventing them from exiting the system. This validation process serves to ensure the accuracy and reliability of the simulation model in replicating real-world scenarios and capturing the expected system behavior.

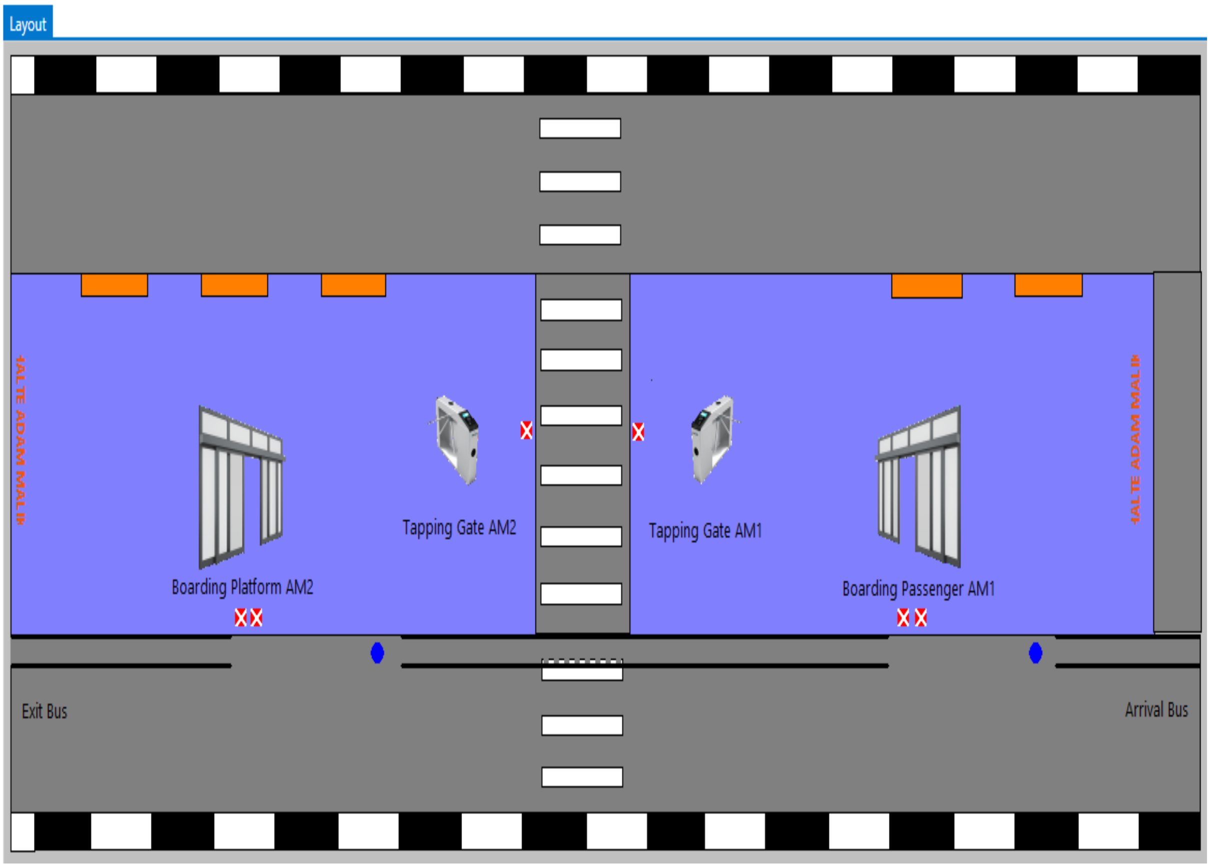

Fig. 2. Model layout

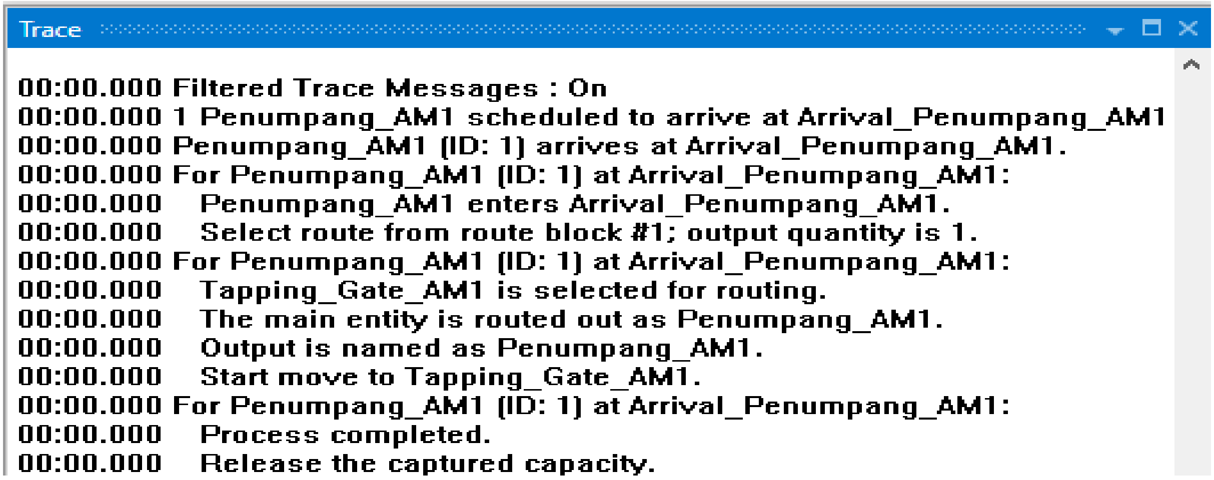

Fig. 3. Verification process

In this research study, 30 sample sizes were conducted at the Adam Malik transfer point to calculate the required replications. As depicted in Table 3, the mean of the collected data was 3058.23 and the standard deviation was 151.93. The critical values $T_{29,0.025}$ and $Z_{0.025}$ were 2.0452 and 1.96, respectively. The calculated confidence interval was 56.73, with a margin of error of 56. Based on these calculations, 30 replications were determined to be necessary for the simulation as it provides a representative sample that meets the requirements of the 95% of confidence level employed in this study. These statistical measures help ensure the accuracy and reliability of the simulation study at the Adam Malik transfer point.

Table 3. Replication calculation

Replication Calculation Components	
Mean ($\bar{x}$)	3058.23
Standard deviation (s)	151.93
Confidence level	0.95
Significance level (α)	0.05
Sample size (n)	30
n-1	29
$T_{29,0.025}$	2.0452
$Z_{0.025}$	1.96
Confidence interval (hW)	56.73
e	56
n’	29

The simulation results of the 30 replications revealed a notable difference between the waiting time experienced by passengers within the system and the predefined standards set by TransJakarta. The waiting time for buses consistently exceeded the established standard, indicating the need for system improvement. The disparities observed in the simulation outcomes are presented in Table 4. The findings revealed that adjustments in passenger boarding procedures and bus interarrival time can have a significant impact on waiting times, total exits, and system efficiency within the TransJakarta BRT system. Increasing passenger boarding rates and reducing bus interarrival time will result in shorter waiting times, faster processing, improved passenger satisfaction, and reduced congestion. These findings emphasize the importance of considering these factors in optimizing public transportation systems and improving the overall passenger experience.

Table 4. Simulation results

Entity	Average Total Exits	Average Time in System (minutes)	Gap with Standardized Interarrival Time
Passenger 13	618	4.48	0.52
Passenger 13B	509	6.12	-1.12
Passenger 13C	1143	5.94	-0.94
Passenger L13E	790	5.46	-0.46
Bus 13	43	2.94	-
Bus 13B	22	2.85	-
Bus 13C	27	2.91	-
Bus L13E	33	3.10	-

To improve the efficiency of the system and address the research gap, it is essential to determine the optimal bus interarrival while taking passenger comfort into account. This study provides an in-depth analysis of 15 scenarios (as shown in Table 5), investigating different combinations of passenger load and bus interarrival time regulation. Scenarios 1-3 concentrate on passenger boarding, 4-6 on bus interarrival time, and 7-15 explore the interaction between passenger load and bus interarrival time. The scenarios encompass passenger loads of 20-30 and bus interarrival times of 3-5 minutes. By considering these scenarios, the study offers a comprehensive evaluation of potential adjustments to optimize system efficiency and passenger comfort

Table 5. Scenario development

Scenario (s)	Max Load (Passengers)	Bus Interarrival (Min)	Scenario (s)	Max Load (Passengers)	Bus Interarrival (Min)
1	20	-	9	20	5
2	25	-	10	25	3
3	30	-	11	25	4
4	-	3	12	25	5
5	-	4	13	30	3
6	-	5	14	30	4
7	20	3	15	30	5
8	20	4			

The simulation results of the proposed scenarios are analyzed in Fig. 4-7. The Fig. 4 compares the average total exits of passengers in different scenarios. Scenarios 1-3, where passenger boarding is regulated, show variations in total exits. Higher passenger boarding leads to more passengers reaching the end of the system. Scenarios 4-6 have higher total exits due to closer bus interarrival times, resulting in more frequent boarding.

The Fig. 5 illustrates the average duration that passengers remain within the system. Scenarios 4-6

Texhibit the shortest average time, attributed to the increased frequency of bus arrivals, thereby reducing passenger waiting periods and enhancing processing efficiency. In Fig. 6, a comparison is made regarding the average number of bus departures. Scenarios 1-3 reveal a lower total number of bus departures as buses wait until reaching their passenger capacity. In contrast, scenarios 4-6 demonstrate higher total bus departures due to immediate passenger boarding and shorter intervals between buses. The analysis presented in Fig. 7 examines the average passenger time within the system. Scenarios 1-3 and 7-15 result in lengthier bus queues, as buses wait for a specific number of passengers. A higher passenger load increases the average time spent by buses within the system, emphasizing the significance of efficient passenger boarding to minimize waiting times and enhance overall system performance. Texhibit the shortest average time, attributed to the increased frequency of bus arrivals, thereby reducing.

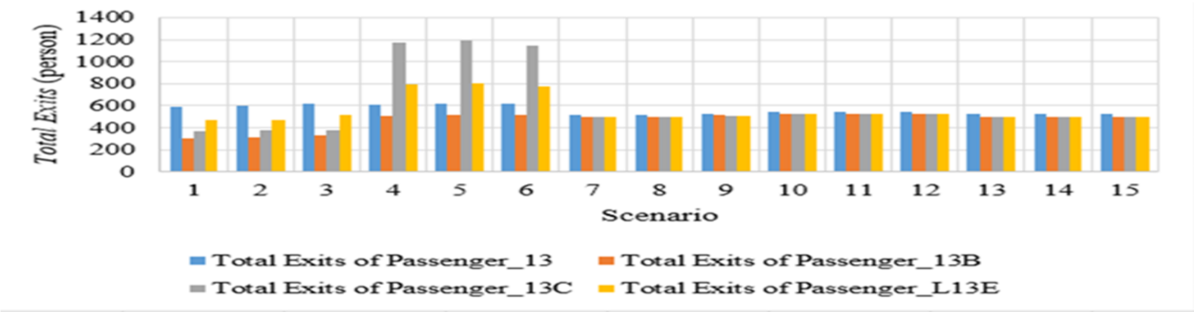

Fig. 4. Comparison of passenger total exit for each scenario

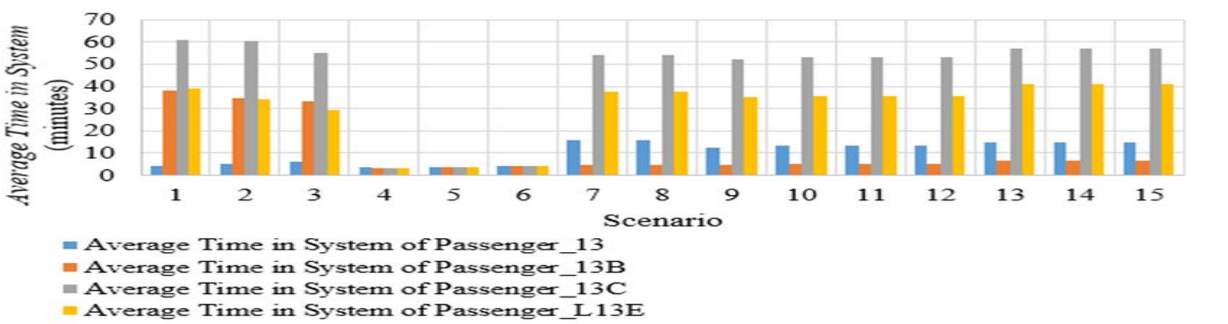

Fig. 5. Comparison of passenger average time in system for each scenario

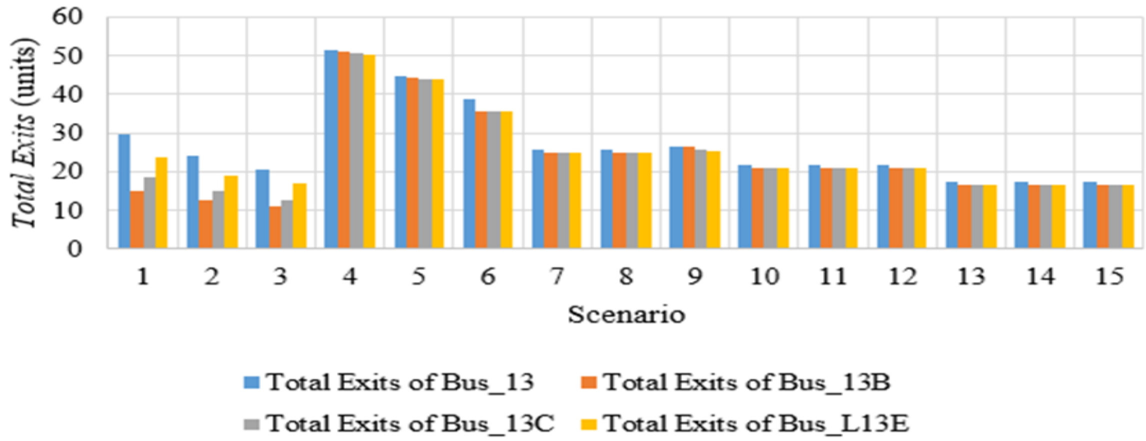

Fig. 6. Comparison of bus total exits for each scenario

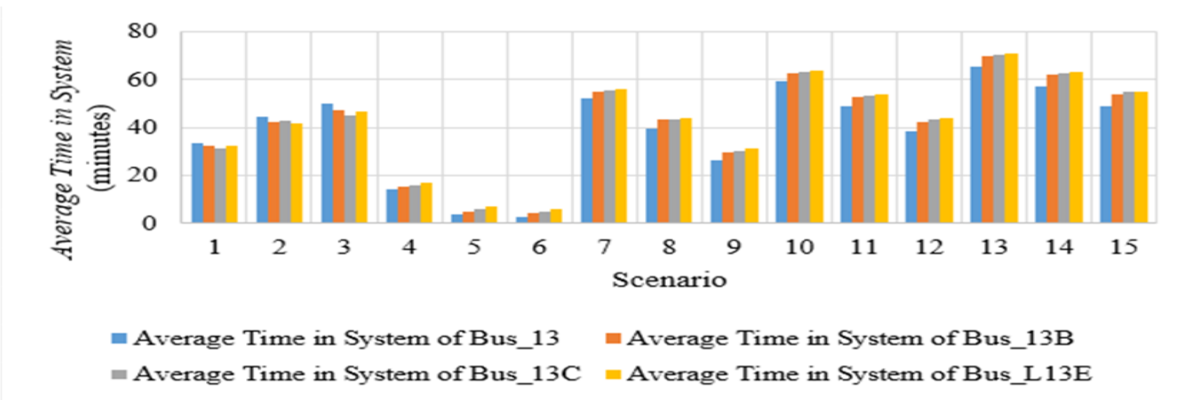

Fig. 7. Comparison of Bus average time in system for each ccenario

The simulation results obtained from this study offer valuable insights into the implications of different scenarios on passenger flow and bus operations at the Adam Malik transfer point. These findings play a crucial role in informing decision-making processes related to resource allocation, infrastructure planning, and policy implementation to improveing the efficiency and effectiveness of the transportation system. By addressing the identified gaps and implementing appropriate measures, the TransJakarta BRT system can enhance the overall commuting experience, optimize passenger flow, and effectively meet the transportation needs of the growing population in the area. Although this study has yielded valuable insights, however, it is important to acknowledge several limitations associated with this research. Firstly, the focus of this study on the Adam Malik transfer point within the TransJakarta BRT system limits the generalizability of the findings to other transfer points or corridors. Each transfer point may possess unique characteristics and experience distinct passenger demand patterns, which could impact the effectiveness of the proposed scenarios. Furthermore, this study focused mainly on the impacts of modifying passenger boarding and bus interarrival time while neglecting other important considerations such as bus capacity, operational constraints, and passenger behavior. The findings of this study rely on the assumptions and limitations of the simulation model used. When implementing these scenarios in real-world contexts, they may be influenced by external factors like varying passenger demand, traffic conditions, and operational limitations. Therefore, additional research and validation are necessary to assess the practicality, effectiveness, and potential improvements in the overall performance of the TransJakarta BRT system.

5. CONCLUSION

The study has provided valuable insights into the impact of adjusting passenger boarding procedures and bus interarrival time on waiting times, total exits, and system efficiency. Increasing passenger boarding rates and reducing bus interarrival time led to shorter waiting times, faster processing, improved passenger satisfaction, and reduced congestion. Finding a balance for passenger comfort and preventing overcrowding is essential. These findings inform transportation policy-making and contribute to optimizing public transportation systems, paving the way for future interventions to enhance the efficiency, reliability, and passenger experience in the TransJakarta BRT system to meet the evolving needs of Jakarta's commuters.

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