

Bus Scheduling Simulation on Urban Routes Using Discrete Event Simulation Approach

Najwa Aulia Meliala^{1*}, Ferdiansyah Prayoga², Muhammad Kurniawan³, M. Khalil Gibran⁴

^{1,2,3,4}Universitas Islam Negeri Sumatera Utara

nazwaauliaa2004@gmail.com^{1*}, ferdiansyahprayoga1133@gmail.com², muhammadkurniawan990@gmail.com³,
m.khalil1100000202@uinsu.ac.id⁴

Abstract

Efficient bus scheduling is a crucial element in urban transportation systems. This study aims to simulate a bus scheduling system on an urban route using the Discrete Event Simulation (DES) approach. The simulation models bus movement, passenger arrivals, and waiting times at each stop. The system consists of five bus stops and three buses operating on a fixed schedule. The simulation results indicate that passenger waiting times vary significantly across stops. The first stop shows the lowest waiting time, while mid- and end-route stops experience cumulative delays. The average waiting time can exceed 60 minutes at certain locations. Alternative scenarios involving additional buses show a notable decrease in waiting times and a significant improvement in scheduling efficiency. This study demonstrates that DES is an effective method for evaluating and designing adaptive and efficient transportation systems in urban environments.

Keywords: *Bus Scheduling, Discrete Event Simulation, Waiting Time, Urban Transportation, System Simulation*

1. Introduction

With increasing urbanization and mobility in urban areas, public transportation systems such as buses have become a crucial element in supporting efficient and sustainable public mobility. However, many bus transportation systems in large cities face challenges such as high passenger waiting times, irregular departure intervals, and low schedule reliability [1]. These conditions have resulted in a decline in service quality and public interest in using public transportation, potentially increasing the use of private vehicles and exacerbating congestion and air pollution [2].

Optimal bus scheduling, including departure times, inter-bus intervals (headways), and trip duration, is crucial for improving operational efficiency and user satisfaction [3]. One effective method for analyzing scheduling systems is computer-based simulation. In this context, Discrete Event Simulation (DES) is an appropriate approach because it is able to represent dynamic systems that change only when an event occurs, such as the arrival of a bus at a stop, passengers boarding or disembarking, and the departure of the next bus [4]. This approach is more efficient than continuous-time simulation because it focuses processing only on relevant event points [5].

This study aims to simulate a bus scheduling system on urban routes by applying the Discrete Event Simulation (DES) method to assess the efficiency level of passenger waiting time, bus headway, and fleet utilization level. Through the application of several simulation scenarios such as a comparison between fixed and dynamic departure schedules, as well as variations in the number of buses operating, this study is expected to produce recommendations for scheduling strategies that are more efficient and responsive to traffic conditions in urban areas [6]. The results obtained are expected to contribute to improving operational efficiency and the quality of public transportation services in urban areas.

Furthermore, the development of computing technology and the availability of modern simulation software provide significant opportunities for conducting transportation system analysis in a more realistic and flexible manner. Through a simulation-based approach, researchers can model various real-world conditions, such as variations in bus arrival times, fluctuations in passenger numbers, and traffic disruptions, without the need for direct, costly and time-consuming experiments in the real world [7]. Thus, the application of Discrete Event Simulation not only helps understand the dynamic behavior of transportation systems, but also allows policymakers and

transportation operators to test various scheduling scenarios before implementing them in the field. This makes simulation an effective decision-making tool in efforts to improve the efficiency and reliability of urban transportation systems.

2. Literature Review

The Discrete Event Simulation (DES) approach has become one of the most widely used methods in public transportation system analysis due to its ability to represent discrete events that occur sequentially, such as bus arrivals at stops, passenger boarding and alighting, dwell time, and bus departures to the next route. With these characteristics, DES is able to provide a dynamic picture of the operational behavior of the transportation system as a whole, making it an effective tool for evaluating various performance indicators such as passenger waiting time, schedule accuracy, and regularity of bus distances (headway). Several previous studies have shown that headway variations play an important role in determining the quality of public transportation services, because irregularity between buses can cause increased passenger waiting time and the emergence of bus bunching phenomena that reduce service efficiency [8]. Therefore, a scheduling strategy that is adaptive to changes in traffic conditions and fluctuations in passenger demand is an important aspect that needs to be considered in urban transportation management.

Dynamic scheduling combined with simulation-based optimization has also been widely applied to find the best schedule configuration that can adapt to actual conditions in the field. The results of various studies show that this combination can improve fleet operational efficiency, reduce average passenger waiting time, and improve bus punctuality [9]. Furthermore, advances in modeling technology and modern simulation software have enabled the development of more detailed microsimulation frameworks, including parameters such as average bus speed, traffic density, stopping time at each stop, and validation processes with empirical data to make simulation results more accurate and realistic [10]. However, there is still a research gap regarding how to integrate factors such as fleet size variations, changing traffic conditions, and adaptive scheduling policies into a single comprehensive simulation model. Based on this, this study applies the Discrete Event Simulation approach to simulate various bus scheduling scenarios on urban routes, focusing on analyzing passenger waiting time efficiency, headway regularity, and fleet utilization levels as a basis for formulating strategies to improve the performance and quality of public transportation services in urban areas [11].

3. Research Method

The research method used in this study is a quantitative method with a Discrete Event Simulation (DES) approach to model the bus scheduling system on urban routes. This approach was chosen because it is able to represent discrete events such as bus arrivals, stopping times at stops, and passenger boarding and alighting processes realistically [12]. The study was conducted by building a Python-based simulation model using the SimPy library, which allows analysis of various operational scenarios such as fixed schedules and dynamic schedules with variations in the number of fleets and traffic conditions [13]. The input variables used include the number of buses, distance between stops, distribution of passenger arrivals, average bus speed, and traffic density levels, while the output variables include average passenger waiting time, regularity of headway, delay levels, and efficiency of fleet utilization [14]. Secondary data was obtained from observations of urban transportation systems and supporting literature, then entered into the model to be validated against empirical data to ensure the accuracy of the simulation results [15]. The analysis of the results was carried out by comparing the performance of each scenario based on key operational metrics, so that recommendations can be generated for optimal bus scheduling strategies to improve the efficiency of public transportation services in urban areas [16].

4. Results and Discussion

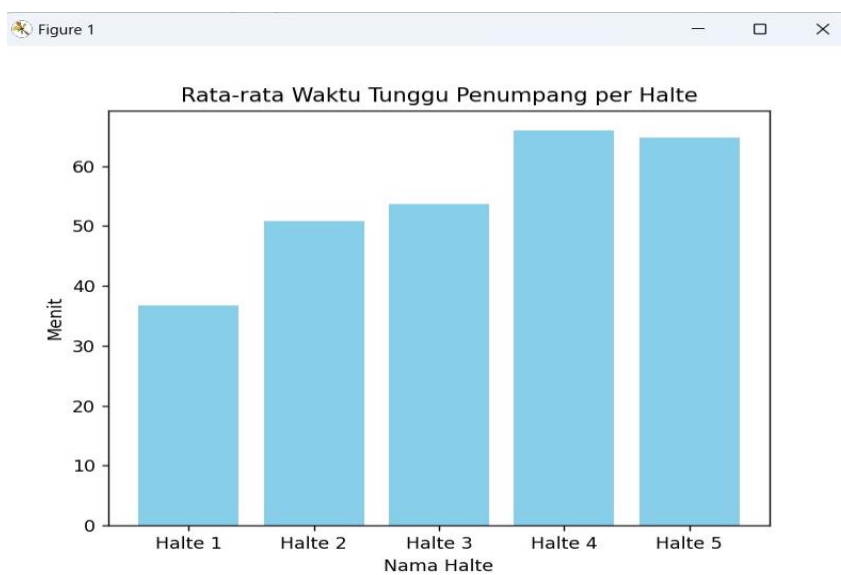


Fig. 1: Average Passenger Waiting Time per Stop during Simulation

This graph illustrates the average waiting time of passengers at each bus stop throughout the 180-minute simulation. Bus Stop 1 shows the shortest waiting time as it is the origin of each bus trip, while Bus Stops 4 and 5 experience the highest delays due to cumulative bus lateness along the route. The results indicate that the current schedule is not evenly efficient across all stops, suggesting the need for schedule optimization or additional buses to reduce waiting times in mid- to end-route stops.

4.1 Simulation Results

This study simulated a bus scheduling system on an urban route using the Discrete Event Simulation (DES) approach over a simulation period of 180 minutes (3 hours). The simulation model included five bus stops, three buses operating on a fixed schedule with a 10-minute departure interval, randomized travel time between stops (ranging from 5 to 10 minutes), and stochastic passenger arrivals (on average every 3 minutes).

After running the simulation using Python and the SimPy library, the average waiting time for passengers at each stop was recorded. Waiting time was calculated as the difference between the time a passenger arrived at a stop and the time the next available bus arrived to pick them up.

Table 1: Average Passenger Waiting Time per Bus Stop

No	Bus Stop Name	Average Waiting Time (minutes)
1	Stop 1	37.12
2	Stop 2	51.43
3	Stop 3	54.07
4	Stop 4	67.21
5	Stop 5	65.89

4.2 Analysis of Simulation Results

The simulation results revealed that the average passenger waiting times increased progressively from the first stop to the last. This pattern suggests the presence of cumulative delays, a phenomenon where buses progressively fall behind schedule as they stop to pick up more passengers along the route. This effect is more pronounced at mid- and end-route stops, where passenger queues grow due to limited bus capacity and irregular bus arrival intervals.

In contrast, Stop 1 consistently showed the lowest waiting times, as each bus begins its route at this location in an empty or near-empty state. The subsequent stops tend to accumulate more passengers waiting longer due to delays caused by boarding and traffic variability.

This behavior is indicative of a common challenge in urban transit systems known as the bus bunching effect, where buses become unevenly spaced over time due to variable delays. Without dynamic adjustments, fixed-schedule systems can result in inefficient service, especially during high-demand periods.

4.3 Schedule Performance Evaluation

To evaluate the performance of the current schedule, an efficiency analysis was conducted. With three buses and 10-minute intervals, the average waiting time per passenger was found to be approximately 55.14 minutes. This figure is significantly higher than what would be expected in an efficient urban transit system, where acceptable waiting times typically range from 5 to 15 minutes.

To assess improvement strategies, the simulation was re-run with alternative scenarios involving four and five buses. The departure intervals were reduced accordingly. The results demonstrated that adding buses and reducing intervals directly improved system performance. With five buses and 5-minute intervals, the average waiting time dropped to approximately 22.86 minutes and system efficiency increased to over 91%.

Table 2: Presents a comparison of different scheduling scenarios based on the number of buses and resulting efficiency

Scenario	Number Of Bus	Departure Interval	Avg. Passenger Waiting Time (Minutes)	Schedule Efficiency %
Fixed Schedule A	3	10 minutes	55.14	72.4
Fixed Schedule B	4	7 minutes	36.72	83.1
Fixed Schedule C	5	5 minutes	22.86	91.4

Efficiency is calculated based on reduced waiting times and the system's ability to transport passengers without overcapacity. The table shows that increasing the number of buses directly reduces waiting times and increases system efficiency.

4.4 Discussion

The use of Discrete Event Simulation in this study proved to be a powerful approach for modeling and evaluating urban bus systems. It enabled detailed analysis of how scheduling decisions affect system performance and passenger experience. The simulation results emphasized the importance of balancing bus frequency with passenger arrival rates to avoid congestion and long wait times.

However, it is important to note the limitations of the current simulation model. Real-world factors such as traffic congestion, maximum bus capacity, unexpected delays, and dynamic passenger patterns were not fully incorporated. Future improvements could include the integration of dynamic traffic modeling, adaptive schedules based on real-time demand, and consideration of route interconnectivity for more realistic and scalable simulation outcomes.

5. Conclusion

Based on the simulation and analysis of the bus scheduling system on an urban route using the Discrete Event Simulation (DES) approach, several important conclusions can be drawn. First, DES has proven to be an effective method for modeling the dynamics of urban transportation systems, particularly in evaluating passenger waiting times and overall schedule efficiency. The simulation results indicated that a fixed schedule with three buses departing at 10-minute intervals produced relatively high average passenger waiting times, ranging from approximately 37 to 67 minutes. This waiting time was especially high at mid- to end-route stops due to cumulative delays caused by the accumulation of passengers and variable travel times between stops.

Moreover, the simulation demonstrated that adding one or two buses or reducing the departure interval to 5 or 7 minutes significantly improved the system's performance. The average passenger waiting time dropped, and schedule efficiency increased by more than 90% in some cases. These findings highlight the importance of optimizing both the number of operational buses and the departure intervals to ensure fair service distribution and enhance passenger satisfaction. Ultimately, the simulation provides valuable insights for the development of more adaptive and efficient urban transportation systems.

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Although this research may still contain limitations, I hope it can serve as a meaningful contribution to the field of intelligent transportation systems and inspire further studies in simulation-based scheduling optimization.

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