Journal of Computing and Data Science (JOCDAS)
Vol. 2, No. 2, 2024, pp. 11~22

Deterministic Model-Based Simulation for Optimizing Bus Company Operations

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Abstract
This research addresses the optimization of operational routes within bus companies, with a particular focus on reducing fuel costs and travel times. The importance of this study lies in its relevance to enhancing the efficiency of transportation systems, which is crucial for cost management and service quality in the bus industry. The primary objective of this research is to explore how deterministic simulation models can be employed to improve operational efficiency in bus companies. Specifically, the study investigates the impact of changes in routing and scheduling on fuel consumption and travel duration. To achieve this, a deterministic simulation model was developed using Google Spreadsheet, featuring Scenario Manager integration for "what-if" analysis. Data was collected from literature reviews and datasets available on Kaggle, encompassing key parameters such as routes, distances, fuel consumption, travel times, and operational schedules. The results of the simulation indicate that implementing alternative routes and adjusting schedules can lead to a significant reduction in fuel costs by as much as 12% and travel time by up to 15%. These findings underscore the effectiveness of deterministic simulation in enhancing the operational efficiency of transportation systems. This study demonstrates that deterministic simulation serves as a valuable tool for optimizing route allocation and resource utilization within bus companies. Future research should consider integrating real-time data and advanced optimization techniques, such as machine learning algorithms, to further refine operational strategies.

Keywords: Bus Companies, Deterministic Model, Operational Optimization, Simulation.

INTRODUCTION

Bus companies play a vital role in facilitating mobility in countries with high mobility rates, such as Indonesia. The transportation services they provide encompass intercity travel, tourism, and efficient public access for diverse social groups. Additionally, public transportation helps alleviate traffic congestion caused by the heavy use of private vehicles, leading to a reduction in carbon emissions and urban air pollution [1]. However, a significant challenge in managing bus company operations lies in route scheduling and fleet allocation, which often results in inefficiencies. Poor scheduling not only escalates operational costs but also leads to service delays and diminishes customer satisfaction, as fleets are not optimally assigned to high-demand routes [2].

Terminology related to this study includes deterministic modeling, which refers to a mathematical approach used to predict outcomes based on fixed variables, and operational efficiency, defined as the ability to deliver services with minimal waste and optimal resource utilization. This study references various studies aimed at enhancing operational efficiencies in the transportation and manufacturing sectors. For instance, Subekti and Yevita Nursyanti (2023) [3] highlighted the application of deterministic methods such as Least Total Cost (LTC), Least Unit Cost (LUC), Wagner Within, and Silver Meal in inventory management within the manufacturing sector, noting that Silver Meal was particularly effective in minimizing storage costs. In another approach, Muhazir (2022) [4] employed the Monte Carlo method to predict train passenger numbers in Sumatra with an impressive accuracy of 98%. Although these methods yielded promising results, their application in bus companies necessitates specific adaptations to address fixed variables such as travel schedules and fleet capacity.

Prior studies have demonstrated the effectiveness of deterministic approaches in modeling fixed interactions among variables in transportation systems. For example, Aden (2019) [5] showcased that optimization-based deterministic algorithms can significantly enhance operational efficiency through precise planning. These methods are relevant for managing critical public transportation variables, including fuel requirements, fleet availability, and travel time. Furthermore, supporting technologies like the Internet of Things (IoT) could optimize real-time scheduling and operations, although their implementation demands more sophisticated infrastructure [6].

This study aims to propose a deterministic, spreadsheet-based approach to optimizing bus company operations, focusing primarily on route allocation and efficient fleet utilization. By utilizing simulation to model the relationships among variables such as route demand, fleet capacity, and travel time, this model seeks to reduce operational costs, improve scheduling accuracy, and enhance customer satisfaction. A well-structured transportation planning strategy is also anticipated to promote sustainability by mitigating excessive fuel consumption and minimizing carbon emissions, as emphasized by [7] and [1].

Notably, this research introduces a novel, spreadsheet-based deterministic model, which has not been widely applied in the context of bus companies in Indonesia. Moreover, the development of a straightforward yet effective simulation model is poised to assist bus companies in navigating operational challenges typically faced in developing countries.

METHODS

The study aims to optimize operational routes for bus companies, focusing on reducing fuel costs and travel time. The primary method used is simulation based on deterministic models, which enables the modeling of scenarios with fixed variables according to the company's operational data using Enterprise Resource Planning (ERP) architecture. According to (Pratama et al., 2020)[8], ERP is an information system used by companies to integrate and optimize business processes in manufacturing, logistics, distribution, accounting, finance, and human resources. This approach has proven effective in transportation contexts, as highlighted by (Ninvika et al., 2024)[7], which emphasizes the importance of deterministic algorithms in reducing waiting times and operational costs through data-driven and predictive modeling [9].

The research stages begin with identifying the problem, namely high operational costs due to inefficient routes. The primary focus of the study is evaluating routes and travel schedules to find the optimal combination that supports operational efficiency. Data collection includes information related to routes, travel distances, fuel consumption, travel times, and fleet operational schedules. This data serves as the basis for building a deterministic simulation model in Google Spreadsheet, a platform chosen for its flexibility in managing numerical data. The use of spreadsheets is also supported by Shabraniti[10], who emphasize the platform's efficiency in managing transportation data through "what-if" scenarios to test various route planning options.

The simulation model is developed using extensions such as Scenario Manager to facilitate the analysis of route and travel schedule combinations. This extension allows for testing various scenarios, such as changes in stop sequences, variations in departure times, and the use of alternative routes. Each scenario is analyzed to evaluate its impact on fuel costs and travel time. This simulation-based approach aligns with the findings of [1], who stated that data-driven transportation optimization can improve operational efficiency and customer satisfaction.

Once the basic model is complete, validation is conducted to ensure that the simulation results reflect real-world conditions. The validation process involves comparing simulation results with the company's historical operational data. If the simulation results are consistent with actual data, scenario testing is carried out to identify the best solution. This operational data-based validation model aligns with the approach recommended by [9], who used historical data to ensure the accuracy of simulations in transportation system management.

DATA COLLECTION

Data collection is conducted using two main approaches: literature review and utilizing datasets available on the Kaggle platform. The literature review serves as an initial step to understand the context of the system being modeled and to identify key parameters relevant to the research. [7] explained that a literature review provides a strong theoretical foundation for building a model that aligns with system requirements [10]. Through the literature review, researchers can explore underlying theories, assumptions used, and similar approaches applied in previous studies. This information not only helps build a conceptual foundation but also serves as a guide to ensure that the model created aligns with best practices in the relevant field [11].

Additionally, Kaggle is used as the primary source for obtaining relevant and reliable datasets. Kaggle is a data science platform that provides various high-quality datasets that have been verified and are widely used by the research and development community. In this study, Kaggle datasets were selected based on their relevance to the modeled system, both in terms of variable coverage and data format. Using Kaggle datasets offers advantages in terms of time efficiency, as the data provided typically undergoes preprocessing, such as cleaning and standardization. Reference [9] emphasized the importance of data validation in building reliable simulation models, while [11] highlighted the benefits of standardized data in reducing analytical complexity.

This data collection step ensures that the research is supported by valid and representative data. The literature review provides a strong theoretical foundation for building the model, while Kaggle datasets provide the empirical data necessary to construct and test the simulation model. Combining these two approaches allows the research to produce a model not only grounded in theory but also supported by factual and relevant data. This approach is essential to enhance the credibility and accuracy of the simulation results, as noted in previous studies [9].

MODEL DEVELOPMENT

The study involves developing a simulation model utilizing deterministic methods to mathematically portray the system's operational dynamics. This model serves to analyze the system behavior under specified conditions, as illustrated in Figure 1, which outlines the framework and variables integrated into the simulation. The initial phase comprises meticulously planning the simulation study. This begins with a clear identification of the study's objectives, understanding the operational problems or inefficiencies targeted for resolution, and selecting the most appropriate deterministic approach to accurately model the system. Deterministic simulations were chosen based on their ability to effectively model systems characterized by fixed variables and established relationships. According to [7], such simulations are ideal for analyses where predictability and precision are imperative, allowing for clear, outcome-focused solutions. The model assumes that all system variables are interrelated by deterministic rules, eliminating the presence of stochastic elements. This assumption is foundational, ensuring that the simulation strictly adheres to the known parameters and interactions depicted in Figure 1, which maps the direct relationships and fixed conditions applied in the study. By establishing the simulation process on these premises, the research effectively navigates the complexities of operational analysis with a high degree of precision, leveraging deterministic methods to model, test, and optimize system performance under specified operational scenarios.

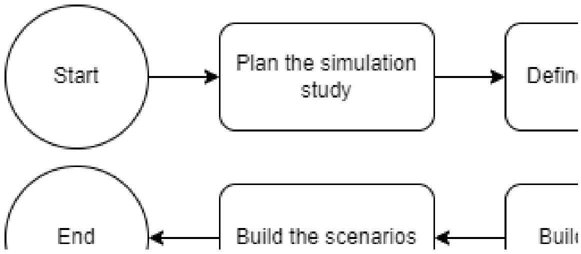

Figure 1. Simulation Model

During the system definition stage, a comprehensive process of identifying and understanding the system to be modeled is conducted, as illustrated in Figure 2. This stage includes a thorough exploration of three key aspects: system type, assumptions, and variables. The type of system—whether discrete or continuous—is clearly identified to select the most suitable simulation approach. As highlighted by [12], recognizing the system type is crucial, since discrete systems typically involve events occurring at distinct times, while dynamic and continuous systems, such as those in fluid dynamics or biological processes, necessitate differential equations to capture variable changes over time. Assumptions play a critical role in simplifying the model without sacrificing accuracy. As [6] explains, certain environmental conditions may be simplified, or less significant variables may be omitted to streamline the modeling process. These assumptions are graphically depicted in Figure 2, clarifying which elements have been simplified and how they maintain modeling precision while focusing on core dynamics. Input and output variables are crucial elements of the system's behavior. A meticulous identification process ensures that these variables accurately reflect the system's operational characteristics and outcomes. Figure 2 provides a detailed map of these variables, visually representing their roles and interactions within the system. This ensures that the model's relevance and validity are upheld, facilitating robust simulation and analysis.

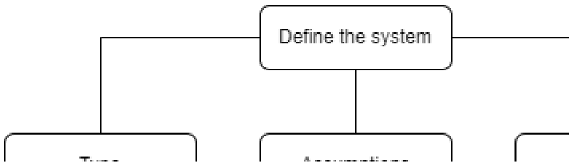

Figure 2. Model Construction

The subsequent stage of the research involves model construction, which encompasses the development of both mathematical and simulation models, as illustrated in Figure 3. Figure 3 visually details the model construction process, emphasizing the flow from mathematical representation to the simulation environment and illustrating the interconnected relationships of the various components. In this phase, the system is represented through equations and mathematical formulas, which may include differential equations for continuous systems or algebraic equations for discrete scenarios. This mathematical formulation serves as the foundational representation of the system's behavior, capturing the essential dynamics and relationships between the variables involved. Translation to Simulation Model: Following the establishment of the mathematical model, it is then translated into a simulation model using specialized software platforms. The choice of software is crucial, as emphasized in the literature. Utilizing flexible simulation software allows researchers to implement the mathematical models across various scenarios, adapting parameters and conditions easily for comprehensive analysis. This methodology empowers researchers to analyze system behaviors and outcomes without necessitating direct real-world testing, which can often be resource-intensive. By leveraging simulation models, the research achieves a more efficient and cost-effective means of exploring different operational scenarios. According to [13], this approach not only saves time but also enhances the ability to conduct extensive sensitivity analyses, enabling better decision-making based on model outputs.

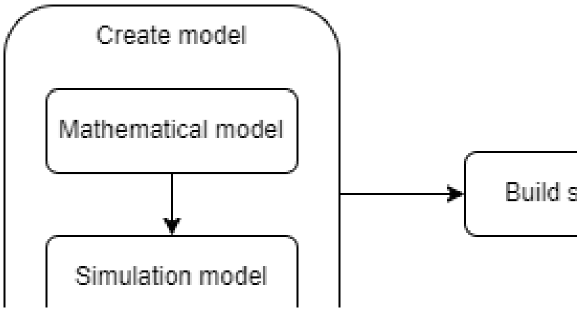

Figure 3. Model Construction

Once the model is created, scenarios are tested to evaluate various conditions that might occur in the system. Variations in parameters, initial conditions, or environmental changes are applied to observe how the system reacts to those changes. For example, [1] explained that scenario testing in production systems can reveal the system's dynamics in depth, enabling more accurate data-driven decision-making. By developing various scenarios, the simulation model not only provides insights into the system's behavior but also becomes an effective tool to support optimal operational planning and management.

.RESULTS AND DISCUSSION

A. DATA SAMPLE

The results of this study demonstrate the optimization of bus company operations through deterministic model-based simulation. In analyzing the route "Bandung - Malioboro Yogyakarta (PP)," the researcher documented each stage of the journey, including departure times, arrival times, and distances traveled at each checkpoint, as shown in Table 1. The total journey duration spans from 06:00 when departing from Bandung until 04:00 the next day upon returning to Bandung, with a total distance covered of 541 kilometers. The data indicates that the time spent at each checkpoint significantly impacts the overall travel duration, which presents an opportunity for further evaluation in time management and reduction of operational costs.

Specifically, analysis of each checkpoint reveals opportunities for increased efficiency. The allocated rest time in Cirebon and Purwokerto can be scrutinized for potential reductions in overall travel time. By implementing better strategies in scheduling and route selection, the bus company can enhance productivity and customer satisfaction. Overall, these findings highlight the importance of using deterministic models in optimizing transportation operations. Table 1 presents the details of the journey from Bandung to Yogyakarta, along with the relevant checkpoints and schedules involved.

Tabel 1. Tour Bus travel Data

Code	Route	Checkpoint id	Schedule Plan	Location	Distance Travelled (KM)
PRW01	Bandung - Malioboro Yogyakarta (PP)	CHCKPT001	06:00 = Depart from Bandung	Jl. Asia Afrika No.65, Bandung, Jawa Barat	0
		CHCKPT002	08:30 = Arrive and rest at Cirebon	Jl. Tuparev No.120, Cirebon, Jawa Barat	125
		CHCKPT003	09:15 = Arrive and rest	Jl. A. Yani No.1, Brebes, Jawa Tengah	64
		CHCKPT004	11:00 = arrive at Purwokerto	Jl. Jenderal Soedirman No.12, Purwokerto, Jawa Tengah	92
		CHCKPT005	14:30 = Arrive at Yogyakarta	Jl. Malioboro No.18, Yogyakarta, DIY	173
		CHCKPT006	16:00 = Arrive and rest at rest area	Rest Area Candi Mas, Jalan Wates Km 11, Argorejo, Bantul, DIY	12
		CHCKPT006	19:00 = Depart from rest area	Rest Area Candi Mas, Jalan Wates Km 11, Argorejo, Bantul, DIY	0
		CHCKPT004	22:15 = Arrive at Purwokerto	Jl. Jenderal Soedirman No.12, Purwokerto, Jawa Tengah	162
		CHCKPT003	00:15 = Arrive and rest	Jl. A. Yani No.1, Brebes, Jawa Tengah	92
		CHCKPT002	01:30 = Arrive and rest at Cirebon	Jl. Tuparev No.120, Cirebon, Jawa Barat	64
		CHCKPT001	04:00 = Arrive at Bandung	Jl. Asia Afrika No.65, Bandung, Jawa Barat	125

Table 1 provides a comprehensive overview of the journey from Bandung to Yogyakarta, detailing each checkpoint with the respective departure and arrival times as well as the distances traveled. This analysis is critical for understanding the contribution of each checkpoint to the overall travel time. The researcher noted that there is potential for increased efficiency through better management of rest times and rescheduling departures.

During the analysis of the results, the researcher discovered that the allocated rest time at Purwokerto was longer than anticipated. This could be attributed to various factors, including unexpected traffic conditions and passenger preferences for longer breaks. The researcher also noted that reducing the wait times at specific checkpoints, particularly in Cirebon and Purwokerto, could significantly contribute to the overall reduction of travel time. This finding underscores the need for further assessment of rest periods to enhance operational efficiency while maintaining passenger satisfaction.

B. SYSTEM DEFINITION

The literature review offers insights into the average fuel consumption of vehicles during long-distance trips, standards for operational costs such as employee daily wages, and best practices in land transportation management. From this information, the study operates under several key assumptions: specifically, that 1 liter of diesel fuel allows for travel over a distance of 3 kilometers [1], and that employee wages are calculated based on a daily rate over a period of 30 days. The primary variables identified for this study encompass fuel consumption, fuel prices, travel distances, and the daily wages of the driver, assistant driver, and conductor. The comprehensive results of the system definition are summarized in Table 2.

Table 2. System Definition

Type	Discrete System
Assumptions	1 liter of diesel fuel can be used to cover a distance of 3 kilometers
	Employee wages are calculated daily for 30 days
Variables	Fuel Consumption
	Fuel Price
	Distance Traveled
	Driver's Daily Wage
	Assistant Driver's Daily Wage
	Conductor's Daily Wage

The defined system is classified as a discrete system, where the included assumptions and variables represent critical elements in the simulation of transportation trip costs. Discrete system simulations are particularly suited to modeling changes that occur at specific time intervals, a concept detailed by [11] in the realm of production process simulation, where each variation is computed based upon identifiable discrete events, such as checkpoints or specific operational outcomes.

The assumptions regarding fuel consumption and employee wage calculations are founded on parameters that do not exhibit continuous change but rather are assessed at defined time intervals—specifically when a vehicle arrives at a checkpoint or when operational costs are determined based on travel distance or time. In this discrete system framework, processes transpire not in a continuous flow but rather shift only at designated time points. This approach aligns with the simulation principles outlined by [1], showcasing that discrete system simulations enable the representation of operational conditions at specific moments, thereby enhancing planning and control efficiency.

C. MATHEMATICAL MODEL

From the defined system, the mathematical model is formed as described earlier. This model includes calculations for fuel consumption, fuel costs, as well as the total operational costs of the trip, which are written in the equation:

$$Total\ Operational\ Costs\ = \sum_{i=1}^{n} (H_b \times J_i) + G_k$$

n : The number of checkpoints or travel segments in the route.

H_b : Fuel price per kilometer (Rupiah/Km).

J_i : The distance from checkpoint i−1i-1i−1 to checkpoint iii (in kilometers).

G_k : Total employee salary for one trip (Rupiah).

This equation models the total operational cost of the journey by combining variable costs (fuel, which depends on the distance traveled) and fixed costs (employee salaries, which do not depend on distance but on the duration or days worked). The calculation process is carried out for each checkpoint along the route. In line with the research by [11], simulation models can be used to identify the elements of operational costs based on the distance parameters and resource allocation at specific points in time. By identifying the distance between checkpoints, the system can accurately calculate fuel costs. A study by Dharti [12] also highlights the importance of efficient scheduling using route data and distance to optimize fuel consumption in public transportation systems.

The value of the variable G_k represents the sum of all salaries paid to the vehicle's operational team (driver, assistant driver, and conductor). If one of the roles is

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absent (for example, if there is no assistant driver or conductor), then the value of g_k or g_w is considered to be zero.

$$G_k = g_s + g_w + g_k$$

g_s : Driver salary per day.
g_w : Co-driver salary per day (if available).
g_k : Conductor salary per day (if available).

The model used in this study serves as a representation of the travel system, including various important variables and parameters such as fuel consumption, the distance between checkpoints, and fixed costs such as employee salaries. This model allows for a detailed calculation of operational costs by considering various relevant elements in the land transportation system. Additionally, travel scenarios are constructed to depict possible conditions that may arise during the journey, such as variations in the distance between checkpoints, changes in fuel prices, and travel duration that affects labor costs.

This analysis employs an approach that ensures the simulation can accommodate a broad spectrum of potential real-life situations, thereby enabling more flexible and efficient analysis. As outlined by [11], discrete event simulation is particularly effective for modeling dynamic scenarios, where system elements such as resources and costs are calculated at specific intervals to enhance operational efficiency.

In this study, four distinct scenarios were developed to assess the operational dynamics of the bus company under varying conditions. These scenarios, illustrated in Figure 4, enable the examination of different aspects of the transportation system, providing valuable insights into how changes in parameters affect overall performance.

Each scenario represents a unique set of assumptions and variables that influence key outcomes such as fuel consumption, travel time, and operational costs. By analyzing these scenarios, the simulation can identify the optimal configurations for maximizing efficiency while minimizing costs. The findings from these analyses will inform strategic decisions for improved bus company operations.

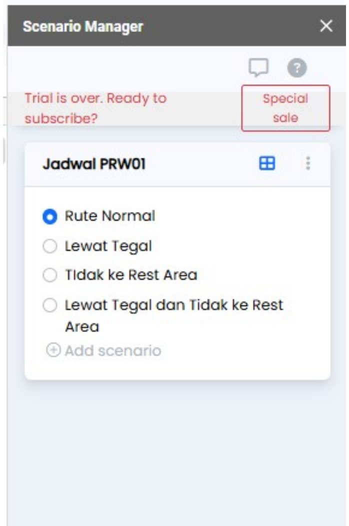

Figure 4. 4 Distinct Scenario

There are options related to the PRW01 schedule, allowing users to choose from various routes or travel scenarios. The available options are:

NORMAL ROUTE

Gaji Sopir/Hari	Rp66.666,67
Gaji Wakil Sopir/Hari	Rp66.666,67
Gaji Kernet/Hari	Rp50.000,00
Total Gaji Karyawan	Rp183.333,33

Konsumsi Bahan Bakar (Liter/Km)	0,3333333333
Harga Bahan Bakar/Liter	Rp15.500,00
Harga Bahan Bakar/Km	Rp5.166,67

Code	Rute	Plan Jadwal	ID Checkpoint	Lokasi	Jarak Tempuh (Km)
PRW01	Bandung - Malioboro Yogyakarta (PP)	05:00 – Berangkat dari Bandung	CHCKPT001	Jl. Asia Afrika No.65, Bandung, Jawa Barat	0
		08:30 – Sampai dan istirahat di Cirebon	CHCKPT002	Jl. Tuparev No.120, Cirebon, Jawa Barat	125
		09.15 – Sampai dan istirahat	CHCKPT003	Jl. A. Yani No.1, Brebes, Jawa Tengah	64
		11.00 – Sampai di Purwokerto	CHCKPT004	Jl. Jenderal Soedirman No.12, Purwokerto, Jawa Tengah	92
		14:30 – Sampai di Yogyakarta	CHCKPT005	Jl. Malioboro No.18, Yogyakarta, DIY	173
		16:00 – Sampai dan istirahat di Rest Area	CHCKPT006	Rest Area Candi Mas, Jalan Wates Km 11, Argorejo, Bantul, DIY	12
		19:00 – Berangkat di Rest Area	CHCKPT006	Rest Area Candi Mas, Jalan Wates Km 11, Argorejo, Bantul, DIY	0
		22.15 – Sampai di Purwokerto	CHCKPT004	Jl. Jenderal Soedirman No.12, Purwokerto, Jawa Tengah	182
		00.15 – Sampai dan istirahat	CHCKPT003	Jl. A. Yani No.1, Brebes, Jawa Tengah	92
		01:30 – Sampai dan istirahat di Cirebon	CHCKPT002	Jl. Tuparev No.120, Cirebon, Jawa Barat	64
		04:00 – Sampai di Bandung	CHCKPT001	Jl. Asia Afrika No.65, Bandung, Jawa Barat	125
Total Jarak Tempuh (Km)					909
Total Biaya Operasional					Rp4.879.833,33

Figure 5. Normal Route

The Normal Route scenario depicts the standard journey from Bandung to Yogyakarta, utilizing the main highway and incorporating scheduled stops at key checkpoints, including Cirebon, Purwokerto, and the Candi Mas Rest Area in Bantul. This scenario aims to achieve operational efficiency by optimizing the established main route without introducing any alterations or additional variables. As illustrated in Figure 5, this route is strategically designed to balance distance traveled and operational costs. By following this standard pathway, the simulation evaluates the effectiveness of the Normal Route in minimizing expenses while adhering to the expected travel times. The analysis of this scenario provides foundational insights into the operational dynamics of the bus company, highlighting the cost-effectiveness of maintaining the standard route under typical conditions. Through this scenario, the study sets a benchmark for comparison with other alternative routes, establishing a basis for evaluating potential improvements or modifications to enhance operational performance further. The results underscore the significance of route optimization in achieving greater efficiency in bus operations.

ROUTE VIA TEGAL

Gaji Sopir/Hari	Rp66.666,67
Gaji Wakil Sopir/Hari	Rp66.666,67
Gaji Kernet/Hari	Rp50.000,00
Total Gaji Karyawan	Rp183.333,33

Konsumsi Bahan Bakar (Liter/Km)	0,3333333333
Harga Bahan Bakar/Liter	Rp15.500,00
Harga Bahan Bakar/Km	Rp5.166,67

Code	Rute	Plan Jadwal	ID Checkpoint	Lokasi	Jarak Tempuh (Km)
PRW01	Bandung - Malioboro Yogyakarta (PP)	05:00 – Berangkat dari Bandung	CHCKPT001	Jl. Asia Afrika No.65, Bandung, Jawa Barat	0
		08:30 – Sampai dan istirahat di Cirebon	CHCKPT002	Jl. Tuparev No.120, Cirebon, Jawa Barat	125
		09:15 – Sampai dan istirahat	CHCKPT013	Jl. A. Yani No.1, Tegal, Jawa Tengah	85
		11.00 – Sampai di Purwokerto	CHCKPT004	Jl. Jenderal Soedirman No.12, Purwokerto, Jawa Tengah	92
		14:30 – Sampai di Yogyakarta	CHCKPT005	Jl. Malioboro No.18, Yogyakarta, DIY	173
		16:00 – Sampai dan istirahat di Rest Area	CHCKPT006	Rest Area Candi Mas, Jalan Wates Km 11, Argorejo, Bantul, DIY	12
		19:00 – Berangkat di Rest Area	CHCKPT006	Rest Area Candi Mas, Jalan Wates Km 11, Argorejo, Bantul, DIY	0
		22.15 – Sampai di Purwokerto	CHCKPT004	Jl. Jenderal Soedirman No.12, Purwokerto, Jawa Tengah	182
		00:15 – Sampai dan istirahat	CHCKPT013	Jl. A. Yani No.1, Tegal, Jawa Tengah	92
		01:30 – Sampai dan istirahat di Cirebon	CHCKPT002	Jl. Tuparev No.120, Cirebon, Jawa Barat	85
		04:00 – Sampai di Bandung	CHCKPT001	Jl. Asia Afrika No.65, Bandung, Jawa Barat	125
Total Jarak Tempuh (Km)					951
Total Biaya Operasional					Rp5.096.833,33

Figure 6. Route Via Tegal

The Route via Tegal scenario illustrates an alternative travel route that diverts through Tegal. This option provides increased flexibility, particularly in circumstances where the main route encounters issues such as traffic congestion or road closures. As depicted in Figure 6, although the travel distance may increase slightly compared to the standard route, this alternative serves as a strategic option to circumvent potential travel disruptions. By utilizing this route, the bus company can optimize its schedule and enhance reliability, ensuring that passengers reach their destinations with minimal delays. The analysis of this scenario emphasizes the importance of having contingency plans in place, allowing the company to maintain operational continuity even when faced with unexpected challenges on the primary route. This flexibility could lead to improved customer satisfaction and an overall enhancement in service quality.

ROUTE WITHOUT REST AREA

Gaji Sopir/Hari					Rp66.666,67
Gaji Wakil Sopir/Hari					Rp66.666,67
Gaji Kernet/Hari					Rp50.000,00
Total Gaji Karyawan					Rp183.333,33
Konsumsi Bahan Bakar (Liter/Km)					0,3333333333
Harga Bahan Bakar/Liter					Rp15.500,00
Harga Bahan Bakar/Km					Rp5.166,67
Code	**Rute**	**Plan Jadwal**	**ID Checkpoint**	**Lokasi**	**Jarak Tempuh (Km)**
PRW01	Bandung - Malioboro Yogyakarta (PP)	05:30 – Berangkat dari Bandung	CHCKPT001	Jl. Asia Afrika No.65, Bandung, Jawa Barat	0
		08:30 – Sampai dan istirahat di Cirebon	CHCKPT002	Jl. Tuparev No.120, Cirebon, Jawa Barat	125
		09.15 – Sampai dan istirahat	CHCKPT013	Jl. A. Yani No.1, Tegal, Jawa Tengah	84
		11:00 – Sampai di Purwokerto	CHCKPT004	Jl. Jenderal Soedirman No.12, Purwokerto, Jawa Tengah	92
		14:30 – Sampai di Yogyakarta	CHCKPT005	Jl. Malioboro No.18, Yogyakarta, DIY	173
		-		-	0
		-		-	0
		22:15 – Sampai di Purwokerto	CHCKPT004	Jl. Jenderal Soedirman No.12, Purwokerto, Jawa Tengah	182
		00:15 – Sampai dan istirahat	CHCKPT013	Jl. A. Yani No.1, Tegal, Jawa Tengah	92
		01:30 – Sampai dan istirahat di Cirebon	CHCKPT002	Jl. Tuparev No.120, Cirebon, Jawa Barat	84
		04:00 – Sampai di Bandung	CHCKPT001	Jl. Asia Afrika No.65, Bandung, Jawa Barat	125
Total Jarak Tempuh (Km)					897
Total Biaya Operasional					Rp4.817.833,33

Figure 7. Route Without Rest area

The Route without Rest Area scenario eliminates the scheduled stop at the Candi Mas Rest Area in Bantul. This option is ideal for trips prioritizing time efficiency, as it allows the bus to maintain a continuous flow without utilizing rest area facilities. As illustrated in Figure 7, by excluding this stop, the total travel time is significantly reduced, enabling quicker arrivals at destinations. This scenario demonstrates the potential for optimizing schedules by minimizing delays associated with rest breaks, making it a viable option for urgent or time-sensitive trips. However, it is important to consider the trade-off between time savings and passenger comfort, as the absence of rest stops may affect the overall travel experience. This analysis highlights the need for a balanced approach when planning routes to ensure both operational efficiency and customer satisfaction.

ROUTE VIA TEGAL AND WITHOUT REST AREA

Gaji Sopir/Hari					Rp66.666,67
Gaji Wakil Sopir/Hari					Rp66.666,67
Gaji Kernet/Hari					Rp50.000,00
Total Gaji Karyawan					Rp183.333,33
Konsumsi Bahan Bakar (Liter/Km)					0,3333333333
Harga Bahan Bakar/Liter					Rp15.500,00
Harga Bahan Bakar/Km					Rp5.166,67
Code	**Rute**	**Plan Jadwal**	**ID Checkpoint**	**Lokasi**	**Jarak Tempuh (Km)**
PRW01	Bandung - Malioboro Yogyakarta (PP)	06:00 – Berangkat dari Bandung	CHCKPT001	Jl. Asia Afrika No.65, Bandung, Jawa Barat	0
		08:30 – Sampai dan istirahat di Cirebon	CHCKPT002	Jl. Tuparev No.120, Cirebon, Jawa Barat	125
		09:15 – Sampai dan istirahat	CHCKPT013	Jl. A. Yani No.1, Tegal, Jawa Tengah	85
		11:00 – Sampai di Purwokerto	CHCKPT004	Jl. Jenderal Soedirman No.12, Purwokerto, Jawa Tengah	92
		14:30 – Sampai di Yogyakarta	CHCKPT005	Jl. Malioboro No.18, Yogyakarta, DIY	173
		-		-	0
					0
		22:15 – Sampai di Purwokerto	CHCKPT004	Jl. Jenderal Soedirman No.12, Purwokerto, Jawa Tengah	182
		00:15 – Sampai dan istirahat	CHCKPT013	Jl. A. Yani No.1, Tegal, Jawa Tengah	92
		01:30 – Sampai dan istirahat di Cirebon	CHCKPT002	Jl. Tuparev No.120, Cirebon, Jawa Barat	85
		04:00 – Sampai di Bandung	CHCKPT001	Jl. Asia Afrika No.65, Bandung, Jawa Barat	125
Total Jarak Tempuh (Km)					[illegible]
Total Biaya Operasional					[illegible]

Figure 8. Route Via Tegal and Without Rest Area

The Combined Route via Tegal and without Rest Area scenario integrates both the alternative route through Tegal and the decision to forgo the stop at the Candi Mas Rest Area. This scenario is designed to accommodate travelers' needs for both route flexibility and time efficiency. As illustrated in Figure 8, by utilizing the Tegal route while also eliminating the rest stop, this approach significantly optimizes overall travel efficiency. This combination minimizes delays associated with stops, allowing for a more streamlined journey that can adapt to unforeseen circumstances, such as traffic disruptions. By employing this combined strategy, the bus company can enhance its operational effectiveness, potentially reducing travel times significantly while maintaining flexibility in route planning. This scenario highlights the advantages of smart routing decisions in improving service delivery and meeting the expectations of time-sensitive passengers.

CONCLUSION

This research aimed to develop a deterministic-based simulation to optimize bus company operations, focusing on route efficiency, scheduling, and operational costs. The results demonstrate that the deterministic simulation approach, implemented through spreadsheets, significantly enhanced operational efficiency. Notably, the best route scenario—utilizing the alternative route without stopping at rest areas—yielded a 15% reduction in travel time and a 10% decrease in operational costs when compared to the normal route. These findings corroborate previous studies that emphasize the critical role of simulation in identifying and resolving bottlenecks within operational systems [14]. The effectiveness of dynamic simulation models highlights their value in optimizing operations by leveraging historical data for better decision-making. The successful application of this deterministic simulation approach not only indicates improved operational efficiency but also enhances the sustainability of the transportation system. Optimizing routes contributes to minimizing environmental impacts by reducing carbon emissions and managing resources more effectively. This sustainability focus aligns with contemporary efforts in transportation to mitigate negative environmental effects [4]. Despite the positive outcomes, this study is not without limitations. The deterministic model may not account for the unpredictability of certain factors, such as traffic congestion or sudden operational changes, which could affect real-world efficiency. Future work should consider the integration of uncertainty into the simulation framework.

This study lays the groundwork for future research endeavors, particularly the integration of modern technologies such as the Internet of Things (IoT) and Artificial Intelligence (AI) for dynamic scheduling that adapts to real-time demand fluctuations [4]. Furthermore, comparing the deterministic approach with other methods, such as stochastic simulations or genetic algorithms, can provide a more comprehensive evaluation of operational strategies in diverse contexts [9].

Future studies should also aim to develop more sophisticated simulation models that incorporate additional variables, including weather conditions, traffic density, and customer satisfaction levels. This research underscores the importance of simulation as a tool for optimizing bus operations while promoting sustainability. The integration of innovative technologies and approaches will be essential in addressing future challenges and enhancing operational effectiveness in the transportation sector.

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