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Analysis of Determinant Factors of Operational Efficiency of Mass Transportation Modes and Their Implications for Social Welfare (Case Study of Urban Transport Networks)

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ABSTRACT

The operational efficiency of mass transportation is a critical factor in urban mobility, with significant implications for social welfare. However, many cities in developing countries face challenges in achieving optimal efficiency, impacting service quality and community accessibility. This study aims to analyze the determinant factors of operational efficiency in urban mass transportation modes and examine their implications for social welfare in the context of Indonesian cities. Employing a quantitative approach, this research utilized Data Envelopment Analysis (DEA) and multiple regression methods to evaluate 15 urban transportation corridors across Jakarta, Surabaya, and Bandung during the 2022-2024 period. Data were collected through direct observation, surveys of 1,200 passengers, and in-depth interviews with operators and regulators. The analysis revealed that service frequency, load factor ratio, and fleet quality are the dominant factors affecting operational efficiency, collectively contributing 68.4% to efficiency variations. Operational efficiency demonstrated a strong positive correlation with accessibility for low-income populations (r=0.742) and contributed to reducing household transportation costs by up to 23.6%. Furthermore, efficient corridors showed significantly lower carbon emissions (0.68 kg CO_2 per passenger-km) compared to inefficient corridors. The findings underscore the crucial relationship between transportation operational efficiency and social welfare outcomes. To maximize both efficiency and social benefits, policymakers should prioritize fleet modernization, optimize operational schedules, and enhance system integration through coordinated tariff structures and infrastructure development.

INTRODUCTION

Urban mass transportation has a strategic role in supporting the mobility of urban communities and contributing to social well-being (Ayuriany et al., 2023). As the backbone of the transportation system in big cities, mass transportation modes not only function as a means of moving people from one place to another, but also become an enabler for people's economic, social, and cultural activities. However, various major cities in Indonesia still face significant challenges related to the operational efficiency of the public transportation system which has an impact on the quality of services and accessibility of the community, especially the lower middle economic group (Ode et al., 2023).

The operational efficiency problem of mass transportation modes includes technical aspects such as fleet utilization, fuel consumption, and delays, as well as managerial aspects including route planning, scheduling, and vehicle maintenance (Wahyuni et al., 2020). This inefficiency condition not only results in financial losses for operators which in turn can threaten the continuity of services, but also reduces the quality of services which ultimately reduces the attractiveness of public transport and encourages people to switch to the use of private vehicles (Aprilia, 2023). This phenomenon creates a negative cycle where a decrease in passenger numbers worsens the financial

condition of the operator, which in turn forces the operator to reduce investment in improving the quality of service.

From a social welfare perspective, an efficient mass transportation system can have a very broad multiplier impact (Guzmán et al., 2015; Rothengatter, 2017). These impacts are in the form of increased accessibility to economic opportunities such as access to workplaces, education centers, and health facilities, reduced burden of household transportation costs that free up resources for other productive consumption, reduced air pollution that impacts public health, and reduced traffic congestion that saves travel time and increases overall economic productivity of the city (Ayuriany et al., 2023). However, the causal relationship between operational efficiency and various social welfare indicators still requires a comprehensive and in-depth empirical study to uncover the mechanism and magnitude of their impact (Ferraz et al., 2025; Wang et al., 2024).

At the global level, cities have shown that investments in efficient mass transportation systems generate significant returns not only in the form of financial returns for operators, but more importantly in the form of social returns in the form of improving people's quality of life, reducing socioeconomic disparities, and building more sustainable cities (Pramesti et al., 2024). However, the context of implementation in developing countries such as Indonesia has unique challenges that differ from developed countries, including resource limitations, fragmentation of operating systems, institutional capacity that still needs to be strengthened, and complexity of coordination between stakeholders (Ferraz et al., 2025; Wang et al., 2024).

This study aims to identify and analyze the factors that determine the operational efficiency of urban mass transportation modes by considering the operational context of Indonesia, measuring the relative efficiency level between transportation corridors to identify best practices and gaps that need to be closed, and evaluating the implications of operational efficiency on various dimensions of social welfare indicators. The case study was conducted on urban transportation networks in three major Indonesian cities with different demographic, geographical, and development characteristics of transportation systems, so as to provide comprehensive insights and apply to various urban contexts in Indonesia (Hidayati et al., 2019; Joewono et al., 2016; Yudhistira et al., 2019).

The significance of this research lies in its contribution in bridging the gap between technical efficiency analysis that tends to focus on operational optimization and social impact analysis that often ignores the efficiency aspect as an intermediary mechanism. By integrating these two perspectives in one comprehensive analytical framework, this study is expected to provide actionable evidence-based recommendations for policy makers and transportation practitioners in designing interventions that not only improve operational efficiency but also produce maximum and inclusive social impact.



Figure 1. Conceptual Framework
Source: Author's Analysis (2025)

Concept of Transportation Operational Efficiency

Operational efficiency in the context of mass transportation is defined as the system's ability to generate maximum service output with minimal resource inputs (Hardi & Murad, 2023). This concept includes three main dimensions, namely technical efficiency that measures the ratio of output to physical inputs, allocative efficiency that assesses the optimal combination of inputs taking into account price, and cost efficiency that integrates the two dimensions (Aprilia, 2023).

The literature shows that the determinants of operational efficiency can be categorized into internal factors including fleet characteristics, operational capacity, management systems, and quality of human resources, as well as external factors including infrastructure conditions, government regulations, demand patterns, and route network characteristics. Research by Cazuza de Sousa Júnior et al. (2023) found that real-time information system integration can improve operational efficiency by up to 18.3% through dispatching and scheduling optimization.

Mass Transportation and Social Welfare

Social well-being in the context of transportation is measured through indicators of accessibility, affordability, reliability of services, and environmental impact (Loilatu et al., 2020). The theory of welfare economics emphasizes that an efficient public transportation system

contributes to an increase in consumer surpluses through reduced travel costs and travel time, as well as positive externalities in the form of reduced pollution and congestion (Ayuriany et al., 2023).

Empirical studies in various developing countries show that every 10% increase in public transport accessibility correlates with a 3.2% increase in the labor force participation of low-income groups. Research by Aprilia (2023) also identified that the operational efficiency of mass transportation has a significant redistributive effect because low-income groups tend to be more dependent on public transportation modes.

Efficiency Measurement Methods

Data Envelopment Analysis (DEA) is a non-parametric method that is widely used to measure the relative efficiency of decision-making units. This method has the advantage of handling multiple inputs and outputs without requiring the assumption of the form of the production function (Riawan & Ahyudanari, 2020). The DEA models commonly used in the transportation sector are CCR (Charnes-Cooper-Rhodes) to measure technical efficiency and BCC (Banker-Charnes-Cooper) to identify purely technical efficiency by considering variable returns to scale (Naim et al., 2022).

RESEARCH METHOD

Research Design and Data Collection

This study uses a quantitative approach with an explanatory research design to explain the causal relationship between the determinants of operational efficiency and the actual level of efficiency, as well as their impact on social welfare. The object of the study was 15 Bus Rapid Transit (BRT) transportation corridors and conventional public transportation in Jakarta, Surabaya, and Bandung which were selected by purposive sampling based on the criteria of passenger volume, route length, and geographical representation.

Primary data was collected through direct observation of fleet operations, a stated preference survey of 1,200 passengers using stratified random sampling techniques, and in-depth interviews with 30 operators and transportation regulators. Secondary data was obtained from operator operational reports, statistical data from the Transportation Agency, and publications from the Central Statistics Agency for the 2022-2024 period.

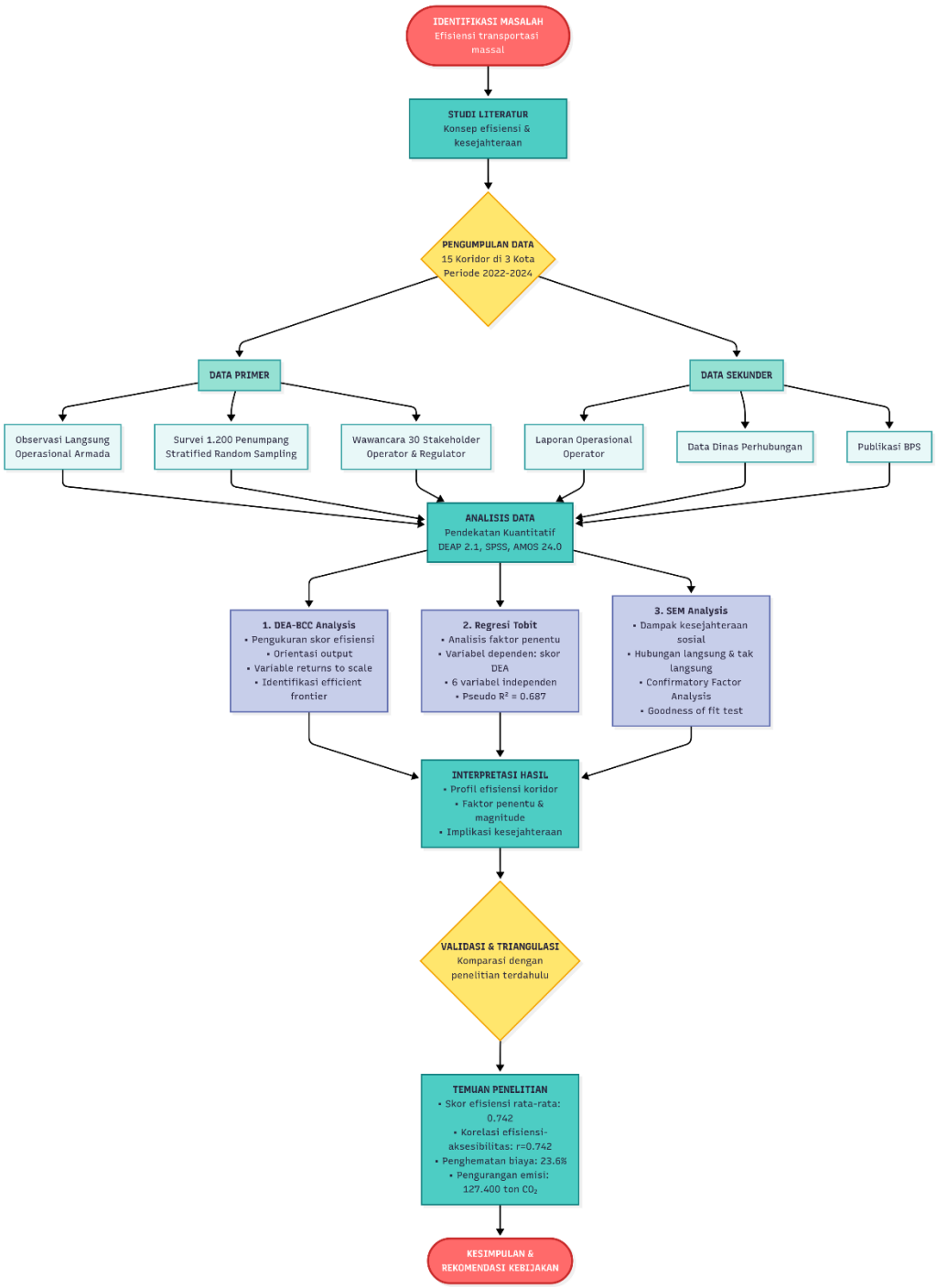


Figure 2. Research Methodology
Source: Author's Analysis (2025)

Research Variables

The input variables in the DEA model include the number of operational fleets, total operating hours per day, fuel consumption per kilometer, and total operating costs (Riawan & Ahyudanari, 2020). The output variables consist of the number of passengers per day, productive mileage, average load factor, and schedule compliance level. Independent variables for efficiency determinant analysis include average fleet age, frequency of service, route length, route density, quality of road infrastructure, and level of system integration (Quiroz Villanueva et al., 2025).

Social welfare dependent variables were measured through an accessibility index developed based on the Hansen method, the percentage of transportation expenditure to household income, average passenger wait time, user satisfaction level using the Likert scale, and estimated carbon emission reduction compared to baseline private vehicle use (Ayuriany et al., 2023).

Data Analysis Techniques

Operational efficiency analysis uses the output-oriented DEA-BCC model to identify corridors operating on efficient frontiers and measure the relative inefficiency levels of other corridors (Zhang et al., 2022). DEAP 2.1 software is used for efficiency score computation assuming variable returns to scale that are more suitable for urban transportation operational conditions.

The analysis of efficiency determinants uses Tobit regression because the dependent variable is in the form of a DEA efficiency score that has a value limit between 0 to 1, so the conventional OLS method will produce biased estimates. The regression model used is:

$$\text{Efisiensi} = \beta^0 + \beta^1 \text{Usia}_{\text{Armada}} + \beta^2 \text{Frekuensi} + \beta^3 \text{Panjang}_{\text{Rute}} + \beta^4 \text{Kepadatan} + \beta^5 \text{Infrastruktur} + \beta^6 \text{Integrasi} + \varepsilon \quad (1)$$

The impact analysis on social welfare uses structural equation modeling (SEM) with AMOS 24.0 software to test the direct and indirect relationship between operational efficiency and various dimensions of social welfare. The construct validity test used confirmatory factor analysis and the reliability test used Cronbach's Alpha value and composite reliability.

RESULTS AND DISCUSSION

Corridor Operational Efficiency Profile

The results of the DEA's analysis showed that of the 15 corridors evaluated, only 4 corridors (26.7%) operated at a full efficient level with a score of 1,000, namely Corridor 1 TransJakarta, Corridor 2 Suroboyo Bus, BRT Corridor A Bandung, and Premium Corridor Surabaya. The overall average efficiency score of the corridor was 0.742 with a standard deviation of 0.186, indicating a considerable variation in the operational performance between the corridors.

The corridor with the highest level of inefficiency is conventional transportation in Bandung with an efficiency score of 0.423, indicating the potential for an increase in output of up to 136.4% with the same input, or a reduction of input of up to 57.7% to produce the same output. The analysis of slack variables revealed that the main inefficiencies came from excess inputs in the form of excessive fuel consumption (average 34.2% above the benchmark) and output deficiency in low load factor (average 41.8% below optimal potential).

Determining Factors of Operational Efficiency

The results of Tobit regression showed that the model had a good goodness of fit with a Pseudo R^2 of 0.687 and a significance of the model at $p<0.001$. Service frequency had a significant positive effect on efficiency with a coefficient of 0.0234 ($p<0.001$), indicating that each addition of 10 trips per day increased the efficiency score by 0.234 points. These findings are consistent with the theory of economies of frequency which states that increased frequency reduces passenger wait times and increases service utility.

The average age of the fleet had a significant negative effect with a coefficient of -0.0187 ($p<0.01$), indicating that older fleets tend to experience higher fuel consumption and increased

maintenance costs. Corridors with fleets aged under 5 years had an average efficiency score of 0.856 compared to 0.634 for fleets aged over 10 years, reflecting a significant difference of 35%.

The level of system integration measured through tariff integration, schedule integration, and infrastructure integration had a positive impact with a coefficient of 0.1456 ($p<0.001$), which was the factor with the greatest magnitude of influence. Fully integrated corridors show 42.3% higher efficiency than corridors that operate in isolation. The route length and route density variables did not show significant influence in the model, indicating that these factors are more relevant for efficiency at the network level than the efficiency of individual corridors (Quiroz Villanueva et al., 2025).

Implications for Social Welfare

The SEM model shows fit indices that meet the cutoff criteria with $\chi^2/df = 2.143$, CFI = 0.942, TLI = 0.931, RMSEA = 0.067, and SRMR = 0.053. Operational efficiency had a significant positive direct effect on accessibility ($\beta = 0.742$, $p<0.001$) and user satisfaction ($\beta = 0.684$, $p<0.001$). The indirect influence through accessibility on economic participation was also significant with a total effect of 0.523.

Descriptive analysis showed that efficient corridor users allocated an average of 14.3% of household income to transportation, compared to 18.7% for inefficient corridors, resulting in an average saving of Rp 312,000 per month per household. The cumulative impact on the household economy is very significant, especially for the group with an income below Rp 4,000,000 per month which is 62.4% of the total respondents.

From an environmental perspective, efficient corridors produce an average of 0.68 kg of CO_2 emissions per passenger-km, compared to 1.23 kg for inefficient corridors and 2.47 kg for baseline travel by motorbike. Improving the efficiency of the entire corridor to the benchmark level could result in an annual emission reduction of 127,400 tons of CO_2 equivalent, equivalent to planting 5.8 million trees.

Discussion and Comparison with Previous Research

The findings of this study are consistent with the study of Hao Zhang (2022) who found that service frequency is the main determinant of the operational efficiency of bus rapid transit in Latin American cities. However, the study found a greater magnitude of influence for system integration factors, which can be explained by the context of higher fragmentation of public transportation services in Indonesia compared to cases in developed countries.

Compared to the study by Kurniati (2021) which found an efficiency-welfare correlation of 0.612, this study found a higher correlation (0.742) which indicates that the impact of operational efficiency on social welfare is more pronounced in the context of developing economies where the penetration of private vehicles is still relatively low and dependence on public transportation is higher.

The fundamental difference with previous studies is the use of a multi-perspective approach that integrates analysis of technical efficiency, operational determinants, and socioeconomic impact in one comprehensive framework. This approach allows for more precise identification of leverage points for policy interventions that can result in a double whammy on efficiency and well-being.

CONCLUSION

This study successfully identifies service frequency, fleet quality, and system integration as the most critical determinants of operational efficiency in urban mass transportation. These factors account for the majority of performance variation across corridors, underscoring that targeted improvements in these areas can yield substantial gains. Furthermore, the research demonstrates that

operational efficiency has a profound and multi-faceted impact on social welfare, significantly enhancing accessibility, affordability, and user satisfaction, while also delivering indirect benefits through increased economic participation and environmental improvements. The progressive distribution of these benefits, with low-income groups gaining proportionally more, highlights that enhancing transportation efficiency concurrently advances both economic efficiency and equity in urban development.

Based on these findings, key policy recommendations include prioritizing fleet modernization, optimizing schedules based on data-driven demand analysis, and accelerating multi-dimensional system integration. To maximize social welfare impacts, these efforts should be supported by reforming subsidies towards performance-based models, updating service standards to include efficiency and quality metrics, and integrating transportation planning with land use policies. While this study provides a robust evidence base for policy and enriches theoretical understanding by linking efficiency determinants to welfare outcomes, its limitations—namely its focus on three major cities and a short observation period suggest avenues for future research. Subsequent studies should expand geographical scope, employ longitudinal designs, investigate network-level efficiency, and explore the impact of emerging technologies and political economies on transportation reform.

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