The Impact of Intelligent Transportation System in Reliability of Bus Rapid Transit in the City of Bandung

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Abstract— Traffic congestion is one of the main problems in large cities around the world, including in the city of Bandung, Indonesia. The congestion in Bandung is caused not only by the close distance of intersections but also by the high level of motorization. With the economic growth of the city of Bandung, the movement needs have increased to support economic activities. The lack of public transportation and the unreliability of existing public transportation have worsened the traffic congestion in Bandung. To solve this, in 2023, the Ministry of Transportation of the Republic of Indonesia promoted the implementation of bus-based public transportation in Bandung. But this bus-based public transportation needs a system that can support the reliability of this public transportation. Recognizing this issue, the implementation of an Intelligent Transportation System needs to be considered to enhance the reliability of public transportation. With the implementation of the Intelligent Transportation System, it is known that delays and the number of bus stops can be reduced, while increasing the operational speed of the buses.

Keywords— Bus rapid transit, congestion, delay, intelligent transportation system, motorization, reliability, public transportation.

1 INTRODUCTION

The Government of Indonesia plans to implement the Indonesia Mass Transit Project (MASTRAN) to address the critical mobility needs of Indonesian cities and improve livability. The Project will cover investments in road-based mass transit systems in Bandung Basin Metropolitan Area (BBMA). The proposed MASTRAN will support the development of a Bus Rapid Transit (BRT) project to enhance connectivity between the east-west urban corridors of BBMA [1].

Bandung level of traffic congestion is the highest in Indonesia and ranked 14th most congested city in Asia [2]. As for the current situation in Bandung, Mass Rapid Transit or Light Rail Transit are not currently operated & built, and buses are also insufficient in quality and quantity to meet traffic demand. Most locals rely heavily on motorbikes, or the paratransit called "Angkot" for daily activities such as commuting to and from school. Even the situation in Angkot is not easy, except for students and the elderly, in the case of ordinary people, there is a tendency to prefer using private transportation. In line with economic growth, the desire to move in and out of the city soared, but it was difficult to cope with the existing transportation infrastructure, which was chronically renovated and repaired. In a situation where the number of cars gradually increased as the income level increased, Bandung City took special measures such as one-way traffic. However, despite these efforts by Bandung City, traffic congestion is gradually intensifying, which leads to various problems such as excessive travel time, lost time on the road, and inability to secure punctuality of public transportation. Considering that Bandung's current public transport utilization rate is only 13% and that IDR 100 trillion of losses occur every year due to traffic jams, reform through changes in public transport is an unconditional essential process for the Bandung citizens.

To solve the traffic jams in Bandung, the use of public transport should be increased. The attraction to using public transportation lies in its reliability or performance. Evaluating transit performance is essential to improve transit service quality and allocate resources efficiently across transit agencies. It entails measuring objective criteria represented by numerical values, which are then compared to established benchmarks or historical data. This study concentrates on assessing service quality through objective measures, conducting a thorough examination and interpretive analysis of indicators previously investigated by researchers. The overarching objective is to present a comprehensive overview of objective indicators and provide suggestions for choosing the most appropriate ones to evaluate different transit services [3]

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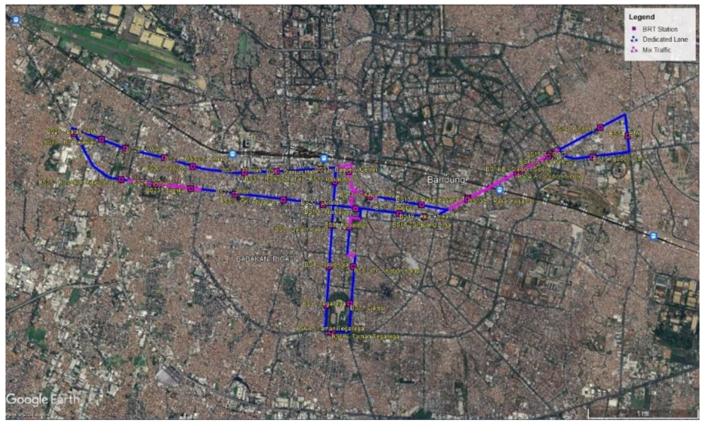


Fig 1. Design of BBMA BRT System

2 THEORITICAL FRAMEWORK

2.1 Planning of BBMA Bus Rapid Transit

The City of Bandung has a population of 2.44 million. It is located about 140 km from Jakarta and is regarded as a major center for economic, academic and tourism activities. The Bandung Basin Metropolitan Area (BBMA) in 2019 is estimated to be 8.87 million. Around 11.9 million trips are made daily within the Greater Bandung metropolitan area, two thirds of which are made by private transport. Mode choice is dominated by motorcycles, which account for 60 percent of private vehicles.

Bandung is a city notorious for heavy traffic, even on weekends. This situation has led to a high reliance on private vehicles and motorcycle taxis (ojek). Currently, 75% of trips in the city are made by motorcycles, with only 20% using cars and a mere 5% utilizing public transportation. It's no surprise that the usage of public transport in Bandung has plummeted by 80%. This is exacerbated by the difficulty in accessing public transportation and the lack of pedestrian access [4].

Several studies have been conducted to provide and improve the quality of public transportation. The studies conducted propose the provision of BRT in the city of Bandung. Study From GIZ [4] concluded that BRT Bandung Metropolitan will have 23 km of dedicated busways, up to 12 direct service routes, 27 bus stops inside the corridor, bus stops outside the corridor where buses will operate in mixed traffic, an integrated ticketing system, information systems, improved pedestrian facilities/access facilities, good intermodal facilities. This study updated by SYSTRA [5] that proposed BRT corridor in Bandung is as long as 21.77 km that passes through strategic areas in the city of Bandung. The orientation of the corridor is west, east, and south. Each end of the corridor is connected and concentrated on settlements. Travel destinations in Bandung are concentrated in the city center. The areas around Braga, Alun-Alun, and Veteran are the CBD area which is the center of activity in the city of Bandung. There are 32 stations that will serve the passengers within the BRT corridor. Most of the station's location at east side and south side of Alun-Alun are still aligned with previous GIZ study proposal. The following figure shows proposed corridor by SYSTRA [5].

2.2 Reliability of Transit Services

The reliability of transit services is extensively studied due to its crucial importance to users. Defined as the ability of transit systems to maintain schedules or consistent intervals between vehicles, reliability is primarily associated with adhering to schedules and uncertainty in vehicle arrivals. The consequences of unreliable service include longer travel and waiting times for passengers, potentially leading to a loss of passengers, while improvements in reliability can attract more passengers [6]. Eboli and Mazzulla [7] confirm the importance of service reliability to users, echoing earlier studies that prioritize punctuality over minimizing travel time. Variability in travel time significantly affects travelers' attitudes toward transportation modes, with waiting or transferring between modes perceived as more burdensome than actual travel time.

Public transit agencies utilize various indicators to assess service reliability, with on-time performance, headway regularity, and running time adherence being the most common. On-time performance is typically measured by the percentage of vehicles arriving or departing on time, with variations in defining "on time" such as allowing up to 5 minutes of lateness. Headway regularity evaluates the consistency of intervals between vehicles, often expressed as a percentage difference from the scheduled headway [8]. Running time adherence compares actual running times with scheduled times, also measured as a percentage difference.

Headway regularity concerns the consistency of time intervals between transit vehicles, typically expressed as a percentage calculated from the average variance between actual and scheduled headways relative to the scheduled headway. Similarly, a comparable measure known as excessive waiting time at stops, determined per line through analysis of operator schedules and on-site data. A transit vehicle is defined as

TABLE 1.
Road Segment Delay Analysis

Year	Mixed Lane	Dedicated Lane W/O ETLE		Dedicated Lane With ETLE	
	Delay (s)	Delay (s)	Improvement	Delay (s)	Improvement
2023	46.72	38.22	18.2%	18.64	60.1%
2024	58.29	40.21	31.0%	18.73	67.9%
2025	72.71	42.30	41.8%	18.82	74.1%
2026	90.71	44.51	50.9%	18.91	79.2%
2027	113.16	46.82	58.6%	19.00	83.2%
2028	141.17	49.26	65.1%	19.09	86.5%
2029	176.1	51.83	70.6%	19.19	89.1%
2030	219.69	54.52	75.2%	19.28	91.2%
2031	274.06	57.36	79.1%	19.37	92.9%
2032	341.89	60.35	82.3%	19.47	94.3%
2033	426.51	63.49	85.1%	19.56	95.4%

TABLE 2.
Road Segment Stop Average Analysis

Year	Mixed Lane	Dedicated Lane W/O ETLE		Dedicated Lane With ETLE	
	Stop Avg.	Stop Avg.	Improvement	Stop Avg.	Improvement
2023	22.62	12.45	45.0%	6.27	72.3%
2024	24.54	13.15	46.4%	6.30	74.3%
2025	26.63	13.88	47.9%	6.33	76.2%
2026	28.89	14.66	49.3%	6.36	78.0%
2027	31.35	15.48	50.6%	6.39	79.6%
2028	34.01	16.35	51.9%	6.42	81.1%
2029	36.90	17.26	53.2%	6.45	82.5%
2030	40.04	18.23	54.5%	6.48	83.8%
2031	43.44	19.25	55.7%	6.51	85.0%
2032	47.14	20.33	56.9%	6.55	86.1%
2033	51.14	21.47	58.0%	6.58	87.1%

"regular" if it falls within specified time intervals of the scheduled frequency. Evaluating the reliability of on-schedule runs involves comparing executed runs to the total scheduled within a given period. Running time adherence, like headway regularity, assesses the average difference between actual and scheduled running times as a percentage of the scheduled running time.

2.3 Impact of ITS Implementation to Transit Services Reliability

Bus Rapid Transit (BRT) systems vary significantly in their design and implementation. However, they commonly incorporate features such as dedicated lanes, distinctive stations and vehicles, efficient fare collection methods, and advanced intelligent transport systems (ITS) like real-time fleet management and traffic signal prioritization [9]. These design principles aim to improve system capacity, prioritize BRT over car traffic, integrate it with other public transport and non-motorized options, and position it as a service comparable to traditional rail systems. For a thorough examination of these characteristics, refer to studies by Jarzab [10], Levinson [11], and Deng and Nelson [12]. Implementing these ITS measures is intended to enhance service speed, reliability, visibility, and ultimately increase ridership. The overarching goal is to create a bus service offering qualities like those of rail-bound services such as light rail or metro systems.

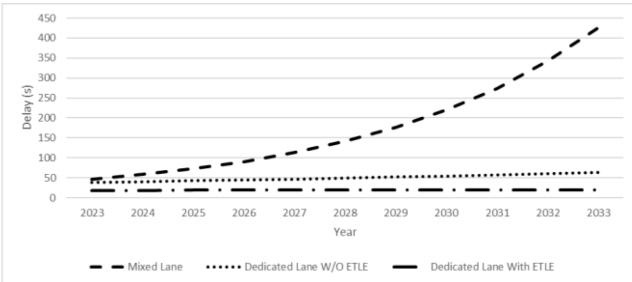


Fig 2. Rate of Increase in Delays

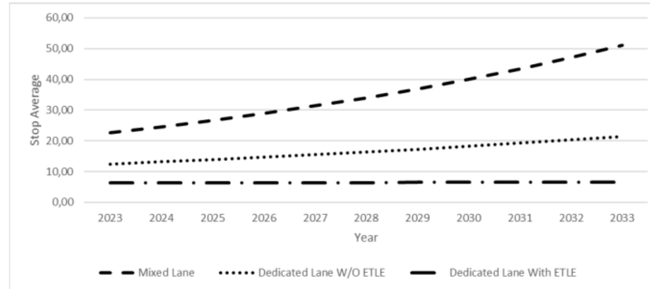


Fig 3. Rate of Increase in Stops Average

3 Methodology

The principle of enhancing the reliability of BRT is crucial to implement. One effort to improve reliability is by utilizing Intelligent Transportation Systems (ITS) such as the Area Traffic Control System (ATCS), Transit Signal Priority (TSP) and Electronic Traffic Law Enforcement (ETLE). ATCS is employed to enhance reliability in terms of travel time and reduce delays at intersections. In addition to addressing delays at intersections, interventions are necessary to keep the BRT lanes clear from other vehicles. ETLE is used to prevent other vehicles from entering the BRT lanes, thus avoiding conflicts between BRT and other vehicles. This research compares the performance of BRT before and after the implementation of ITS. The performance comparison is conducted at intersection locations and road segments aided by the PTV Vissim software. The implementation of dedicated BRT lane in Bandung is suitable on one-way roads. For the two-way roads, mixed-traffic operation will be implemented since most two-way roads have less than 4 lanes and the lane reduction will heavily reduce the overall traffic performance. As samples, Jalan Rajawali are selected to illustrate the implementation of ITS on-BRT performance in the city of Bandung.

3 BRT Reliability Analysis

3.1 ITS Implementation for Road Section

In the implementation of Bus Rapid Transit (BRT), the separation between BRT and other vehicles is a crucial aspect that supports the reliability of the BRT system. The concept of organizing BRT in Bandung is to ensure that BRT has dedicated lanes that are not disrupted by other vehicles as much as possible. This poses a significant challenge for the implementation of BRT in Bandung. The difficulty arises from the relatively short distance between intersections in the city, resulting in numerous openings for BRT lanes. Additionally, the composition of motorcycle users accounts for more than 60% of the total volume on each road segment in Bandung, posing a potential risk of violations against the dedicated BRT lanes.

As an effort to ensure the reliability of BRT on road segments, the use of ETLE is proposed to penalize violators of the dedicated BRT lanes. ETLE cameras are planned to be installed at intersections, and a separator will be provided to make the BRT lane exclusive from the mixed traffic. This is expected to reduce the potential level of violations that may occur on the designated BRT lanes. To demonstrate the importance of implementing dedicated BRT lanes and ETLE, simulations are conducted to compare the operational performance of BRT on road segments without dedicated lanes, road segments with dedicated lanes without ETLE, and road segments with dedicated lanes and ETLE implementation.

Based on traffic surveys, it is known that the peak hour on Jalan Rajawali occurs on Mondays with 10,177 vehicles per hour. The proportion of motorcycles during peak hours is 74.53%, passenger cars are 15.93%, and heavy vehicles are 9.54%. This traffic data will be used as input for simulations using PTV Vissim.

Based on the analysis in Table 1, it is known that in the base year, the implementation of dedicated BRT lanes without ETLE resulted in a decrease in delay values by 18.2%, and by the year 2033, it will lead to an 85.1% improvement in performance compared to BRT operations without dedicated lanes. This performance improvement will be even more significant if the dedicated BRT lanes are equipped with ETLE, with the expectation that no violators enter the dedicated BRT lanes. The performance improvement reaches 60.1% compared to BRT operations without dedicated lanes and achieves a 95.4% reduction in delays by the year 2033. Additionally, with the implementation of dedicated BRT lanes and ETLE, the rate of increase in delays can be reduced as shown in Figure 2.

Analysis was also conducted for the indicator of the number of stops made by the BRT. Analysis in Table 2 shows that in the base year, there is a decrease in the average number of stops when dedicated BRT lanes are constructed by 45.0%, and it increases to 72.3% when these dedicated BRT lanes are equipped with ETLE. The illustration in Figure 3 shows that there is a difference in the rate of increase in the average number of stops between BRT operations without dedicated lanes, dedicated lanes without ETLE, and dedicated lanes with ETLE. The rate of increase in the average number of stops tends to be gentler for BRT operations on dedicated lanes compared to those without dedicated lanes.

Another performance indicator of BRT that was analyzed

TABLE 3.
Road Segment Speed Average Analysis

Year	Mixed Lane	Dedicated Lane W/O ETLE		Dedicated Lane With ETLE	
	Speed Avg. (km/h)	Speed Avg. (km/h)	Improvement	Speed Avg. (km/h)	Improvement
2023	19.77	28.46	43.9%	33.20	67.9%
2024	17.20	27.61	60.5%	32.87	91.1%
2025	14.97	26.78	78.9%	32.54	117.4%
2026	13.02	25.97	99.5%	32.21	147.4%
2027	11.33	25.20	122.4%	31.89	181.5%
2028	9.85	24.44	148.0%	31.57	220.4%
2029	8.57	23.71	176.5%	31.26	264.6%
2030	7.46	23.00	208.3%	30.94	314.9%
2031	6.49	22.31	243.7%	30.64	372.1%
2032	5.65	21.64	283.2%	30.33	437.2%
2033	4.91	20.99	327.3%	30.03	511.3%

TABLE 4.
Brt Corridor Performance Analysis

Indicators	Without ATCS and TSP	With ATCS and TSP	Improvement
Delay Avg (s)	446.7	237	46.9%
Stops Avg	25.7	18.4	28.4%
Speed Avg (km/h)	10.5	13.2	20.5%
Travel Time (min)	18.8	15.1	19.7%

is the average speed of BRT along a road segment. Analysis in Table 3 indicates that in the base year, the implementation of dedicated BRT lanes will result in a 43.9% improvement in BRT performance, increasing from the initial 19.77 km/h to 28.46 km/h. This improvement can be achieved even better when ETLE is used. The performance improvement will increase to 33.20 km/h or 67.9% compared to BRT performance without dedicated lanes. In 2033, it can also be observed that the performance of average BRT speed is 511.3% higher on lanes with ETLE compared to BRT operations without dedicated lanes. The rate of decrease in speed from year to year is also smaller for BRT operations with dedicated lanes and ETLE compared to BRT operations without dedicated lanes, as shown in Figure 4. This indicates that the implementation of dedicated BRT lanes and ETLE has a positive impact on BRT reliability.

3.2 ITS Implementation for BRT Corridor

The implementation of ITS at intersections proposed for the operation of BRT in Bandung includes the use of ATCS and TSP. TSP is utilized to prioritize BRT vehicles to pass through intersections, in addition to the implementation of dedicated lanes to separate BRT from other vehicles. The principle of using TSP is to support the signal priority of BRT, thereby ensuring good reliability of the BRT. In practice, the green light prioritization using ATCS and TSP will be applied to all vehicles from the intersection leg where the BRT originates. This configuration is more practical and beneficial since the BRT corridor is located on major-arterial roads with high volume and one-directional traffic. Creating a specific signal for BRT movement will increase the cycle time and reduce the overall traffic performance for other vehicles. Figure 5 (a) illustrates a PTV Vissim simulation for conditions without the implementation of ATCS and TSP, while Figure 5 (b) illustrates a PTV Vissim simulation for conditions with the implementation of ATCS and TSP.

The analysis conducted is a combination of road segments between several intersections. Delays, average stops, and average speeds are composite values between road segments and intersections. This analysis is carried out along Jalan Rajawali to Jalan Kebonjati in Bandung, passing through 6 intersections.

Table 4 illustrates the comparison of BRT performance in the corridor without ATCS and TSP with BRT in the corridor with ATCS and TSP. With the use of ATCS and TSP, the average

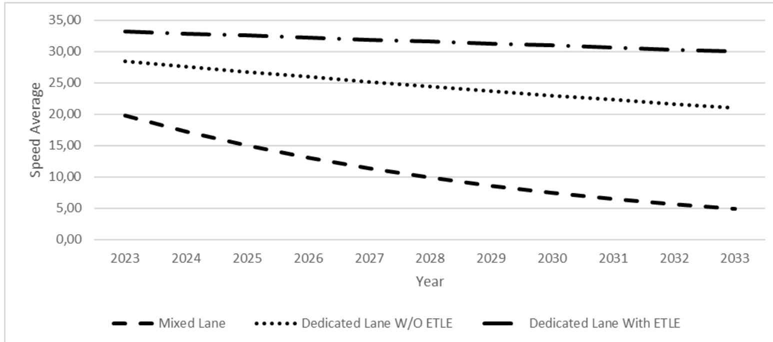
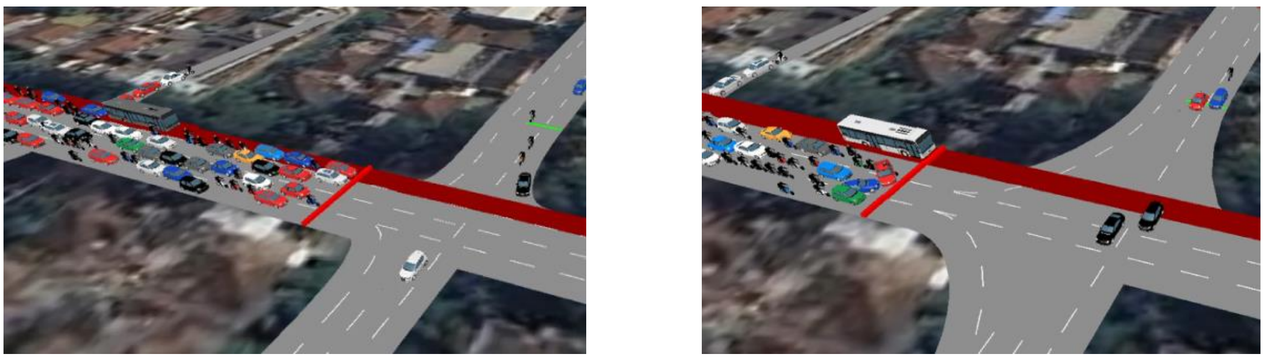


Fig 4. Rate of Decrease Speed Average



(a) (b)

Fig 5. Illustration of the difference in conditions for BRT dedicated lanes: (a) without TSP and ATCS, (b) with TSP and ATCS

delay value decreased by 46.9% from 446.7 seconds to 237 seconds. Additionally, the average number of stops decreased by 28.4%, the average corridor speed increased by 20.5%, and the corridor travel time improved by 19.7% compared to the corridor without ATCS and TSP. These indicators demonstrate improvements in the corridor with the use of ATCS and TSP.

4 Conclusions

The provision of reliable public transportation is not merely accomplished through conventional methods but also requires support from cutting-edge technology that is adaptive to the needs of the time and the social conditions of the community. To enhance the reliability of BRT implementation in Bandung, it is not sufficient to solely establish dedicated BRT lanes; interventions through ITS in the form of ATCS, TSP, and ETLE are also necessary.

Performance analysis of BRT on road segments indicates that the construction of dedicated BRT lanes will reduce delays by 11.8% in the base year. Meanwhile, if ETLE is implemented, it is expected to reduce delays by up to 60.1% in the base year, increasing to a 95.4% reduction in delays over the next 10 years. The improvement in BRT performance is also demonstrated by the reduction in the average number of stops from 22.62 times to 12.45 times in the base year when dedicated BRT lanes are established, further decreasing to 6.27 times with ETLE implementation. The reduction in the average number of stops reaches 72.3% with ETLE implementation. The indicator of average speed also shows significant improvement. In the base year, the implementation of dedicated BRT lanes and ETLE provides a 67.9% increase, rising to 511.3% over the next 10 years.

The reliability of BRT was also analyzed to determine the impact of using ATCS and TSP on BRT operations in a corridor consisting of segments and intersections. The analysis conducted in the base year shows a decrease in delay values of 46.9%, a reduction in the average number of stops by 28.4%, a 20.5% increase in the average system speed, and a 19.7% decrease in corridor travel time. Based on the analysis conducted, the implementation of ITS and its derivatives has a very positive impact on the reliability of BRT performance in Bandung. With this increased reliability of BRT, it is expected to attract more users and enhance public transportation usage in Bandung.

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