Effect of Road Gradient and Traffic Performance on Speed of BRT Trans Jateng (Case Study: Corridor 1 and 3)

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Abstract: The city of Semarang faces mobility challenges due to population and economic growth. BRT Trans Jateng is expected to reduce congestion; however, it struggles with schedule inconsistencies influenced by travel delays. Many factors impact the speed of BRT Trans Jateng. Among them are road gradients and traffic performance. This paper analyzed the impact of road gradient and traffic performance on BRT speed in Corridor 1 (mostly hilly gradient) and Corridor 3 (flat gradient). Using quantitative methods and statistical analysis (normality, difference, and correlation), the results indicated a very weak relationship between road gradient and speed in Corridor 1 (with *Correlation Coefficient (r)* < 0.25). At the same time, traffic performance has a moderate influence (r = 0.26–0.5). Overall, traffic performance has a more significant impact on BRT speed.

Keywords: Road gradient, traffic performance, operational speed, Bus Rapid Transit, Trans Jateng.

1. INTRODUCTION

Transportation in the city of Semarang consists of various modes, both private and public. Private vehicles dominate the roads, causing congestion, especially during peak hours. Public transportation is crucial to mitigating traffic congestion and enhancing residents' mobility. Public transportation refers to passenger transport systems that operate on a fare-based or rental basis, aiming to move many passengers to various destinations (Firmansyah & Putra, 2019). Different forms of public transportation have long been operating in Semarang. However, a more efficient and reliable public transport system with increasing population growth and mobility demands is needed.

One proposed solution to this challenge is the bus rapid transit (BRT) system. The Institute for Transportation & Development Policy (ITDP) defines bus rapid transit (BRT) as a high-capacity bus-based transport system that offers fast, comfortable, and efficient services. BRT Trans Jateng is an initiative by the Central Java Provincial Government to improve the quality of public transportation in Central Java, including Semarang.

In practice, BRT Trans Jateng faces several complaints and issues from users. Common problems include frequent schedule inconsistencies, especially during peak hours, irregular departure frequencies, fleet reliability, and suboptimal supporting infrastructure. One of the key issues affecting BRT Trans Jateng's schedule accuracy is travel delays, which directly impact its operational speed.

Various factors, including vehicle type, road geometry, lane distribution, road surface and type, weather conditions, speed limits, and traffic volume, influence BRT speed. Road geometry includes elements such as gradient, horizontal curves, and vertical curves. Roads with steep gradients often require drivers to reduce speed for safety, especially on downhill segments.

In Corridor 1 (Semarang—Bawen), several uphill and downhill segments are suspected of affecting BRT Trans Jateng's speed, thereby impacting its schedule accuracy. Along this corridor, the bus traverses various gradients, land use patterns, and diverse traffic conditions. In contrast, Corridor 3 (Semarang—Kendal) features a relatively flatter gradient and a more homogeneous land use and traffic condition compared to Corridor 1.

This study examines the influence of road gradient and traffic performance on BRT Trans Jateng's speed in Corridor 1 (Semarang—Bawen) and Corridor 3 (Semarang—Kendal). A detailed analysis of both corridors is essential to better understand how traffic characteristics and geographical conditions in Semarang affect BRT Trans Jateng's speed.

2. BRT SYSTEM IN CENTRAL JAVA

2.1 Trans Jateng

Trans Jateng is a leading transportation mode launched by the Central Java Provincial Government in 2017. It operates as a bus rapid transit (BRT) system to support urban agglomeration transport across Central Java Province (Purnomo & Herijanto, 2021). Trans Jateng provides an alternative for commuters to shift from private vehicles or other modes of transportation. Currently, there are seven BRT Trans Jateng corridors serving Central Java Province. Three of these corridors operate across Semarang City, namely:

1. Corridor 1 (Semarang – Bawen): TIC Pemuda, Semarang – Bawen Bus Station
2. Corridor 3 (Semarang – Kendal): Mangkang Bus Station, Semarang – Bahurekso Bus Station, Kendal
3. Corridor 6 (Semarang – Grobogan): Penggaron Bus Station, Semarang – Gubug Bus Station, Grobogan

2.2 Speed

According to Walker et al. (2014), speed is a vector quantity that measures how fast and in what direction an object moves. Speed is also defined as the derivative of an object's position to time, encompassing both the rate of position change and the direction of movement. The speed of a vehicle is influenced by various factors, including those related to the driver (such as psychological and physiological traits), as well as general environmental conditions (Hobbs, 1995). The main elements of the environment directly experienced by the driver are the type of vehicle, road geometry, road division, type of road pavement, weather, speed limits, and traffic volume.

2.3 Road Gradient

Gradient or vertical alignment refers to the profile along the road centerline, formed by a series of segments with longitudinal slopes. To simplify the reference in the following discussion, the road gradient range is classified into three categories: flat for a gradient of less than 5%, hilly for a gradient of 5 – 6%, and mountainous for a gradient of more than 6%.

2.4 Traffic Performance

Traffic performance is the overall quality of traffic flow on a roadway or transportation network. It arises from the interaction between drivers, vehicles, roads, and their environment (May, 1990). Using Google Maps, a typical traffic layer shows traffic performance on the road network, with green standing for smooth traffic, yellow for congested traffic, and red for highly congested traffic.

3. RESEARCH METHODOLOGY

The research methodology consists of two main steps as follows.

1. Data collections: involved onboard surveys inside BRT Trans Jateng buses, GPS recording, and typical traffic data from Google Maps. The collected data consisted of coordinate points (longitude and latitude), travel time between two reference points, and traffic performance. The gradient comparison is represented by two corridors with different longitudinal profiles: Corridor 1 (mostly hilly) and Corridor 3 (mostly flat).
2. Data analysis. The data analysis technique applied was descriptive analysis, while the statistical analysis included normality, difference, and correlation tests.

4. RESULTS AND DISCUSSIONS

4.1 Road Gradient Characteristics

The road gradient characteristics of Corridor 1 and Corridor 3 exhibit different gradient variations. The road gradient in Corridor 1 (Semarang–Bawen) has a diverse range. TIC Pemuda, the starting point, lies about 5 m above sea level (MASL), whilst Terminal Bawen itself lies about 541 MASL at the foot of Mount Ungaran (Fig. 1). The gradient ranges from -9% to 15% at the Semarang–Bawen route and -17% to 9% at the Bawen–Semarang route.

Meanwhile, Corridor 3 (Semarang–Kendal) is located along the coastline of the Java Sea, as seen in Fig. 2. Mangkang Terminal lies at about 25 MASL, and Terminal Bahurekso at about 11 MASL. The road gradient at Corridor 3 has a smaller gradient difference, ranging from -5% to 4% at the Semarang–Kendal route and -4% to 5% at the Kendal–Semarang route.

Since the journey was observed in two directions, the gradient values are classified into five categories: Flat, Positive Hilly (ascending), Negative Hilly (descending), Positive Mountainous (ascending), and Negative Mountainous (descending).

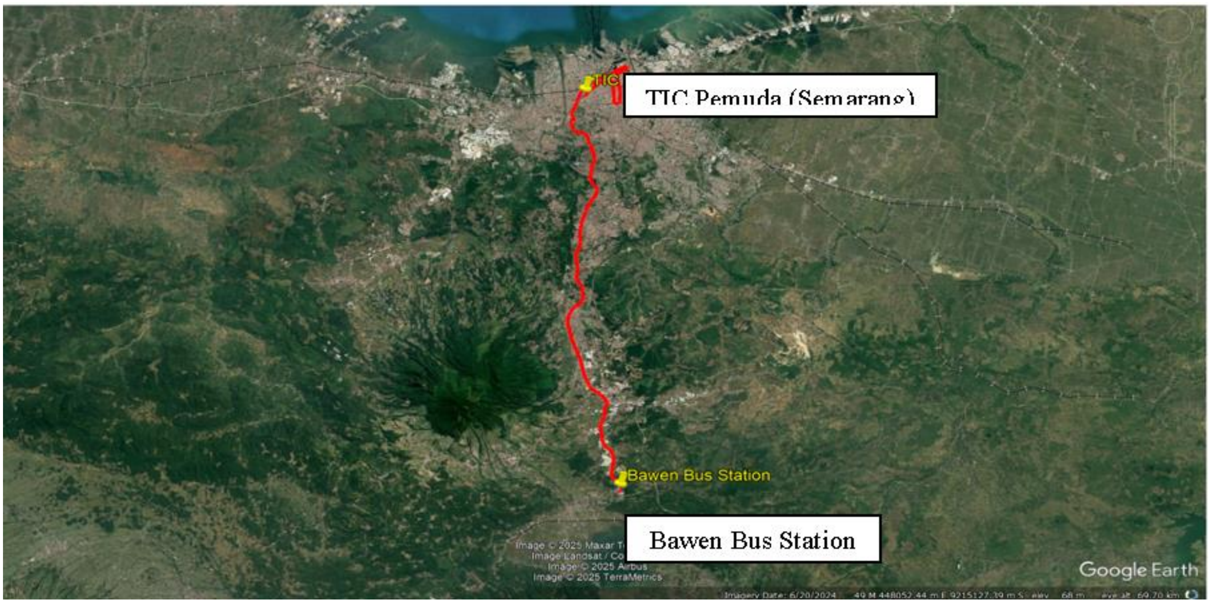

Fig 1. Corridor 1 (Semarang – Bawen)

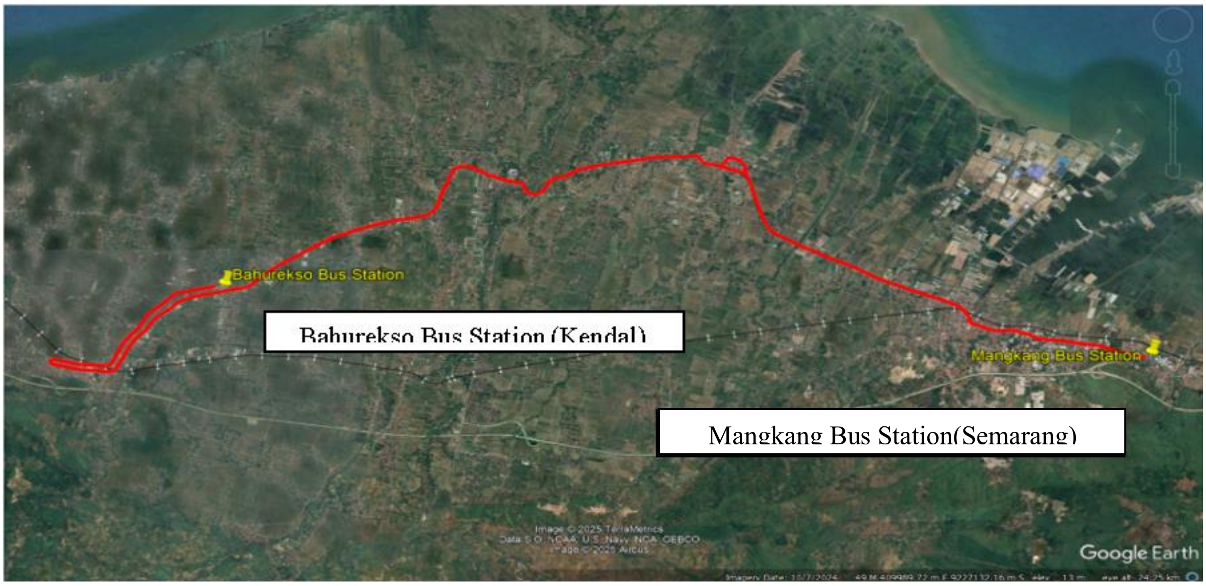

Fig 2. Corridor 3 (Semarang – Kendal)

4.2 Traffic Performance

Traffic performance obtained from Google Maps' typical traffic data is categorized into three groups: smooth (indicated by the green line), congested (yellow line), and highly congested (red line). The traffic characteristics of Corridor 1 (Semarang–Bawen) and Corridor 3 (Semarang–Kendal) are still predominantly smooth. However, specific locations experience traffic congestion. In Corridor 1, congestion generally occurs at intersections equipped with traffic lights. Meanwhile, in Corridor 3, congestion tends to occur at intersections with traffic lights, railway crossings, and areas around markets. Traffic characteristics for both corridors can be seen in Fig. 3 and Fig. 4. At the figures, green stands for good condition (vehicle can move smoothly without significant interruption), yellow for average (some interruptions), and red for poor (vehicle cannot move smoothly because of so many interruptions).

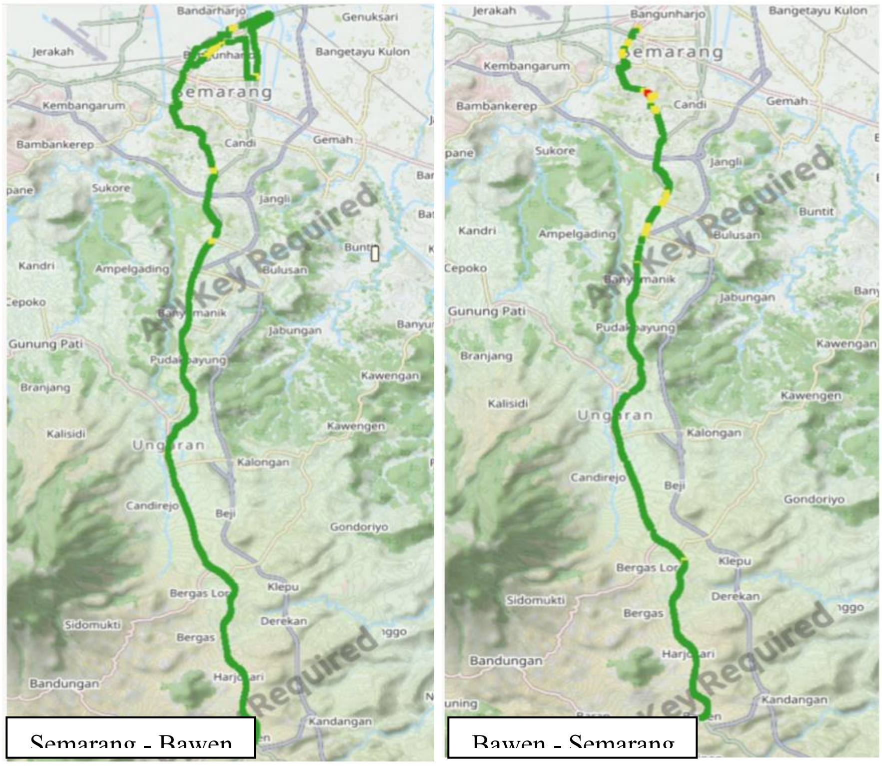

Fig. 3. Traffic Performance of Corridor 1

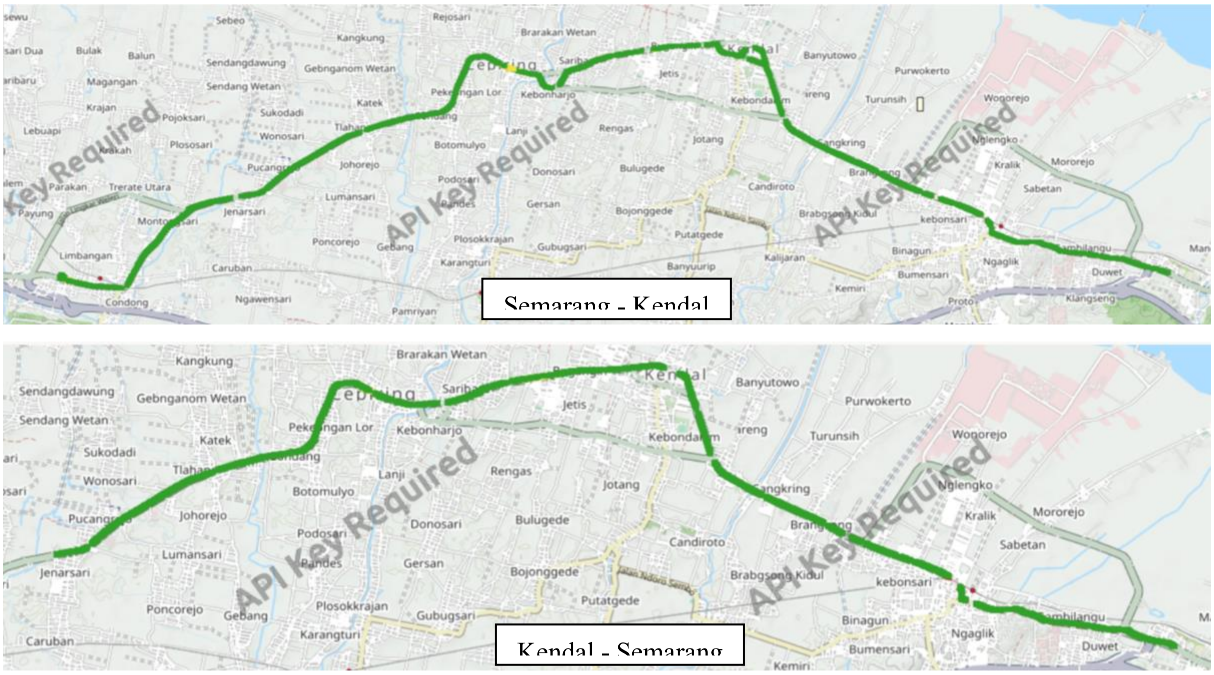

Fig. 4. Traffic Performance of Corridor 3

4.3 BRT Trans Jateng Speed Characteristics Based on Road Gradient

The speed characteristics of BRT Trans Jateng, based on road gradient at Corridor 1 and Corridor 3, show varying patterns, with speed fluctuations across different road profiles, including flat, positive hilly, negative hilly, positive mountainous, and negative mountainous. The speed deviation of BRT Trans Jateng based on road gradient is presented in Table 1.

Table 1. Deviation of BRT Speed due to Various Road Gradient at Corridor 1 (Semarang–Bawen) and Corridor 3 (Semarang–Kendal)

Description		*Weekday*				*Weekend*			
		1a	1b	2a	2b	1a	1b	2a	2b
Flat to Negative Hilly	Flat (km/h)	35.48	34.54	35.00	34.09	37.94	34.12	40.37	39.44
	Negative Hilly (km/h)	48.48	44.24	-	-	50.66	41.77	-	-
	Deviation (%)	36.64	28.08	-	-	33.53	22.42	-	-
Negative Hillyto Negative Mountainous	Negative Hilly (km/h)	48.48	44.24	-	-	50.66	41.77	-	-
	Negative Mountainous (km/h)	46.19	40.16	-	-	51.87	40.15	-	-
	Deviation (%)	-4.72	-9.22	-	-	2.39	-3.88	-	-
Flat to Positive Hilly	Flat (km/h)	35.48	34.54	35.00	34.09	37.94	34.12	40.37	39.44
	Positive Hilly (km/h)	34.81	37.8	-	-	40.74	34.36	-	-
	Deviation (%)	-1.89	9.44	-	-	7.38	0.70	-	-
Positive Hilly to Positive Mountainous	Positive Hilly (km/h)	34.81	37.8	-	-	40.74	34.36	-	-
	Positive Mountainous (km/h)	31.88	42.22	35.00	34.09	37.94	34.12	-	-
	Deviation (%)	-8.42	11.69	-	-	50.66	41.77	-	-

Remarks:
1a = Semarang – Bawen Route 2a = Semarang – Kendal Route
1b = Bawen – Semarang Route 2b = Kendal – Semarang Route

In Table 1, the average speed of BRT at Corridor 1 from flat to negative hilly gradient increased on the Semarang–Bawen and Bawen–Semarang routes due to a downhill slope of -5 to -6%. However, from negative hilly to negative mountainous, speed decreased on the Semarang–Bawen route (on weekdays) and Bawen–Semarang route (on weekdays and weekends) due to extreme slopes (-7% to -17%) for safety reasons.

The speed of BRT at this corridor from flat to positive hilly gradient increased on the Semarang–Bawen route (weekend) and the Bawen–Semarang route (weekday and weekend), with a slope of around +6%. Conversely, speed decreased on the Semarang–Bawen route from positive hilly to positive mountainous due to a steeper slope (+7% to +15%). Speed remained stable on the Bawen–Semarang route with a milder slope (+7% to +9%).

On Corridor 3 (Semarang–Kendal), which consists only of flat gradients, the speed was higher compared to Corridor 1. Due to the homogeneous road gradient, speeds on weekdays range from 34.09 to 35.00 km/h, while on weekends, they range from 39.44 to 40.37 km/h.

4.4 BRT Trans Jateng Speed Characteristics Based on Traffic Performance

The speed of BRT Trans Jateng based on traffic performance is depicted in Table 2.

Table 2. Deviation of BRT Speed due to Traffic Performance on Corridor 1 (Semarang–Bawen) and Corridor 3 (Semarang–Kendal)

Description		Speed (km/h)			Deviation (%)	
		Smooth	Congested	Highly Congested	Smooth to Congested	Congested to Highly Congested
Weekday	1a	36.98	16.44	4.15	-55.54	-74.76
	1b	36.18	21.33	8.12	-41.04	-61.93
	2a	35.61	23.92	8.02	-32.83	-66.47
	2b	34.61	26.54	4.79	-23.32	-81.95
Weekend	1a	39.19	17.83	9.11	-54.50	-48.91
	1b	35.61	23.87	5.37	-32.97	-77.50
	2a	40.89	24.77	6.41	-39.42	-74.12
	2b	40.02	27.35	-	-31.66	-

Remarks:
1a = Semarang – Bawen Route 2a = Semarang – Kendal Route
1b = Bawen – Semarang Route 2b = Kendal – Semarang Route

Based on Table 2, both corridors exhibit a varied pattern, with speed fluctuations across different traffic performances: smooth, congested, and highly congested. When the journey shifted from free-flowing to congested conditions, speed decreased in Corridor 1 (Semarang–Bawen) and Corridor 3 (Semarang–Kendal) on both weekdays and weekends. When the journey transitions from congested to highly congested conditions, speed decreases in both corridors, regardless of the route or the day of travel. This indicates that the transition from free-flowing to congested conditions results in a more extreme speed reduction due to severe traffic congestion, such as queue length, road narrowing, or more intensive traffic conflict points.

4.5 BRT Trans Jateng Speed Characteristics Based on Road Gradient and Traffic Performance

The speed characteristics based on road gradient and traffic performance can only be examined in Corridor 1 (Semarang–Bawen). Since Corridor 3 lacks gradient variation, it only features flat road conditions. The characteristics and speed deviations of BRT Trans Jateng based on road gradient and traffic conditions in Corridor 1 (Semarang–Bawen) are presented in Table 3.

Table 3. Characteristics and Speed Deviation of BRT Trans Jateng Due to Road Gradient and Traffic Characteristics on Corridor 1 (Semarang – Bawen)

Description			A	B	C	D	E
Weekday	1a	Smooth (km/h)	31.88	34.81	37.64	46.19	48.48
		Congested (km/h)	-	-	16.44	-	-
		Highly Congested (km/h)	-	-	4.15	-	-
		Smooth to Congested (%)	-	-	-56.32%	-	-
		Congested to Highly Congested (%)	-	-	-74.76%	-	-
	1b	Smooth (km/h)	42.22	37.8	35.58	40.16	44.24
		Congested (km/h)	-	-	21.33	-	-
		Highly Congested (km/h)	-	-	8.12	-	-
		Smooth to Congested (%)	-	-	-40.05%	-	-
		Congested to Highly Congested (%)	-	-	-61.93%	-	-
Weekend	1a	Smooth (km/h)	35.99	40.74	39.29	51.87	50.66
		Congested (km/h)	-	-	17.83	-	-
		Highly Congested (km/h)	-	-	9.11	-	-
		Smooth to Congested (%)	-	-	-54.62%	-	-
		Congested to Highly Congested (%)	-	-	-48.91%	-	-
	1b	Smooth (km/h)	39.66	34.36	35.07	40.15	41.77
		Congested (km/h)	-	-	23.87	-	-
		Highly Congested (km/h)	-	-	5.37	-	-
		Smooth to Congested (%)	-	-	-31.94%	-	-
		Congested to Highly Congested (%)	-	-	-77.50%	-	-

Remarks:
1a = Semarang – Bawen Route
1b = Bawen – Semarang Route
A = Positive Mountainous
B = Positive Hilly
C = Flat
D = Negative Mountainous
E = Negative Hilly

Table 3 shows that speed in flat road conditions is more influenced by traffic performance, both on the Semarang–Bawen and Bawen–Semarang routes and on weekdays and weekends. Speed in a negative gradient (hill descent and mountain descent) is more affected by road gradient on both routes and across different days. However, due to the steeper downhill slope, drivers tend to reduce speed on mountain descent gradient for safety reasons. Additionally, traffic conditions in both negative gradients tend to remain stable in free-flowing conditions, likely due to minimal road obstacles. Speed in positive gradients is also more influenced by road gradient conditions in both directions on weekdays and weekends. However, speed tends to decrease in positive-mountainous gradient due to vehicle engine capacity limitations. Similar to negative gradients, traffic performance in positive hilly gradients tends to remain stable in free-flowing conditions, likely due to minimal road obstacles on negative hilly gradients.

4.6 Data Analysis

The relationship analysis conducted in this study includes normality tests to examine data distribution, difference tests to compare speed based on road gradient conditions and traffic characteristics, and correlation tests to identify relationships between related variables.

The normality test was performed using the Kolmogorov-Smirnov test. Based on road gradient conditions and traffic characteristics, the speed data of BRT Trans Jateng in Corridor 1 (Semarang–Bawen) and Corridor 3 (Semarang–Kendal) showed a tendency toward a non-normal distribution, with an Asymptotic significance 2-tailed value less than 0.05.

The difference test on BRT Trans Jateng speed was conducted in two stages: an overall test using the Friedman Test and an inter-group test using the Wilcoxon Signed-Rank Test, as the data was not normally distributed. The overall test results indicated a significant difference in BRT speed in Corridor 1 (Semarang–Bawen) and Corridor 3 (Semarang–Kendal), based on both road gradient conditions and traffic characteristics, with an Asymp. Sig. < 0.05, leading to the acceptance of Ha1 (road slope has an effect) and Ha2 (traffic characteristics have an effect). The inter-group test also produced similar results, with P-Value < 0.05, further confirming that road slope and traffic characteristics influence the speed of BRT Trans Jateng.

The correlation test was performed using the Spearman Rank Correlation due to the non-normal data distribution. The relationship between BRT Trans Jateng speed and both road gradient conditions and traffic characteristics in Corridor 1 (Semarang–Bawen) and Corridor 3 (Semarang–Kendal) showed significant results (Sig. < 0.05), leading to the acceptance of Ha1 (road gradient conditions have an effect) and Ha2 (traffic characteristics have an effect). In Corridor 1, the correlation between speed and road gradient conditions was very weak (Correlation Coefficient < 0.25), whereas the correlation with traffic characteristics was moderate (0.26–0.50). Conversely, in Corridor 3, the correlation between speed and traffic characteristics was very weak (Correlation Coefficient < 0.25), indicating that traffic characteristics have a more dominant influence on speed, particularly in Corridor 1.

4.7 Micro-Scale Analysis

To gain deeper insights, a micro-scale analysis was conducted on specific segments that potentially exhibit a stronger relationship between BRT Trans Jateng speed, road gradient, and traffic performance. The results of this analysis are presented in Table 4.

Table 4 shows a relationship between road gradient and traffic performance on BRT Trans Jateng speed in Corridor 1 (Semarang–Bawen) and Corridor 3 (Semarang–Kendal). With varying strengths across different segments on weekdays and weekends, the relationship between speed and road gradient in the Semarang–Bawen corridor falls into the moderate category in the Bapang positive gradient segment—a correlation coefficient ranging from 0.26 to 0.50. A stronger relationship is found in the ADA Setiabudi intersection segment, where traffic performance significantly influenced speed, with a strong correlation (0.51–0.75). However, in the Gombel positive gradient segment, the relationship with road gradient is very weak (value < 0.25) due to two bus stops and a relatively narrow road.

Table 4. Correlation Test Results between Variables with Road Segment Review (Micro Scale)

Segment		Road Gradient – Speed		Traffic Performance – Speed	
		Sig. (2-tailed)	*Correlation Coeff.*	*Sig. (2-tailed)*	*Correlation Coeff.*
Weekday	Semarang-Bawen				
	1. Gombel Ascent	0.000	0.168	-	-
	2. Bapang Ascent	0.000	0.603	-	-
	3. ADA Setiabudi Intersection	-	-	0.000	0.713
	Bawen-Semarang				
	1. Bapang Descent	0.000	0.317	-	-
	2. Gombel Descent	0.000	0.261	-	-
	3. Don Bosco Intersetion	-	-	0.000	0.482
Weekend	Semarang-Bawen				
	1. Gombel Ascent	0.021	0.057	-	-
	2. Bapang Ascent	0.000	0.300	-	-
	3. ADA Setiabudi Intersection	-	-	0.000	0.753
	Bawen-Semarang				
	1. Bapang Descent	0.000	0.426	-	-
	2. Gombel Descent	0.000	0.245	-	-
	3. Don Bosco Intersection	-	-	0.000	0.323
Weekday	Semarang-Kendal				
	1. Cepiring Market	-	-	0.000	0.416
	Kendal Semarang				
	1. UBK Kendal Intersection	-	-	0.000	0.427
Weekend	Semarang-Kendal				
	1. Cepiring Market	-	-	0.000	0.499
	Kendal Semarang				
	1. UBK Kendal Intersection	-	-	0.000	0.505

A similar pattern occurs in the opposite direction (Bawen–Semarang route). The relationship with road gradient in the Bapang downhill segment falls into the moderate category (0.26–0.50), as does the relationship with traffic performance in the Don Bosco intersection segment. However, in the Gombel downhill segment, the relationship between speed and road gradient is also very weak (<0.25) due to the influence of two bus stops and nearby intersections, which slows down vehicle speed.

In Corridor 3 (Semarang–Kendal), the relationship between speed and traffic performance in Cepiring Market Segment falls into the moderate category, with a Correlation Coefficient ranging from 0.26 to 0.50. A similar pattern is observed in the Kendal–Semarang route, where the UBK Kendal intersection segment shows a moderate relationship between speed and traffic performance.

5. CONCLUSIONS

1. The road slope performance in Corridor 1 (Semarang–Bawen) shows more significant variation compared to Corridor 3 (Semarang–Kendal). Corridor 1 has slopes ranging from -9% to 15% for the Semarang–Bawen route and -17% to 9% for the Bawen–Semarang route. Meanwhile, Corridor 3 has relatively uniform slopes, ranging from -5% to 4% for the Semarang–Kendal route and -4% to 5% for the Kendal–Semarang route.
2. Smooth traffic conditions dominate the traffic performance in Corridor 1 (Semarang–Bawen) and Corridor 3 (Semarang–Kendal). In Corridor 1, traffic congestion occurs at intersections equipped with traffic lights (APILL). Meanwhile, congestion in Corridor 3 is frequently observed at intersections with traffic lights, railway crossings, and market areas.
3. The speed performance of BRT Trans Jateng in both Corridor 1 (Semarang–Bawen) and

Corridor 3 (Semarang–Kendal) exhibit significant variations. In Corridor 1, speed based on road gradient ranges from 31.88 km/h to 51.87 km/h, while traffic performance varies between 4.15 km/h and 39.19 km/h. In Corridor 3, speed based on road gradient ranges from 34.09 km/h to 40.37 km/h, while traffic performance ranges from 4.79 km/h to 40.89 km/h.

4. From a macroscopic perspective, in Corridor 1 (Semarang–Bawen), there is a relationship between BRT Trans Jateng speed and both road gradient and traffic performance. The correlation with road gradient is very weak (Correlation Coefficient < 0.25), while the correlation with traffic performance is moderate (Correlation Coefficient 0.26–0.50). In this condition, drivers try to maintain their speed due to the speed limit regulations in BRT Trans Jateng. This condition prevents the slope from having an impact on operational speed. In Corridor 3 (Semarang–Kendal), a relationship is only observed with traffic performance, which is classified as very weak (Correlation Coefficient < 0.25). Meanwhile, from a micro perspective, both corridors show an increase in correlation strength between speed and road gradient and traffic performance, classified as moderate (Correlation Coefficient 0.26–0.50).

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