Assessing the Performance of Bus Priority Lane on Galle Road, Sri Lanka

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Abstract: Transport experts worldwide attempt to boost bus ridership by setting different priority schemes for buses. This research intends to investigate the performance of two sections of bus priority lane (BPL) introduced on an experimental basis along the Galle corridor, Sri Lanka. This research measures the performance of BPL by (a) analyzing the speed of buses before and after implementing the BPL, (b) comparing the flow speeds of the BPL and the general-purpose lane, and (c) reporting bus speeds according to the route. This research indicates that there is a significant improvement in the speeds of buses after implementing the BPL. However, it is found that bus speeds in BPL are still lower than motor vehicles' speed in the adjacent mixed traffic lanes. Further, results highlight that when some bus routes maintain significantly lower speeds than others, the smooth flow of the BPL disrupts, causing overall speeds to reduce.

keywords: Bus priority lane, General-purpose lane, Speed comparison, Galle corridor, Sri Lanka

1. INTRODUCTION

Most of the trip attractions of a country demonstrate the wider characteristic of its urban fabric. The incapability to manage the traffic demand on urban arterials create inconvenient and costly traffic congestion. This matter has become one of the key mobility issues in urban life. One can point out that increasing traffic facilities' capacity as a simple solution to solve this dilemma. However, it hardly becomes a sustainable solution as an extreme cannot be identified in increasing the capacity every time the demand increases. Particularly in developing countries, the ability to bear the cost of such developments is questionable. Hence, most of the transport experts' opinion is to manage this demand effectively using different strategies. One of the salient schemes here is to improve the public transport systems as those are space-efficient means of transporting a large volume of people (Viegas and Lu, 2001). Moreover, buses having an average occupancy of around 50 passengers get pointed up as their improvement motivates private vehicle users of the same arterial to use buses, directly impacting the urban traffic congestion level.

Nevertheless, the matter is how to improve bus transportation in attracting more passengers away from the perceived reliability of using their private transport. Thus, different methods of providing a priority to buses in traffic over other vehicles are applied throughout the world, known as bus priority schemes. This concept's origin comes from as far as the 1960s in France (Yu, 2009). From then on, different forms have emerged in the present-day.

Dadashzadeh and Ergun (2018) reviewed the available bus priority schemes and categorized those mainly as time-based and spatial based prioritization methods. (Yu, 2009) highlighted three benefits of utilizing bus priority schemes as the direct economic benefit through reduced transport cost and increased operating income, the indirect economic benefit from saved travel time, social benefit from reduced exhaust emissions, and improved buses' promptness.

As the Sri Lankan economy's nerve-centre, Colombo is subject to urban traffic congestion over several decades. The travel speed in Colombo Metropolitan Region (CMR) shows an average value of 17 km/h, while within the Colombo Municipal Council (CMC), it is as lower as 12 km/h (JICA, 2015). The number of trips generated per day within the CMR is more than 10 million, whereas 1.9 million daily passengers enter the CMC every day using seven corridors (JICA, 2015). Galle Road (A002) can be identified as one of the key corridors that notably contribute to this demand. Traffic congestion in the Galle road at morning and evening peaks is reported to be intolerable as a consequence. This concern is further indicated through reported Level of Service (LOS) of 'E', peak factor of 0.8535 with around 4800 hourly vehicle volume for both inbound and outbound directions in the peak periods (Damsara et al., 2018). Thus, different initiatives have been taken to mitigate the traffic along this corridor, whereas the 'Bus Priority Lane' (BPL) is highlighted. During the past two decades, BPL has been introduced, although leaving doubt whether lessons from one initiative were taken to the subsequent. The most recent initiatives were taken place in 2017 and 2020 at the "Moratuwa-Rathmalana" and "Wellawatta-Kollupitiya" sections along the route as depicted in Table 1.

Table1. BPL sections

Section number	Section starts	Section end	Section length	Lanes per direction
1	Moratuwa- Cross Junction	Rathmalana- Maliban Junction	5km	3
2	Wellawatta- Savoy Cinema	Kollupitiya- Kollupitiya Junction	4km	3

Figure 1. BPL sections along Galle corridor

A fact to understand is that this BPL's performances should have been carefully considered to improve this to provide convenient mobility for the users. An extensive study about this BPL's performances is a valuable input for the communities in developing countries with similar bus transport networks to refer to when implementing such initiatives. Hence, this study was carried out as a performance analysis while fulfilling the objectives of identifying the impact of buses, general traffic from BPL, and identifying its impact on individual bus operators' operational behaviours.

2. LITERATURE REVIEW

Different priority schemes have been introduced to improve bus systems' attractiveness, which is not needed in building new infrastructures (Eichler and Daganzo, 2006). Transit signal priority (TSP) is the one way of prioritizing the buses at intersections by providing the right-of-way to proceed unrestricted through intersections but not an ideal solution with heavy traffic (Eichler and Daganzo, 2006). The dedicated bus lane (DBL) is another way of prioritizing the buses, which provide an exclusive way by freeing a lane from the general traffic (Eichler and Daganzo, 2006). Even though there are many successful DBL applications worldwide, DBL's main downside is to reduce the capacity for general traffic lanes and thereby increase congestion (Xu et al., 2013). This limitation can be minimized by opening the bus lane to general traffic when buses do not occupy the bus lane called intermittent bus lane (IBL) (Eichler and Daganzo, 2006). Viegas and Lu (2001) introduce the concept of IBL and analyze effectiveness. Using pure TSP strategies is not effective, and combining TSP with DBL or IBL priority schemes can further improve buses' speeds (Eichler and Daganzo, 2006).

Dedicated bus lanes (DBL) improve buses' speed significantly compared to buses' speed under mixed traffic conditions (Vu et al., 2013). Past research highlighted that DBL is only applicable under low traffic flow conditions for two-lane road systems (Satiennam, 2005), Zhu, 2010). Setting a DBL is an appropriate solution when road demand is less than 80% of its bottleneck capacity (Eichler & Daganzo, 2006). Further, Traffic engineers do not recommend DBL for low-frequency bus services (Viegas and Lu, 2001). As a general practice, at least 30 buses per hour are required to recommend DBL (Viegas and Lu, 2001). Since bus frequency is low during off-peak hours, bus lanes are less effective for that period (Vu et al., 2013). Allocating a dedicated lane for buses is not sufficient to improve the attractiveness of the buses. Sakamoto et al. (2007) highlighted that leverage the use of park and ride, provide better service to bus passengers at reasonable fare, improve the service frequency and schedules of buses are required to smooth the traffic flow in both bus lanes and general-purpose lane.

If road demand is closer to the bottleneck capacity, intermittent bus lane (IBL) is better than DBL (Eichler and Daganzo, 2006). Providing a dedicated lane for buses is a waste when bus flow is very low compared to the general traffic flow (Sakamoto et al., 2007). Since DBL reducing the road capacity permanently, the loss of time for the general traffic is much higher than the time saving for the bus passengers (Sakamoto et al., 2007). IBL encourages public bus services while imposing less burden on general traffic users (Viegas and Lu, 2001). When buses arrive in the IBL sections, lights are flash on to indicate the bus's arrival to clear the path from other vehicles (Viegas and Lu, 2001).

Evaluation of the bus priority lanes' effectiveness is conduct for intersections and road sections separately to measure buses' performance and the other social vehicles before and after implementation (Yu, 2009). In addition to evaluating before and after setting the priority lane, it is essential to monitoring regular performances (Xu et al., 2013). Yu (2009) emphasises establishing and evaluating an index for bus priority lanes with a human orientation by considering all trip makers equally. After implementing BPL, road sections' improvements are mainly measured using section travel time by public buses, social vehicles, and travel time on each person (Yu, 2009). Further, delay at intersections, capacity, and saturation at intersections are the parameters used to measure the performance at intersections (Yu, 2009). Reliability in bus travel time is a key consideration expect by setting a priority lane (Xu et al., 2013).

Minimizing the variation in bus travel time components (waiting, in transit, signal stop) improves schedule adherence. Additionally, passenger throughput, the bus and car occupant flow ratio, and public perception are important parameters to measure bus priority lanes' performances (Xu et al., 2013).

Bus priority introduced to the Galle corridor in Sri Lanka has failed to continue its momentum over the last two decades. Fifty-five thousand ninety-six from total daily commuters of 110,619 had been catered from the public buses at Moratuwa along the Galle corridor in 2014, giving a model share of around 50%. Kumarage et al. (2003) is a very first study conducted on the Galle corridor, focused on the theoretical calculation of the level of service (LOS) for the mixed traffic condition and the two possible designs of the bus lane, (a) with all the buses on the bus lane and (b) only slow-moving buses on the bus lane for three sections. The study highlighted that the bus priority lane is a feasible solution to mitigate the road sections' traffic with at least three lanes per direction along the Galle corridor (Kumarage et al., 2003). Further, the study highlighted that though the implementation of the bus lane is feasible. Theoretically, it fails to achieve its expected outcomes due to cyclist and pedestrian movements on the bus lane, parking of vehicles in the bus lane, and slow-moving bus operators (Kumarage et al., 2003).

Weerasekera (2010) conducted a study by applying queuing theory to reveal the behaviour of traffic flow under three conditions, (a) without implementing transit lane, (b) transit lane operation under the strict supervision of police and, (c) transit lane operation without the supervision of police, based on the Kerbside bus lane along Galle corridor on an experimental basis. Results of the study highlighted that traffic flow of case (a) similar to an M/M/2 type queuing model with two service facilities, case (b) similar to two M/M/1 models, and case (c) does not support similar to either M/M/2 or M/M/1 queuing models (Weerasekera, 2010). The study shows that the transit lane's smooth flow is disturbed under case (c) (Weerasekera, 2010). Thereby the study recommended establishing random checking points and take action against drivers who do not adhere to the transit lane (Weerasekera, 2010).

S. W. M. P. Senevirathne et al. (2016) studied the stakeholder perspective regarding the bus priority lane implementation along the Galle corridor. Majority of bus drivers and bus passengers provided positive feedbacks towards the implementation of the BPL. Further, three-wheel drivers complain about the difficulties they faced to pick passengers in the BPL sections (Senevirathne et al., 2016). Further, shop owners who are doing their commercial activities adjacent to the bus lane complained about the parking issues due to BPL implementation (Senevirathne et al., 2016). None of the studies conducted in the Sri Lankan context had extensively considered the impact on bus speeds before and after implementing BPL and individual bus operators' behaviour. The study supposes to analyze the behaviour of different operators in the bus lane, thereby analysing how their behaviour impacts the BPL sections' overall performance along the Galle corridor.

3. METHODOLOGY

The BPL project was carried out as a solution for decrease in bus ridership and low travel speeds in the Colombo Municipal Council (CMC) area. During the morning and evening peak period, the curbside bus lane was only implemented for sections with at least three lanes per direction. This study includes a bus priority lane implemented through two sections, referred to as section 1 and section 2 in Table 1. The study's main objective is to evaluate bus priority lanes' performance along Galle road and identify buses' behaviour to plan the bus routes effectively and efficiently.

3.1. Data Collection and Preparation

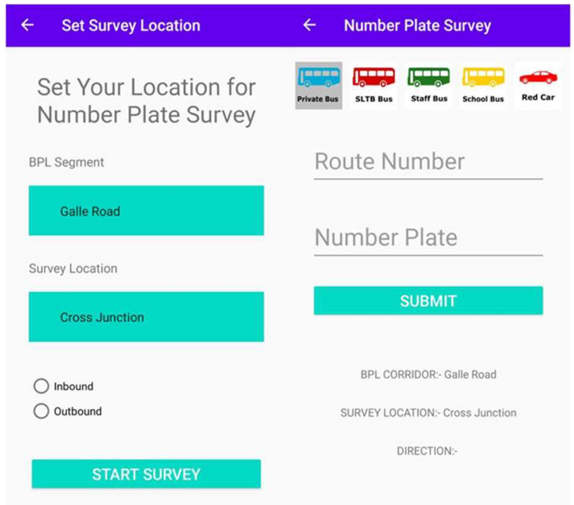

Figure 2. Number plate survey app interface

The data was obtained mainly through number plate surveys conducted by the University of Moratuwa and the SAHASARA project team. Primarily, data for this study have been collected in two stages. Firstly, the data was collected in 2017 and then in 2020 for a second time. In 2017 surveys were conducted for, before, and after the implementation of BPL. Whereas in 2020, the survey was conducted only after the implementation of BPL. The number plate surveys were conducted at four survey locations, Cross Junction, Maliban Junction, Savoy Cinema, and Kollupitiya Junction along the Galle corridor. Further, surveys were conducted for five working days during the morning peak (6.00 am-9.00am) for all three occasions explained before. A developed mobile application was used to do the number plate survey and collected data continuously during the morning peak. As the fields of data Bus registration number, bus route number, and service provider's name need to be fed into the system by the data collector, and the respective time of the entry is designed to be stored automatically. As a precautionary measure for the incident in 2020, data was collected for normal cars as well. Additionally, a field observation survey was done during the BPL hours to inspect the success of operation. After the data collection process, data preparation was handled using the R language. Mainly two parts were included in data preparation. In the initial stage, corrupt and inaccurate records of the survey data were detected and corrected.

3.2. Measuring the performance of BPL sections

This study is planned in three steps to measure the performances of BPL, (a) analyze the speed of buses before and after implementing the BPL, (b) compare the speed of the BPL, and the general-purpose lane, and (c) conduct bus operator's speed comparison.

3.2.1. Analyzing the speed of buses before and after implementing the BPL

This study's first objective is to identify the effects of BPL in improving the speeds of buses based on the data collected in 2017. The before and after research design is more accurate in demonstrating the immediate impacts of short-term programs. However, the accuracy of this method is low when evaluating longer-term interventions. More conditions can arise over the itinerary of a longer period, making it difficult to understand an intervention's effects. On this occasion, it was needed to evaluate two road segments separately. According to the data distribution, a paired-sample t-test or Wilcoxon sign rank test was performed to calculate significance. The null hypothesis of the paired-sample t-test is that the mean value of bus speed is equal to zero.

3.2.2. Comparing the flow speeds of BPL and general-purpose lane

Here the general-purpose lane is defined as the lane adjacent to BPL that carry mixed traffic. Collected car speed data was used to compare the flow speeds of BPL and general-purpose lanes. This comparison aims to check the bus's attractiveness compared to the car in terms of travel speed.

3.2.3. Comparing the bus speed according to the routes

Maintaining a smooth bus flow is one of the key success factors of bus priority lane strategy, especially in the Sri Lankan context as a single lane is included in BPL. In Galle road, both short-run and long-run buses operate at the same time. Since the two groups have different behaviour, it could be a problem for the bus flow's smoothness. Buses operating in five different routes were selected to compare the speeds during BPL implementation based on data adequacy. Route number 100 (Moratuwa to Petta), route number 101(Moratuwa to Pettah), route number 02(Galle to Pettah), route number 400 (Aluthgama to Pettah), and route number 430(Matugama to Pettah) are those. Here, route numbers 100 and 101 belong to short-distance buses, and route number 02 belongs to the long-distance category. Further, 400 and 430 routes can be categorized as intermediate distance buses. F ANOVA test was performed to identify equality of mean speed of five bus routes. If it is not equal, then post hoc analysis can be performed to identify which bus route differs from others.

4. RESULTS AND DISCUSSION

4.1. Comparison of Bus Speed Before and After Implementing the BPL

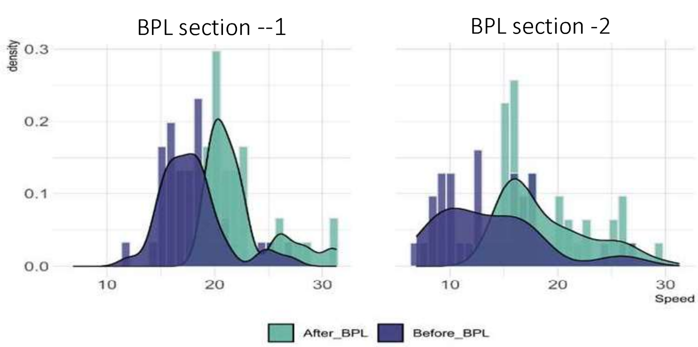

Figure 3. Results on improvements in bus speeds after implementing BPL by section

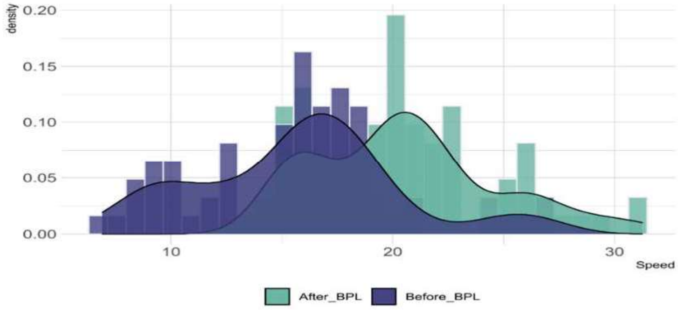

Figure 4. Results on overall improvements in bus speeds after implementing BPL

Table 2. The mean bus speed of selected sections before and after the implementation of BPL

BPL section	Mean speed-before BPL (km/h)	Mean speed-after BPL (km/h)	P-value
Section 1	18	23	0.00 (Paired sample t-test)
Section 2	14	18	0.00 (Paired sample Wilcoxon test)
Overall	15.7	20.6	0.00 (Paired sample t-test)

According to analysis, the mean speed of BPL section 1 was increased from 18km/h to 23km/h. The paired sample t-test showed a significant increment in the bus flow speed after implementing BPL for the section. The mean speed of the BPL section 2 was increased from 14km/h to 18km/h. The paired sample Wilcoxon sign rank test concluded a significant increment in the bus flow speed after implementing a bus priority lane. When considered with the overall effect of BPL, the mean speed of bus flow was increased from 15.7km/h to 20.6km/h. Thus, the paired sample t-test concluded a significant increment in the bus flow's overall speed after implementing BPL for the selected two sections. Hence BPL has improved the speed of buses effectively. The average peak traffic flow in the Galle Corridor usually has a spread between 1500-2000 vehicles per hour. Data collectors ensured that the general traffic flows during these two data collection periods did not show a much different than these general values. This observation helps us to deduce that these speed values are not impacted from the affects could occur from different flow rates.

4.2. Comparison of the Flow Speeds of BPL and General-Purpose Lane

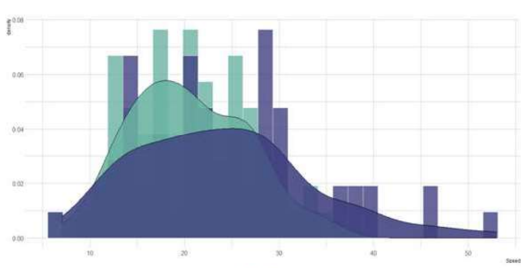

Figure 5.Comparison of flow speed of BPL and general-purpose lane

The main objective of setting BPL is minimizing the travel time while encouraging car passengers to use the bus. Bus speed comparison of Before and after setting BPL confirmed that bus speed improved due to this implementation. The comparison of BPL and general-purpose lane flow speeds shows that BPL sections' overall speed is still lower than the speed of general-purpose lane. It indicates that further optimization of BPL operation is needed to attract private vehicle users to the bus.

4.2.1 Possible reasons for differentiated speeds between BPL and general-purpose lane

A field survey was conducted to identify the qualitative factors for having lower speeds for buses that operates in BPL despite given the priority comparing to the general-purpose lane. Observations of this survey provides some insights to further improve the BPL operations to exploit its maximum benefits. Provided with the left most lane on the road, it was observed that at several locations the bus lane has become narrower which decreases the speed of buses caused from a slight fraction. Another key observation is that having a slow-moving bus on the lane makes the behind buses to adopt to its speed as the buses are prohibited with changing the lanes to overtake. The only opportunity that a bus in behind gets to overtake a slow-moving bus comes at the bus bay and until that point number of buses must maintain a lower speed which drastically degrades BPLs' performance. Some issues regarding the quality of the road surface also had been noticed. For instance, gullies prohibit drivers from maintaining continuous higher speeds which causes from reducing the speeds to avoid unnecessary shakes. Not having thorough observations on bus lane rule violations also impacts to its performances from incidents such as unnecessary parking along the bus lane. Possible improvements of bus lanes performances can be expected from taking necessary actions to overcome these identified barriers.

4.3. Bus Operator's Speed Comparison

Table 3.The mean speed comparison by bus route

Bus route	**Moratuwa-Rathmalana BPL section**		**Wallawatte-Kollupitiya BPL section**	
	Mean Speed (km/h)	**SD**	**Mean Speed (km/h)**	**SD**
Moratuwa - Pettah (100)	19.80	3.02	22.83	3.62
Moratuwa - Pettah (101)	17.38	2.92	21.40	4.10
Galle - Colombo (2)	25.81	6.90	27.96	4.48
Aluthgama - Colombo (400)	23.84	4.83	27.14	3.99
Matugama - Colombo (430)	24.07	5.25	27.10	3.90

Route	100	101	2	400	430
100	–	0.129	0.005	0.001	0.002
101		–	0.004	0.001	0.001
2			–	0.993	1.000
400				–	1.000
430					–

Figure5. The adjusted P-value of post hoc analysis for BPL section 1

Route	100	101	2	400	430
100	–	0.076	0.00	0.00	0.00
101		–	0.00	0.00	0.00
2			–	0.402	1.00
400				–	1.00
430					–

Figure 6. The adjusted P-value of post hoc analysis for BPL section 2

A repeated measure ANOVA test was conducted for the two BPL sections separately to identify the bus route with significantly different speeds. The repeated measure ANOVA test results are F ratio- 13.53, p-value- 0.000, and F ratio-14.5p-value-0.000 for BPL section 1 and section 2, respectively. The statistics prove that at least one bus route is significantly different from others for both BPL sections. Post hoc analysis was conducted for two BPL sections separately to identify the exact bus routes with significantly different mean section speeds than others. Adjusted P-value of the Post hoc analysis clearly shows that Moratuwa - Pettah (100) and Moratuwa - Pettah (101) have a significantly lower mean speed than other bus routes for both BPL sections, Moratuwa-Rathmalana and Wallawatte-Kollupitiya. A few bus operators maintain relatively lower speeds than others, causing disruptions to the smooth flow of the BPL and cannot achieve the fullest outcomes of the implementation.

5. CONCLUSION

Despite the fact that most developed countries experience successful BPL schemes, some developing countries still struggle with adaptation. As a corridor that caters to around 50% of its passengers from public buses towards the Colombo city, Galle road in Sri Lanka has been tested with BPL schemes from time to time, leaving a question of whether it causes a significant passenger flow improvement. The current study elaborates that after implementing BPL, bus speeds have improved by 27.7% in the BPL section 1 and 22.2% in BPL section 2, emphasizing that bus passengers are subjected to a considerable time saving when the BPL is in operation. Though it is a significant improvement, buses' flow speed in the BPL was lower than the vehicles' flow speed in the general-purpose lane. It negatively impacts the objective of attracting private vehicle users to public services from BPL. Hence, further optimization of BPL sections' operation is needed to achieve the intended outcomes out it. One possible approach could be identified from the bus route vise analysis: route number 100 and 101 buses maintain relatively lower speed than others, which affects the bus lane's smooth flow, causing a decrease in buses' overall flow. Therefore, it is recommended to impose a minimum speed for all the bus operators and follow up on the schedule adherence of slow-moving buses in developing the BPL scheme on this corridor. Further studies are required to investigate this concern in-depth, especially to estimate the buses' minimum speed limits.

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