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Bus priority lane in Bengaluru: A study on its effectiveness and driver stress

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ABSTRACT

This paper studies the effectiveness of the bus priority lane (BPL) for public transport buses in the city of Bengaluru in India. We use the travel times on the BPL corridor as a measure of the effectiveness of the BPL. We find that there is a significant improvement in the travel times after the introduction of the BPL; for the worst 10% of the travel times, we find an improvement between 4% and 28%. Our methodology involves extracting trips on the BPL and computing the travel times for these trips from a time series of GPS information. Our methodology is scalable and can be used to compute the travel times between any two given points in other similar studies. We supplement our results with a novel test (called the *D-test*) for comparing the levels of stressful driving in the following scenarios: (a) morning peak hours (IST 07:00 h to 11:00 h) versus evening peak hours (IST 17:00 h to 21:00 h), and (b) northward trips versus southward trips on the BPL. We are able to infer that the drivers are generally more stressed during the morning peak hours and during the southward trips on the BPL. Partitioning the BPL into segments, we show that a majority of the segments exhibit similar effectiveness and driver stress trends as the full BPL stretch. We anticipate that corrective measures for the betterment of travel times and driver stress levels (e.g., introducing additional buses subject to vehicle re-balancing constraints, carefully planning the bus schedules to regulate bus traffic throughout the day, etc.) in some segments can lead to further improvements in travel times and reduction in driver stress levels.

1. Introduction

Bengaluru, the capital city of the Indian state Karnataka, has a population of over 12 million people (est. 2020). The commute time to the workplace is an important factor that has a direct impact on the work productivity of an individual (van Ommeren and Gutiérrez-i-Puigarnau, 2011). Despite a considerable fraction of the commuters using public transport (managed by the Bengaluru Metropolitan Transport Corporation (BMTC) which runs a fleet of 6500 buses BMTC, 2019a), commuters still spend a considerable amount of time on the roads of Bengaluru. Therefore, it is pertinent for transport agencies like BMTC to undertake measures to (a) enhance public transport ridership, and (b) reduce commute time. Towards meeting these objectives, the Government of Karnataka implemented an experimental bus-only lane, called the Bus Priority Lane (BPL), exclusively for the BMTC buses (BMTC, 2019b) starting November 15, 2019. The BPL is a 21-km stretch of dedicated lane for the BMTC buses that runs from the Central Silk Board junction in South Bengaluru to Baiyappanahalli in North Bengaluru (Fig. 1).

The idea behind the BPL is to prevent the entry of non-BMTC vehicles (such as privately owned cars, buses, trucks, etc.) and provide a dedicated passageway to transit buses, thereby leading to reduced travel times on the BPL.

Urban road traffic in cities of developing nations share many common factors. These include inadequately maintained roads (Agarwal and Toshniwal, 2019), coexistence of multiple modes of transport (private car, public transport, taxi, and two wheelers) (Olafsson et al.,

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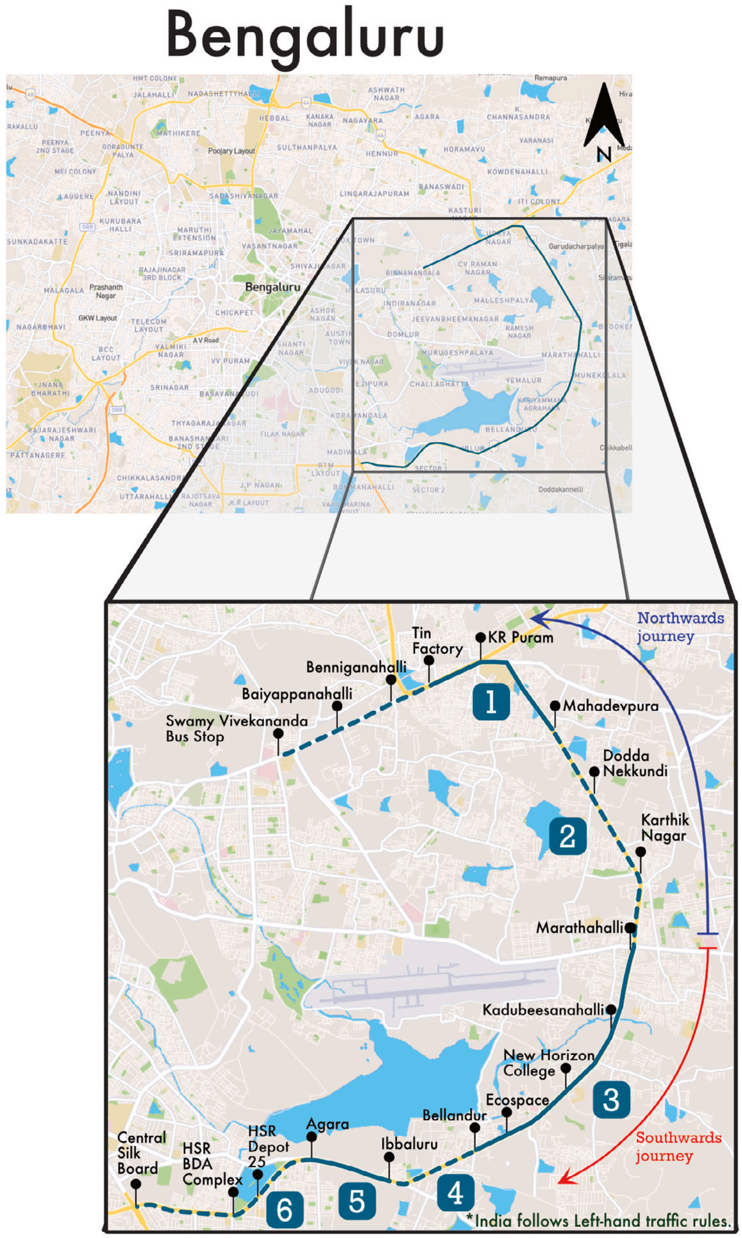

Fig. 1. A schematic view of the BPL and its segments. Segment 1 is between Tin Factory and Mahadevapura, Segment 2 is between Mahadevapura and Marathahalli, Segment 3 is between Marathahalli and Bellandur, Segment 4 is between Bellandur and Ibbaluru, Segment 5 is between Ibbaluru and Agara, and Segment 6 is between Agara and Central Silk Board.

2016; Singh, 2005), different degrees of automation on the roads which affect traffic flow (Ma, 2021), weak lane discipline, etc. Modelling of traffic flows in such conditions can be enormously complex. However, learnings from empirical studies in one city, such as the use of BPLs to improve travel times, can be of use in other similar cities.

In this paper, we examine the data from an experiment, compare the actual travel times before and after the implementation of the BPL, and conclude that the BPL had a positive impact. The worst 10% of the travel times found improvements of 4%–28%. Our study outcomes may be of relevance to other similarly congested cities.

The BPL connects the Central Silk Board junction in South Bengaluru to Baiyappanahalli in North Bengaluru (see Fig. 1). In each direction of travel (marked northwards and southwards respectively in Fig. 1), the BPL occupies the leftmost one-third part of the road (India follows the left-hand rule for traffic flow). Provisions are made for non-BMTC vehicles to use the BPL to change lanes or to make their way into crossroads at designated cut-in locations. The "Bus Only" markings painted on the lane demarcate the BPL's boundaries.

Every BMTC bus is fitted with a proprietary device that is capable of recording the GPS coordinates (latitude and longitude) of the subject bus once every second. We identified 40 BMTC buses of the *Vajra A/C type* plying along the BPL and fitted each of these buses with Netradyne's *Driveri* (Netradye Inc., 2019) device. The Driveri devices record the GPS coordinates of the buses once every 10 s. In addition, they raise *alerts* (in the form of audio beeps) under circumstances such as hard braking, following the vehicle in front too closely, the driver not wearing the seatbelt, etc. Our study uses (a) the GPS data coming from the proprietary devices on all the buses (both Vajra A/C type and regular) plying along the BPL, which are available both before the implementation of the BPL and after the implementation of the BPL, and (b) the GPS and the alerts data coming from the Driveri devices which are available only after the implementation of the BPL.

1.1. An overview of the prior works

It is known that travel times in public buses exhibit high spatial and temporal variance (see, e.g., Yetiskul and Senbil (2012) for a case study in Ankara, Turkey). BPLs, also known as bus rapid transit systems, bus rapid transit corridors, bus priority corridors, bus-only lanes, etc., are generally known to improve the travel times on both the bus priority lanes and the mixed vehicle lanes (McDonnell and Zellner, 2011; Levinson et al., 2002). They have been implemented in several cities across the world such as Honolulu, Silver Line in Boston, Beijing, and Shizuoka City. In India, recognising their importance for sustainability (Ponnaluri, 2011), BPLs have already been implemented in Ahmedabad, Surat, Pune and New Delhi (Kathuria et al., 2016).

There have been many works that study the effectiveness of BPLs using model-based simulations. In Hensher and Golob (2008), the authors provide a comparative assessment of BPLs in various cities around the world, examine the benefits they offer, the factors that contribute to their success, the challenges that BPLs face such as competition from other modes of transport, and the need for effective management and planning. The paper Hensher and Golob (2008) concludes that BPLs can be an effective and efficient mode of public transport, but their success depends on careful planning, management, and implementation. A separate study (Li and Ju, 2009) evaluates the effectiveness of BPLs in improving bus service quality and reducing travel time. The authors use data from a case study in Beijing, China, to analyse the impacts of BPLs on bus travel time, bus speed, and passenger waiting time. The study finds that BPLs can significantly reduce travel time and improve bus speed, especially during peak hours. The study also shows that the effectiveness of BPLs depends on various factors such as the length of the exclusive lanes, the number of bus routes using the lanes, and the level of enforcement. The authors conclude that the evaluation of BPLs is important for decision-makers to make informed decisions about the implementation of such lanes in urban areas.

Using a queue-based simulation model, Li and Ju (2009) assessed the effectiveness of BPLs and Ben-Dor et al. (2018) analysed an agent-based model for the Sioux Falls transportation network in South Dakota. By proposing a metric known as "volume-to-capacity (V-C) ratio", Godavarthi et al. (2014) studied the effectiveness of the BPLs in New Delhi and Ahmedabad by comparing, among other things, the travel time, volume, capacity, and delay incurred by general vehicles on the mixed-vehicle lanes with those incurred by buses on the BPLs. They concluded that if the V-C ratio exceeds 0.688, then the 5–6-km BPL in their study becomes untenable and, therefore, ineffective. The paper Mavi et al. (2018) considers a simulation of the BPL in Tehran and studies, via simulation, the impact of the following factors towards reducing the bus travel times: (a) adding more buses to the BPL, (b) increasing the speed of the buses along the BPL, (c) reducing the time spent by the buses at the bus stops, and (d) increasing the capacity of the buses. By evaluating each of the factors against select criteria (environmental, social, risk, safety, etc.) and assigning weights to the factors based on a novel weights assignment technique, the study reports that adding more buses to the BPL is the best option (in terms of having the largest weight) to improve the bus travel times. A study of the combined effect of BPL and transit signal priority (TSP), where select buses are prioritised to pass signalised intersections, is undertaken in Al-Deek et al. (2017). Here, the model of the BPL in Orlando, Florida, is simulated on a test-bed, and the impact of the following scenarios on the travel times is analysed: (a) No BPL, no TSP; (b) No BPL, only TSP; (c) BPL+ TSP-3, where buses running 3 or more minutes behind schedule are assigned topmost priority, and (d) BPL+ TSP-5, where buses running 5 or more minutes behind schedule are assigned topmost priority. Using real-world data to calibrate the simulation model, the authors report that BPL+ TSP-3 is most effective in improving the travel times. In contrast to the above-mentioned simulation-based works, our work deals with a field experiment to study the effectiveness of a real-world BPL in Bengaluru.

In Chen et al. (2020), the authors propose a new bi-objective optimisation model for designing bus priority networks. The model aims to improve the efficiency and reliability of bus networks by optimising the allocation of bus priority measures, such as BPLs and traffic signal priority, on road segments. In another study (Yao et al., 2015), the authors evaluate the effectiveness of BPLs in a bi-modal degradable road network which includes both buses and private vehicles. The authors develop a mathematical model to analyse the impacts of BPLs on bus and private vehicle travel times and total system travel time.

There have also been prior works that study the effectiveness of BPLs by using methods other than model-based simulation. Using questionnaires and surveys before and after the study, Zheng and Jiaqing (2007) and Sakamoto et al. (2007) measured the effectiveness of BPLs in Beijing and in Shizuoka City, respectively. The BPL in Shizuoka was implemented only during the morning peak hours from 07:30 h to 09:00 h, and in only one direction (towards Shizuoka station). The surveys in Sakamoto et al. (2007) studied the variability of several parameters such as the number of vehicles using the main road, the length of vehicular queues at traffic jams, the travel times of buses, the travel times of general vehicles, the time spent by a bus at a bus station, etc., and Sakamoto et al. (2007) reported improvements in most of these quantities due to the BPL. In Honolulu (Cham et al., 2006) and Boston (Schimek et al., 2005), GPS information was collected from Automatic Vehicle Location (AVL) devices, and the data from these devices was used to compute the travel times and assess the effectiveness of the BPLs in these locations.

In Dai et al. (2019), using real-world data from the buses, the authors propose a "path travel time estimation" algorithm to compute the travel times on the BPL. They fit a shifted log-normal distribution to the path travel times extracted from real-world measurements and report the goodness of fit. The extraction of the path travel times in Dai et al. (2019) is based on the exact time instants of entry into and exit out of the bus stations that are available for each bus. Specifically, the GPS information collected from the buses has explicit information about the bus stations. This, to some extent, provides hints about the exact routes of the buses. Such explicit information on the exact routes is unfortunately missing from the GPS data that we use in our work.

Example case studies from India (Fatima and Kumar, 2014; Arasan and Perumal, 2009) show trends in increased bus ridership after the introduction of BPL systems. The authors in Bhattacharyya et al. (2019) investigate the combined effect of BPL and Queue-Jump-Lane (QJL) (whereby buses are allowed to bypass signalised intersections) for the city of Kolkata, India, under the following scenarios: (a) no BPL implementation, (b) BPL with QJL, and (c) BPL along with QJL and pre-signal traffic for non-priority vehicles (manual intervention for other vehicles to bypass signalised intersections). They report that the scenario in (c) above is most effective in terms of reducing the travel times. In Tiwari and Jain (2012), for the BPL in Delhi, based on user surveys, the authors report a 33% improvement (resp. 14% increase) in the total travel time on the bus-lane (resp. non-bus lane) after the implementation of the BPL. However, in this paper, we analyse real-world data from the buses to quantify the effectiveness in travel times, and we report the improvements in the worst $x\%$ travel times, where x varies between 10 and 50. These provide more insights into the travel-time distribution. We further analyse the alerts data and provide insights on various congestion points on the BPL.

A study of the various factors that impact the effectiveness of BPLs such as the volume of traffic, the spacing between bus stops, the frequency of buses, etc. is undertaken in Schramm et al. (2010). A related line of research on BPLs is the study of a bi-objective optimisation problem involving (a) selection of routes on which priority for buses is to be implemented, and (b) scheduling the timings of bus priority rule enforcement, as carried out, for example, in Khoo et al. (2014). Also, there have been many works on designing BPLs for various cities around the globe; for instance, in Hadas and Nahum (2016), the authors study a design problem wherein the objective is to come up with a BPL that maximises the travel time gains and maintains balanced origin–destination stations, subject to a construction budget constraint. They propose an optimisation problem for this objective and come up with a bus priority lane design for Petah Tikva, Israel. For a study in developing countries, see Cracknell et al. (1990) which studied BPLs in Sao Paolo, Brazil. They highlight the use of BPLs in Abidjan (Ivory Coast), in Bogota (Colombia), and Lima (Peru). They explored the positioning of the BPLs (median versus edge), proposed the median, and highlighted the need for efficient boarding procedures. Another work focuses on other effects of BPLs such as the increase in bus ridership, changes in the mode of transport from car to bus, and changes in urban property values; see Ingvardson and Nielsen (2018), which studies 86 BPLs around the world, and the reference therein. However, in this paper, our focus is mainly on quantifying the effectiveness of BPLs in terms of the improvements in travel times. While we focus on BPL in Bengaluru, India, our methodology is general enough to be applicable to any situation wherein one has access to GPS time-series data from buses.

The design of BPLs (i.e., deciding where to implement BPLs) may itself be viewed as an optimisation problem, and from this perspective, Tsitsokas et al. (2021) formulates a discrete optimisation problem for BPL design in San Francisco using the actual bus frequencies and routes as constraints. By integrating dynamic congestion as a variable, Tsitsokas et al. (2021) proposes a novel greedy algorithm based on large neighbourhood search to solve the optimisation problem. While such studies play an important role during the planning phase of the BPLs (pre-implementation), our work deals with a post-implementation effectiveness study.

1.2. Challenges

In contrast to Li and Ju (2009) and Ben-Dor et al. (2018) which relied on simulations or (Zheng and Jiaqing, 2007; Sakamoto et al., 2007) which relied on surveys, our work relies on real world data coming from the Internet of Things (IoT) devices fitted on the buses and collected on a daily basis. The sheer volume of the data (approximately 150 Gigabytes per month) poses challenges in storing, reading and analysing large chunks of data. Whereas Godavarthi et al. (2014) dealt with a 5.7-km stretch of the bus priority lane, we deal with a longer 21-km stretch. In Schimek et al. (2005) and Cham et al. (2006), the buses plied along fixed and designated routes that remained static throughout the study period. However, in our work, some buses do not ply along fixed routes. Our collected data reveals instances of (a) buses plying along a certain route on a given day and not plying along the same route the following day, (b) buses plying along the same route on weekdays and following a different route on weekends, and (c) buses exiting the BPL before travelling the complete stretch of the BPL.[3] Such variations in the bus routes add to the difficulty in travel time computations.

In Dai et al. (2019), the exact time instants of entry into and exit out of the bus stations are available for each bus. These may be used to compute the time spent by the buses between any two consecutive bus stations, which when added across all the bus stations visited by the buses gives the total travel times of the buses. In our work, there is no explicit information about the exit and entry times to the bus stations. Additionally, we see instances of (a) the buses exiting the BPL, or (b) the buses halting at a bus station and restarting the trip, for instance, an hour later, or (c) both. Such considerations are necessitated in our work because the data collection process is constrained to not interfere with the normal functioning of the buses, thereby leading to further challenges in travel time computations.

1.3. Contributions

We demonstrate that the BPL has had an overall positive impact by showing that the distributions of the travel times before and after the implementation of the BPL are different. We find that the smallest travel time among the worst (largest) 10% of the travel times sees an improvement (reduction) between 4% and 28% after the implementation of the BPL. We also identify the stretches of the BPL that see the largest improvement in the travel times.

On the data processing front, we propose a novel data filtering technique known as “geo-fencing” to filter out trips that are not undertaken on the BPL, using only the GPS information available from the proprietary devices and the Driveri devices. This technique is easily scalable and may be used in other similar studies where only the time-series of GPS data is available.

To compare the levels of stressful driving across a pair of scenarios (for e.g., trips undertaken during the morning peak hours versus evening peak hours), we propose a novel metric. This metric uses the well-known Kullback–Leibler divergence, and is computed using the alerts data generated by the Driveri devices. We find that the drivers are more stressed during the morning peak hours and during the southward trips on the BPL.

Finally, we partition the BPL into six segments with respect to important traffic junctions along the BPL, and analyse each segment. We find that most of the segments inherit the same travel time improvement and driver stress level trends as the full stretch of the BPL, thereby broadly corroborating the results for the latter but also suggesting the need for a closer examination of traffic patterns in two scenarios: northward trips on segment 1 undertaken during the evening peak hours, and southward trips on segment 4 at all times.

We then propose certain policy interventions for BMTC that, if undertaken, could lead to further improvements in travel times and reduction in driver stress levels. In what follows, we discuss each contribution in slightly greater detail.

Discussion: In our work, we compute the travel times of trips on the BPL solely based on the time-series of GPS information available from the proprietary devices and the Driveri devices using a filtering technique called geo-fencing. In this technique, we first create a polygonal boundary around the BPL, and for each data point in the GPS time-series, we test whether the GPS coordinates of the data point falls on or within the polygonal boundary. All data points whose GPS coordinates fall outside the polygonal boundary are filtered out, and only the trips undertaken on the BPL are subsequently used to compute the travel times. More details are given in Section 2.2.

On the computed travel times, we carry out 2-sample Kolmogorov–Smirnov (KS) tests to test whether the distributions of the travel times before and after the implementation of the BPL are different. We observe that the p-values of the tests are very close to 0, thereby indicating that with high confidence, the distributions of the travel times before and after the implementation of the BPL are different.

We obtain the cumulative distribution functions (CDFs) of the travel times before and after the implementation of the BPL, and report the mean, standard deviation, and the median of the travel times. We also report the smallest travel time seen by the worst $(100 - x)\%$ of the trips, where x ranges from 50 to 90 in steps of 10. Reporting this information is more valuable than merely reporting the mean values of the travel times (as done, for instance, in the works Cham et al., 2006 and Schimek et al., 2005) as it helps us capture the event when the worst-case travel times see an improvement (reduction). We present the mean, standard deviation, median, and worst-case travel times separately for (a) the trips undertaken during the morning peak hours

[3] In our collected data, such instances occur when buses start from the Central Silk Board junction, exit the BPL corridor at Marathahalli, ply towards the airport, and eventually reach Tin Factory. Clearly, the times spent by the buses triping from Marathahalli to Tin Factory via the airport must not be considered when computing the travel times of trips from Central Silk Board junction to Tin Factory. Such trips need to be isolated and discarded from consideration on Central Silk Board junction to Tin Factory trips.

Table 1
Segments of the BPL (see Fig. 1).

Segment number	Stretch
Segment 1	Tin Factory to Mahadevapura
Segment 2	Mahadevapura to Marathahalli
Segment 3	Marathahalli to Bellandur
Segment 4	Bellandur to Ibbaluru
Segment 5	Ibbaluru to Agara
Segment 6	Agara to Central Silk Board

(07:00 h to 11:00 h), (b) the trips undertaken during evening peak hours (17:00 h to 21:00 h), and (c) the trips undertaken during the off-peak (or non-peak) hours which include all times outside the morning and the evening peak hours. Additionally, we mark the trips on the BPL as northward (Central Silk Board junction to Tin Factory) or southward (Tin Factory to Central Silk Board junction), and present the above statistics separately for the travel times of (a) northward trips, and (b) southward trips undertaken on the BPL. We find that there is a significant improvement in the travel times after the introduction of the BPL; for the worst 10% of the travel times, the improvement is between 4% and 28%.

We propose a test, called the *D-test*, to compare the levels of stressful driving in the following scenarios: (a) morning peak hours versus evening peak hours, and (b) northward trips versus southward trips on the BPL. This test is based on (i) the counts of the various alerts generated by the Driveri devices and (ii) the total hours driven by the buses as recorded by the Driveri devices, and uses the well-known Kullback–Leibler divergence metric. We find that the drivers are generally more stressed during the morning peak hours when compared with the evening peak hours, and more stressed during the southward trips when compared with the northward trips. Our results suggest that the fleet manager (i.e., BMTC) could possibly allocate more buses to ply along the southward direction of the BPL during the morning peak hours, subject to, of course, vehicle re-balancing constraints.

Finally, we partition the BPL into six specific segments as shown in Table 1 (also, see Fig. 1). The idea behind segmenting the BPL is to understand the impact of BPL at a finer granular scale and arrive at localised policy interventions. For example, we find that the southward trips undertaken on segment 5 exhibit the largest improvement in the mean travel time during both morning and evening peak hours.

2. Methodology

To study the effectiveness of the BPL, we compare the travel times on the BPL corridor before and after its implementation. We also study the impact of the BPL on stressful driving using the alerts generated by the Driveri devices. This section explains the datasets used in the study, the methodology to extract the travel times on the BPL from the datasets, and the *D-test* to compare the levels of stressful driving across different scenarios. We begin with a description of the datasets.

2.1. Description of the datasets

2.1.1. Dataset of GPS timestamps

In order to provide a baseline for comparing the travel times before and after the implementation of the BPL, we work with two datasets of GPS timestamps: one based on the data collected from the Driveri devices[4] between December 2019 and February 2020, and the other based on the data from the proprietary devices collected between August 2019 and February 2020. In the sequel, we shall refer to the data from the proprietary devices as *BMTC data*.

[4] These devices were incrementally installed on the buses starting from 21 October 2020. On 15 November 2019, the official start date of the BPL, these devices were installed on 8 Vajra A/C type buses, and on 15 December 2019, they were installed on 24 Vajra A/C type buses.

Table 2
A snapshot of the Driveri dataset.

Device ID	Latitude	Longitude	Timestamp
150812585	12.978247	77.573181	2019-08-31 23:59:53
150811027	12.960953	77.701447	2019-09-13 00:08:21

Table 3
A list of important alerts types measured with the aid of Netradyne's Driveri devices.

Collision-warning
Driver-distraction
Driver-drowsiness
Following-distance
Hard-braking
Hard-turn
Seatbelt-compliance

A snapshot of the data coming from the Driveri devices is shown in Table 2. Each data point has the following fields: `Device ID`, `Latitude`, `Longitude` and `Timestamp`. The `Device ID` uniquely identifies a bus. The other fields are self-explanatory. Thus, for instance, the first row of Table 2 indicates that at 23:59:53 h on 31 August 2019, the bus with `Device ID` 150812585 is at the location (12°58′41.7″N, 77°34′23.5″E), which corresponds to a `Latitude` value of 12.978247 and a `Longitude` value of 77.573181. The BMTC dataset is along similar lines as the Driveri dataset.

2.1.2. Dataset of alerts

In addition to providing GPS information, the Driveri devices are also capable of recording interesting events such as hard braking, tailgating, distracted driving, etc., with the help of various sensors present onboard. Upon detecting any such event, the Driveri devices raise an *alert*. A partial list of alerts raised by the Driveri devices is provided in Table 3. A "Collision-warning" alert is raised when the subject bus (the bus on which the Driveri device is mounted) is within a certain distance from the vehicle in front, hinting the possibility of a collision. Similarly, a "Following-distance" alert is raised when the subject bus is within a certain distance from the vehicle in front and this persists for a relatively long duration of time. A "Hard-braking" alert is raised when a driver applies the brakes suddenly (either to negotiate a speed-breaker, or to avoid a collision with a vehicle in front, etc.). The counts of the various alerts serve as a rough indicator of the natures of the traffic encountered by the buses during their trips, and therefore serves as an indicator of the levels of stressful driving experienced by the drivers. In a later section, we shall use the alerts data to compare the levels of stressful driving across different scenarios. The alerts data from the Driveri devices were collected from November 2019 to March 2020.

2.2. Travel time computation

We now present an algorithm for computing the travel times. Our algorithm is an instance of the "path travel time estimation" algorithm in Dai et al. (2019). Broadly, our algorithm involves the following 3 steps: (i) data clean-up, (ii) geo-fencing the BPL, and (iii) marking of the bus trips on the BPL as northward (from Central Silk Board junction towards Tin Factory) or southward (from Tin Factory towards Central Silk Board junction).

2.2.1. Data clean-up

In this step, we remove the invalid data points from the GPS datasets. Such data points arise when the devices mounted on the buses are unable to communicate reliably with the GPS satellites, resulting in invalid values for `Latitude` and `Longitude`; for e.g., a data point with Latitude = 91 and Longitude = 181 is invalid because this is outside the region of service. We also remove the data points with an invalid Timestamp value, i.e., any data point whose Timestamp value falls outside the data collection period.

2.2.2. Geo-fencing the BPL

With the invalid data points removed, the next step is to extract those data points whose GPS coordinates lie on the BPL. For this, we create a geo-fence, i.e., a polygonal boundary demarcating the BPL. We then check whether a given (valid) data point falls within the geo-fenced region, after accounting for the standard errors, using the shapely.geometry package of Python. In this way, for each bus, we maintain a record of all the data points for which the bus stays within the BPL. Note that the geo-fenced data points corresponding to any given bus may be obtained from multiple trips on the BPL in either direction (from Central Silk Board junction to Tin Factory, or vice-versa). To create smaller segments of the BPL, we follow the above geo-fencing procedure and provide the GPS coordinates corresponding to the boundaries of each segment.

2.2.3. Marking of trips on the BPL as northward and southward

This is the final step. To describe this step of our algorithm, we consider a bus whose $\texttt{DeviceID} = d$ and detail the procedure for marking a northward trip. Note that in order to mark a trip as northward, it is not sufficient to search for two time instants t_1 and $t_2 > t_1$ such that the bus with $\texttt{DeviceID} = d$ is near a small neighbourhood of Central Silk Board junction and near a small neighbourhood of Tin Factory at times t_1 and t_2 respectively. This is because the bus may possibly exit the BPL at Marathahalli, ply towards the airport, rejoin the BPL at Marathahalli, and ply towards Tin Factory. Similarly, the bus may start from Central Silk Board junction, halt at Marathahalli for one night, return to Central Silk Board junction the next morning, and then travel on the BPL corridor to reach Tin Factory. A naive computation, as alluded to above, may incorrectly result in a very large travel time in the above described anomalous circumstances.

To mark a trip as northward, we first extract pairs of data points of the form $(d, t_1, \texttt{lat}_1, \texttt{long}_1)$, $(d, t_2, \texttt{lat}_2, \texttt{long}_2)$ that satisfy the following conditions:

(i) $(\texttt{lat}_1, \texttt{long}_1)$ and $(\texttt{lat}_2, \texttt{long}_2)$ fall within small neighbourhoods of Central Silk Board junction and Tin Factory respectively,

(ii) for all data points from the bus with $\texttt{DeviceID} = d$ whose Timestamp values lie between t_1 and t_2,

  (a) the associated Latitude and Longitude values must lie within the geo-fenced region of the BPL, and

  (b) the direction of travel must be from Central Silk Board junction to Tin Factory.

We now describe how to check for the conditions in (i), (ii)(a) and (ii)(b).

To check for (i), we arrange the data points (satisfying the aforementioned conditions) according to Timestamp values, from the earliest to the latest. Let the ith data point in this list be denoted by $(d, t(i), \theta(i), \phi(i))$. Fix a parameter T (we set $T = 10$ in our algorithm, which corresponds to 10 seconds). Starting with the first data point, we search sequentially for an index i_1 such that $(\theta(i_1), \phi(i_1))$ lies in a neighbourhood of Central Silk Board junction, and $(\theta(i_1+T), \phi(i_1+T))$ lies on the BPL in the direction from Central Silk Board junction to Tin Factory and is away from this neighbourhood. This means that at time $t(i_1)$, the bus is plying towards Tin Factory along the BPL. We then proceed to find the smallest index $i_2 > i_1$ such that $(\theta(i_2), \phi(i_2))$ is along the direction from Central Silk Board junction towards Tin Factory, and $(\theta(i_2+T), \phi(i_2+T))$ lies in a neighbourhood of Tin Factory. This means that at time $t(i_2)$, the bus is approaching Tin Factory along the BPL. We have thus found a pair of data points that meets the requirement (i) in the previous paragraph.

To check for the condition in (ii)(a), we check that all the data points whose associated Timestamp values lie between $t(i_1)$ and $t(i_2)$ fall within the geo-fenced region. To check for the condition in (ii)(b), we consider all pairs (i, j) of data points for which $t(i)$ and $t(j)$ range between $t(i_1)$ and $t(i_2)$ and satisfy $t(j) - t(i) = 5$ min. We then compute the inner product of the vector $(\texttt{lat}(j) - \texttt{lat}(i), \texttt{long}(j) - \texttt{long}(i))$ with the tangent at the location $(\theta(i), \phi(i))$, and check that the sign of this inner product is positive. We repeat this for all the valid data points i and make sure that at least 90% of the data points with Timestamp values ranging between $t(i_1)$ and $t(i_2)$ yield a positive inner product. We also ensure that the bus under consideration does not stop at any location for a considerably long duration of time. This is accomplished by ensuring that for at least 50% of the pairs (i, j) of data points with Timestamp values ranging between $t(i_1)$ and $t(i_2)$ and satisfying $t(j) - t(i) = 5$ min, we have that $\theta(i) \neq \theta(j)$. Additionally, we check that the bus under consideration does not halt at a *bus depot*[5] for more than 30 min between the time instants $t(i_1)$ and $t(i_2)$. From the above exercises, we conclude that the bus under consideration is travelling northward along the BPL between the times $t(i_1)$ and $t(i_2)$. For each northward trip, we store the values of Timestamp, Latitude and Longitude corresponding to the start and end of the trip for later use. Once a northward trip between the time instants $t(i_1)$ and $t(i_2)$ is identified successfully, $t(i_2)-t(i_1)$ gives us the corresponding travel time.

Identification of southward trips on the BPL is along similar lines as above. For the segment-wise analysis, we use the above methodology to identify trips along each segment of the BPL by providing the latitudes and longitudes of the boundaries of the corresponding segment.

2.3. The KS test for deciding if the BPL has had an impact

On the computed travel times, we carry out 2-sample Kolmogorov–Smirnov (KS) tests to check whether the distributions of the travel times before and after the implementation of the BPL are different. We consider different scenarios, northward or southward, time of the day, and segment index, and study the impact of BPL at a fine level of granularity.

2.4. The D-test for comparing levels of stressful driving

We now present the *D-test* for comparing the levels of stressful driving in the following scenarios: (a) morning peak hours (07:00 h to 11:00 h) versus evening peak hours (17:00 h to 21:00 h), and (b) northward trips versus southward trips on the BPL.

Before describing the test, we introduce a few notations. Given an alert of type a, where a is any one among the list of alerts presented in Table 3, let n_a^{m} denote the total number of alerts of type a generated during the morning peak hours, and let n_a^{e} be the corresponding number for the evening peak hours. Further, let n_a^{n} (resp. n_a^{s}) denote the number of alerts of type a generated during the northward (resp. southward) trips on the BPL. Let h^{m} denote the total hours driven during the morning peak hours, computed across all the 40 Vajra A/C type buses fitted with the Driveri devices. Let h^{e}, h^{n} and h^{s} denote the corresponding numbers for the evening peak hours, the northward trips, and the southward trips on the BPL, respectively. Let

$$q_{\mathrm{me}} := \left(\frac{h^{\mathrm{m}}}{h^{\mathrm{m}} + h^{\mathrm{e}}}, \frac{h^{\mathrm{e}}}{h^{\mathrm{m}} + h^{\mathrm{e}}} \right), \tag{1}$$

and for an alert of type a, let

$$p_{a,\mathrm{me}} := \left(\frac{n_a^{\mathrm{m}}}{n_a^{\mathrm{m}} + n_a^{\mathrm{e}}}, \frac{n_a^{\mathrm{e}}}{n_a^{\mathrm{m}} + n_a^{\mathrm{e}}} \right). \tag{2}$$

[5] A bus depot differs from a bus station in that a bus may halt at a bus depot for a considerably long duration of time; e.g., during the night. There are two bus depots on the BPL, one near Agara lake and another near KR Puram (see Fig. 1).

Then, our statistic for comparing the levels of stressful driving between the morning peak hours and the evening peak hours, which we shall denote by S_{me}, is defined as

$$S_{\mathrm{me}} := \sum_a (n_a^{\mathrm{m}} + n_a^{\mathrm{e}})\, D_{\mathrm{KL}}(p_{a,\mathrm{me}} \parallel q_{\mathrm{me}}), \tag{3}$$

where D_{KL} in (3) denotes the Kullback–Leibler divergence. Along similar lines, defining

$$q_{\mathrm{ns}} := \left(\frac{h^{\mathrm{n}}}{h^{\mathrm{n}}+h^{\mathrm{s}}}, \frac{h^{\mathrm{s}}}{h^{\mathrm{n}}+h^{\mathrm{s}}}\right), \tag{4}$$

$$p_{a,\mathrm{ns}} := \left(\frac{n_a^{\mathrm{n}}}{n_a^{\mathrm{n}}+n_a^{\mathrm{s}}}, \frac{n_a^{\mathrm{s}}}{n_a^{\mathrm{n}}+n_a^{\mathrm{s}}}\right) \tag{5}$$

for an alert of type a, our statistic for comparing the levels of stressful driving between the northward trips and the southward trips on the BPL, which we shall denote by S_{ns}, is defined as

$$S_{\mathrm{ns}} := \sum_a (n_a^{\mathrm{n}} + n_a^{\mathrm{s}})\, D_{\mathrm{KL}}(p_{a,\mathrm{ns}} \parallel q_{\mathrm{ns}}). \tag{6}$$

The D-Test:

Notice that $D_{\mathrm{KL}}(p_{a,\mathrm{me}} \parallel q_{\mathrm{me}}), D_{\mathrm{KL}}(p_{a,\mathrm{ns}} \parallel q_{\mathrm{ns}}) \geq 0$, with equality if and only if $p_{a,\mathrm{me}} = q_{\mathrm{me}}$ and $p_{a,\mathrm{ns}} = q_{\mathrm{ns}}$ for all a. We first check whether $D_{\mathrm{KL}}(p_{a,\mathrm{me}} \parallel q_{\mathrm{me}}) = 0$ for all a. If so, then we have

$$\frac{n_a^{\mathrm{m}}}{n_a^{\mathrm{m}}+n_a^{\mathrm{e}}} = \frac{h^{\mathrm{m}}}{h^{\mathrm{m}}+h^{\mathrm{e}}}$$

for all a. Applying the componendo and dividendo rule, we get

$$\frac{n_a^{\mathrm{m}}}{n_a^{\mathrm{e}}} = \frac{h^{\mathrm{m}}}{h^{\mathrm{e}}}$$

for all a, or equivalently, $n_a^{\mathrm{m}}/h^{\mathrm{m}} = n_a^{\mathrm{e}}/h^{\mathrm{e}}$ for all a. That is, for each a, the rate at which alert a is generated during the morning peak hours (given by the ratio $n_a^{\mathrm{m}}/h^{\mathrm{m}}$) is equal to the rate for the evening peak hours (given by the ratio $n_a^{\mathrm{e}}/h^{\mathrm{e}}$). This suggests that the levels of stressful driving during the morning peak hours are equal to those during the evening peak hours. On the contrary, if $D_{\mathrm{KL}}(p_{a,\mathrm{me}} \parallel q_{\mathrm{me}}) > 0$ for some a, we get that $n_a^{\mathrm{m}}/h^{\mathrm{m}} \neq n_a^{\mathrm{e}}/h^{\mathrm{e}}$. If $n_a^{\mathrm{m}}/h^{\mathrm{m}} > n_a^{\mathrm{e}}/h^{\mathrm{e}}$ for majority a, we conclude that the levels of stressful driving during the morning peak hours is more than that during the evening peak hours. Else, if $n_a^{\mathrm{m}}/h^{\mathrm{m}} < n_a^{\mathrm{e}}/h^{\mathrm{e}}$ for majority a, we conclude that the levels of stressful driving during the evening peak hours is more than that during the morning peak hours. Else, the test is inconclusive. Further, the statistic S_{me} provides an overall assessment of differences between the morning peak hours and evening peak hours travels by weighing the relative entropy of an alert type by its frequency before combining. More frequent alerts naturally get a larger weight. The larger the value of S_{me}, the greater the difference in the travel times for the morning peak hours and the evening peak hours. The motivation for this statistic comes from a generalised likelihood ratio test.

We use a similar procedure as above to compare the levels of stressful driving between the northward trips and the southward trips on the BPL.

3. Results

In this section, we present the results of our experiments for the full stretch of the BPL and each of its segments. We first report the results of the 2-sample KS tests carried out on the travel times obtained from the proprietary devices before the implementation of the BPL, and from the Driveri devices and the proprietary devices after the implementation of the BPL. We then provide the plots of the CDFs of the travel times before and after the implementation of the BPL for various scenarios and quantify the effectiveness of the BPL. Lastly, we present the results of the *D-tests*.

Table 4
Results of the 2-sample KS tests for the full BPL and its segments.

Segment	KS test results				
	Hours	D_N^{KS}	p_N^{KS}	D_S^{KS}	p_S^{KS}
Segment 1	Morning peak	0.13	4.08×10^{-12}	0.07	2.82×10^{-10}
	Evening peak	0.06	1.83×10^{-5}	0.06	8.22×10^{-3}
	Off-peak	0.04	1.96×10^{-2}	0.05	1.18×10^{-5}
Segment 2	Morning peak	0.09	2.67×10^{-16}	0.16	2.87×10^{-58}
	Evening peak	0.12	1.83×10^{-26}	0.19	2.46×10^{-61}
	Off-peak	0.04	1.45×10^{-6}	0.13	3.67×10^{-60}
Segment 3	Morning peak	0.11	2.05×10^{-23}	0.17	3.39×10^{-56}
	Evening peak	0.32	1.38×10^{-157}	0.13	2.22×10^{-15}
	Off-peak	0.17	6.55×10^{-98}	0.03	1.48×10^{-3}
Segment 4	Morning peak	0.13	4.55×10^{-15}	0.17	5.16×10^{-24}
	Evening peak	0.07	1.74×10^{-7}	0.06	1.78×10^{-7}
	Off-peak	0.08	7.62×10^{-13}	0.11	3.11×10^{-15}
Segment 5	Morning peak	0.24	1.99×10^{-15}	0.33	1.52×10^{-5}
	Evening peak	0.31	4.04×10^{-8}	0.39	1.75×10^{-7}
	Off-peak	0.16	1.97×10^{-12}	0.37	3.17×10^{-119}
Segment 6	Morning peak	0.14	3.31×10^{-55}	0.04	2.21×10^{-5}
	Evening peak	0.20	4.21×10^{-69}	0.13	1.31×10^{-32}
	Off-peak	0.183	4.98×10^{-12}	0.05	5.36×10^{-11}
Full BPL	Morning peak	0.103	4.08×10^{-12}	0.105	2.89×10^{-13}
	Evening peak	0.222	1.22×10^{-15}	0.267	2.34×10^{-50}
	Off-peak	0.05	2.96×10^{-60}	0.222	1.26×10^{-83}

3.1. 2-Sample KS test results

We now present the results of the 2-sample KS tests for the full stretch of the BPL and for each of its six segments, taking into account northward trips and southward trips separately, leading to a total of 14 tests. In each of these tests, the two samples correspond to the travel times of the trips undertaken before (sample 1) and after (sample 2) the implementation of the BPL, both computed based on the data coming from the proprietary devices. For each test, we report the D-value and the p-value (denoted by D^{KS} and p^{KS} for clarity[6]). The results are summarised in Table 4.

It is overwhelmingly clear from the values of D^{KS} and p^{KS} for each of the segments and the full stretch of the BPL that with high confidence, the two samples corresponding to (a) the travel times before the implementation of the BPL, and (b) the travel times after the implementation of the BPL, follow different distributions. However, it is not clear from the results of the KS tests if the mean (average travel time) of one distribution is lesser than the other. To obtain insights into the exact trend, in the following section, we report the mean, the standard deviation, and the median of the distributions of the travel times before and after the implementation of the BPL, to get an idea on whether the BPL's impact has been positive or not. We also report the improvement in the worst $(100-x)$% of the trips (i.e., cumulative distribution function (CDF) tails), where x ranges from 50% to 90% in steps of 10%; varying x helps us capture improvements that may otherwise be non-evident for fixed values of x.

3.2. Results on the travel times for BPL northward trips

For the northward trips on the BPL, Fig. 2(A)–(D) indicate an overall *reduction* in the travel times after the implementation of the BPL. The CDF tails along with the mean, median, and standard deviation are reported in Table 5. We present the results separately for the BMTC and the Driveri datasets.

[6] The statistic D^{KS} is normalised by the number of samples used to compute it; we use the package `scipy.stats.ks_2samp` from Python to implement the 2-sample KS test.

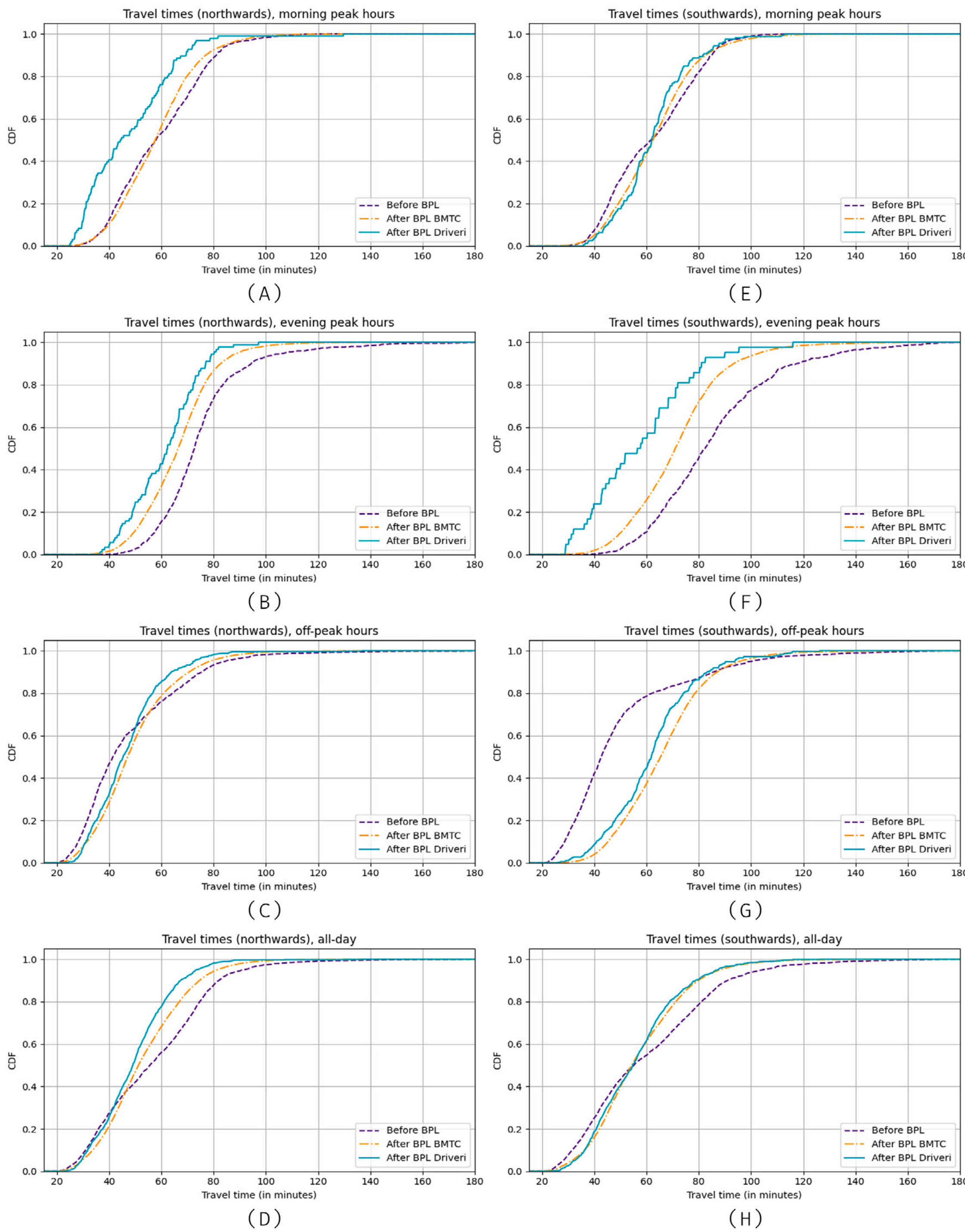

Fig. 2. CDFs of travel times for trips in the northward/southward directions on the BPL and in the morning/evening/off-peak hours.

Morning peak hours: For the northward trips undertaken during the morning peak hours, we observe that the mean travel time after the implementation of the BPL as computed from the BMTC (resp. Driveri) dataset has reduced by 1.88% (resp. 19.5%), the median has reduced by 0.53% (resp. 18.47%), the standard deviation has reduced by 10.67% (resp. 6.13%), and the smallest travel time among the worst 30% of the travel times has reduced by 6.74% (resp. 20.37%) after the implementation of the BPL.

Evening peak hours: For the northward trips undertaken during the evening peak hours, we see that the mean travel time computed from the BMTC (resp. Driveri) dataset has reduced by 12% (resp. 20.11%), the median has reduced by 8.86% (resp. 17.28%), the standard deviation has reduced by 23.06% (resp. 37.82%), and the smallest travel time among the worst 10% of the travel times has reduced by 13.57% (resp. 18.42%) after the implementation of the BPL.

Off-peak hours: For the northward trips undertaken during the off-peak hours, we see that the mean travel time computed from the BMTC (resp. Driveri) dataset is roughly the same, the median travel time has increased by 13.61% (resp. 10.53%), the standard deviation has reduced by 25.93% (resp. 35.89%), and the smallest travel time among the worst 10% of the travel times has reduced by 10.88% (resp. 12.19%) after the implementation of the BPL.

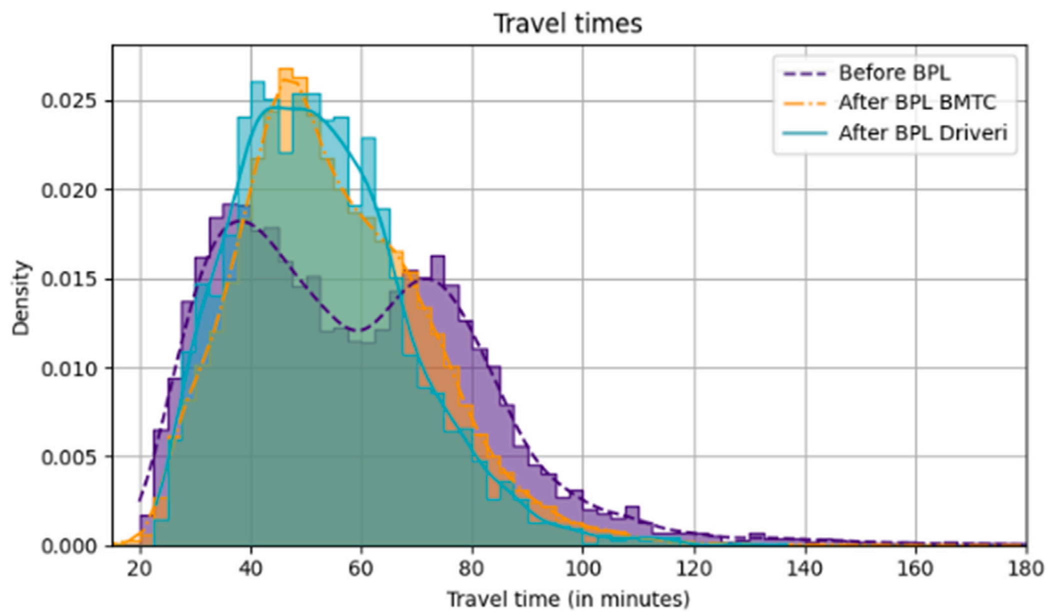

Fig. 3. Histogram of the travel times, taking into account all the trips on the BPL (northward/southward and morning/evening/off-peak hours), prior to and after the implementation of the BPL.

Table 5
Travel times (in minutes) before and after the implementation of the BPL.

Duration	CDF tail	Northwards					Southwards				
		Before BPL	After BPL		Improvements (%)		Before BPL	After BPL		Improvements (%)	
			BMTC	Driveri	BMTC	Driveri		BMTC	Driveri	BMTC	Driveri
Morning peak hours	50%	57.86	56.25	46.33	2.78	19.93	61.36	61.81	61.21	−0.73	0.24
	60%	63.71	59.69	51.99	6.31	18.40	68.10	65.32	63.69	4.08	6.48
	70%	69.55	64.86	55.38	6.74	20.37	73.15	68.83	66.99	5.91	8.42
	80%	74.42	68.30	59.90	8.22	19.51	78.20	74.09	73.61	5.26	5.87
	90%	80.27	76.91	64.43	4.19	19.73	84.94	81.11	81.05	4.51	4.58
	Mean	59.45	58.33	47.86	1.88	19.50	62.41	63.25	62.75	−1.35	−0.54
	Median	57.98	57.67	47.27	0.53	18.47	61.77	62.67	61.70	−1.46	0.11
	Std dev	16.97	15.16	15.93	10.67	6.13	16.93	15.91	14.10	6.02	16.72
Evening peak hours	50%	71.62	65.96	60.08	7.90	16.11	82.02	69.72	59.23	15.00	27.79
	60%	75.00	65.96	62.11	12.05	17.19	86.19	74.02	64.24	14.12	25.47
	70%	78.37	70.93	66.17	9.49	15.57	93.12	78.31	70.24	15.90	24.57
	80%	83.44	75.90	70.91	9.04	15.02	102.83	82.60	78.25	19.67	23.90
	90%	93.57	80.87	76.33	13.57	18.42	116.71	93.34	89.26	20.02	23.52
	Mean	75.60	66.53	60.40	12.00	20.11	85.94	72.08	61.96	16.13	27.90
	Median	72.78	66.33	60.20	8.86	17.28	82.50	71.08	59.42	13.84	27.98
	Std dev	19.17	14.75	11.92	23.06	37.82	24.27	18.85	21.21	22.33	12.61
Off-peak hours	50%	40.48	45.94	45.72	−13.49	−12.94	42.17	49.08	50.49	−16.39	−19.73
	60%	46.08	45.94	49.14	0.30	−6.64	45.20	51.51	55.95	−13.96	−23.78
	70%	53.55	50.96	52.55	4.84	1.87	49.76	58.79	60.49	−18.15	−21.56
	80%	62.89	55.99	57.10	10.97	9.21	61.90	66.08	65.04	−6.75	−5.07
	90%	74.10	66.04	65.07	10.88	12.19	84.67	73.36	75.04	13.36	11.37
	Mean	48.19	49.55	47.58	−2.82	1.27	50.11	53.08	53.16	−5.93	−6.09
	Median	41.52	47.17	45.89	−13.61	−10.53	42.69	50.00	50.93	−17.12	−19.30
	Std dev	21.48	15.91	13.77	25.93	35.89	24.34	17.41	15.95	28.47	34.47
All-day	50%	55.42	50.96	48.00	8.05	13.39	53.85	53.94	54.14	−0.17	−0.54
	60%	62.89	50.96	51.41	18.97	18.25	64.83	58.79	58.26	9.32	10.13
	70%	68.49	55.99	55.97	18.25	18.28	72.67	63.65	62.39	12.41	14.15
	80%	74.10	66.04	60.52	10.88	18.33	80.51	70.93	68.57	11.90	14.83
	90%	81.57	71.07	67.35	12.87	17.43	89.92	78.22	77.85	13.01	13.42
	Mean	57.12	53.33	49.80	6.64	12.82	60.17	56.95	56.17	5.35	6.65
	Median	55.62	51.17	49.12	8.00	11.69	55.13	54.33	54.73	1.45	0.73
	Std dev	21.98	16.40	13.92	25.39	36.67	25.30	18.14	17.06	28.30	32.57

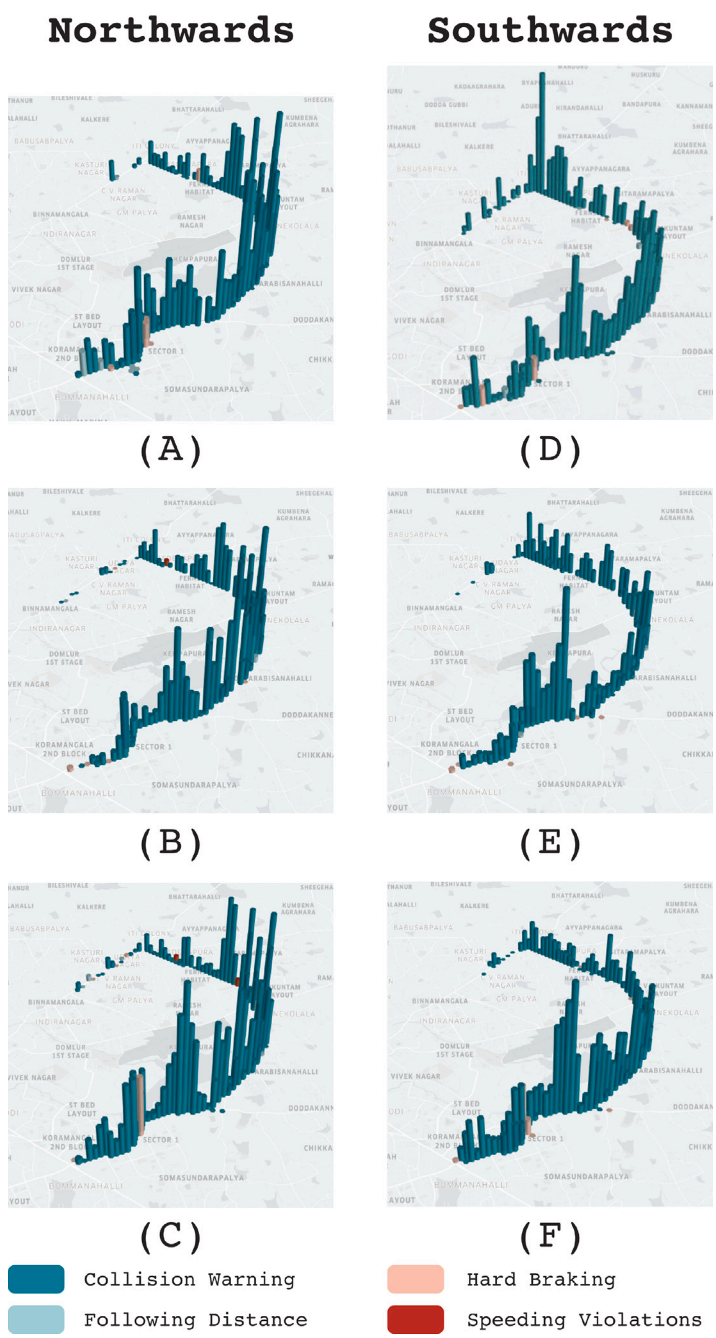

Fig. 4. Bar plots showing the spread of alert counts spatially on the BPL in the northward and southward directions. Figures (A) and (D) represent the spread of alerts during morning peak hours, (B) and (E) during the evening peak hours, and (C) and (F) during the off-peak hours.

Table 6
Improvements in travel times (in %) from BMTC devices in each segment before and after the implementation of the BPL.

Duration	CDF tail	Northwards (% Improvement)						Southwards (% Improvement)					
		Seg. 1	Seg. 2	Seg. 3	Seg. 4	Seg. 5	Seg. 6	Seg. 1	Seg. 2	Seg. 3	Seg. 4	Seg. 5	Seg. 6
Morning peak hours	50%	7.1	4.38	5.44	9.57	13.23	14.7	2.27	15.23	14.65	−5.57	42.99	1.75
	60%	9.3	5.26	4.26	6.44	13.81	14.36	1.56	12.51	15.67	−8.77	43.77	2.75
	70%	9.88	5.57	4.56	8.19	14.49	13.55	0.3	11.97	15.96	−10.27	38.14	3.58
	80%	12.27	5.76	3.63	9.96	13.58	13.59	−0.07	13.06	11.87	−14.59	26.91	3.4
	90%	17.04	6.02	3.08	10.84	11.32	13.58	0.02	12.01	6.26	−16.44	22.39	3.72
	Mean	7.51	5.98	6.47	8.09	9.91	9.94	1.25	13.38	8.87	−7.68	33.68	0.86
	Median	6.82	4.21	5.41	9.11	12.85	14.9	1.93	15.23	14.24	−5.73	38.09	1.82
	Std dev	−11.69	22.8	9.79	11.93	−28.5	0.13	−11.91	10.74	−1.77	−46.83	18.34	−22.88
Evening peak hours	50%	−3.53	7.02	15.15	5.92	20.52	8.15	3.31	14.68	10.77	1.04	19.38	7.81
	60%	−6.1	6.4	15.06	6.59	23.88	10.76	3.38	15.81	10.96	−0.22	15.88	9.15
	70%	−5.46	6.06	15.11	6.68	29.0	16.86	3.72	16.59	10.98	−1.32	14.21	12.22
	80%	−5.73	6.82	16.6	8.81	32.88	22.37	3.22	16.13	11.11	−3.19	12.01	16.14
	90%	−4.09	8.51	18.9	8.22	32.06	28.39	7.99	20.04	10.7	−3.22	9.92	19.17
	Mean	−0.96	8.69	18.97	8.08	32.26	16.02	7.19	14.98	10.67	1.29	18.13	9.39
	Median	−3.54	6.81	15.35	5.68	21.29	7.97	3.29	14.59	10.44	1.41	19.22	7.67
	Std dev	6.58	32.83	41.06	18.51	50.8	46.81	32.88	22.98	14.33	−9.78	−36.65	6.23
Off-peak hours	50%	2.34	−0.03	7.21	6.46	6.18	−1.43	1.72	6.77	−1.41	−13.61	20.16	−2.92
	60%	2.65	2.57	10.99	5.94	8.83	−1.74	−0.09	7.72	−3.34	−12.22	17.46	−2.97
	70%	3.42	0.44	16.8	4.13	6.87	−1.68	−1.37	9.98	−1.24	−4.89	13.5	−1.06
	80%	4.49	3.32	20.89	1.82	4.71	−0.92	−3.83	14.17	−2.46	−1.63	9.84	0.1
	90%	3.19	5.24	23.7	0.92	0.48	−1.16	−8.08	19.56	−8.58	1.53	5.93	1.47
	Mean	4.1	4.26	15.07	3.33	2.54	−0.99	−3.64	10.99	−2.13	−3.58	19.25	−2.15
	Median	2.42	0.46	7.16	6.01	5.94	−1.93	1.74	6.95	−1.73	−13.39	19.89	−2.94
	Std dev	14.86	31.96	37.33	−11.87	−85.77	4.33	−41.24	20.88	10.39	10.29	−34.69	−9.17
All-day	50%	7.88	4.31	11.1	4.93	11.63	3.06	2.21	13.28	6.04	−3.14	20.12	1.74
	60%	8.42	5.37	14.02	4.38	12.45	5.07	1.63	17.85	8.55	−1.35	18.69	1.72
	70%	8.7	6.28	16.27	4.58	12.99	10.52	−0.14	19.25	11.51	−0.45	15.09	4.21
	80%	4.06	6.58	18.61	4.8	12.61	17.29	−1.38	17.52	11.19	−1.45	12.66	5.28
	90%	−0.43	8.2	19.44	3.8	11.89	17.75	−2.47	16.42	9.5	−1.87	8.8	8.72
	Mean	5.42	6.74	15.41	5.68	10.64	8.45	−0.41	14.79	7.49	−2.32	19.83	3.06
	Median	7.69	3.97	11.15	4.69	11.24	3.23	1.93	13.22	5.8	−3.24	20.07	1.41
	Std dev	6.55	28.27	34.02	8.84	1.89	13.46	−23.56	19.24	12.93	1.1	−32.78	1.09

Table 7
A table of the alert rates and the values of S_{me} for each segment and for the full stretch of the BPL, for comparing the driver stress levels between the morning peak hours and the evening peak hours.

Alert type (a)	Seg. 1		Seg. 2		Seg. 3		Seg. 4		Seg. 5		Seg. 6		Full BPL	
	h^m	h^e	h^m	h^e	h^m	h^e	h^m	h^e	h^m	h^e	h^m	h^e	h^m	h^e
	818.78	881.35	1069.83	939.66	727.83	1001.69	1059.89	1231.54	421.28	328.06	551.57	460.51	4649.18	4842.81
	$S_{me} = 172$		$S_{me} = 118$		$S_{me} = 382$		$S_{me} = 232$		$S_{me} = 60$		$S_{me} = 34$		$S_{me} = 175.95$	
	$\frac{n_a^m}{h^m}$	$\frac{n_a^e}{h^e}$	$\frac{n_a^m}{h^m}$	$\frac{n_a^e}{h^e}$	$\frac{n_a^m}{h^m}$	$\frac{n_a^e}{h^e}$	$\frac{n_a^m}{h^m}$	$\frac{n_a^e}{h^e}$	$\frac{n_a^m}{h^m}$	$\frac{n_a^e}{h^e}$	$\frac{n_a^m}{h^m}$	$\frac{n_a^e}{h^e}$	$\frac{n_a^m}{h^m}$	$\frac{n_a^e}{h^e}$
Collision-warning	0.68	0.46	2.05	2.23	3.09	1.78	2.26	1.62	2.91	3.76	1.33	1.15	0.84	0.71
Driver-distraction	0.34	0.13	0.47	0.24	0.89	0.26	0.54	0.21	0.58	0.33	0.32	0.18	0.17	0.08
Driver-drowsiness	0.09	0.02	0.13	0.03	0.17	0.03	0.16	0.02	0.18	0.03	0.09	0.01	0.03	0.008
Following-distance	0.07	0.04	0.23	0.28	0.44	0.25	0.24	0.18	0.24	0.34	0.14	0.09	0.06	0.06
Hard-braking	0.06	0.04	0.10	0.06	0.06	0.05	0.06	0.04	0.07	0.04	0.04	0.03	0.03	0.02
Hard-turn	–	–	0.03	0.01	–	–	–	–	–	–	–	–	0.006	0.002
Seatbelt-compliance	0.28	0.04	0.18	0.06	0.06	0.05	0.03	0.01	0.03	0.01	0.03	0.03	0.04	0.01

All-day: Finally, when all the northward trips on the BPL are taken into account, we see that the mean travel time computed from the BMTC (resp. Driveri) dataset has reduced by 6.64% (resp. 12.82%), the median has reduced by 8% (resp. 11.69%), the standard deviation has reduced by 25.39% (resp. 36.67%), and the smallest travel time among the worst 20% of the trips has reduced by 10.88% (resp. 18.33%) after the implementation of the BPL.

3.3. Results on the travel times for BPL southward trips

Fig. 2(E)–(H) show the plots for the travel times of the southward trips along the BPL during the morning peak hours, evening peak hours, off-peak hours and all-day.

Morning peak hours: For the southward trips undertaken during the morning peak hours, we see that the mean travel time computed using the BMTC (resp. Driveri) dataset has increased by 1.35% (resp. 0.54%), and the median has increased by 1.46% (resp. decreased by 0.11%), the standard deviation has decreased by 6.02% (resp. 16.72%), after the implementation of the BPL, and the smallest travel time among the worst 30% of the travel times has reduced by 5.91% (resp. 8.42%) after the implementation of the BPL. Table 5 summarises these trends.

Evening peak hours: For southward trips undertaken during the evening peak hours, we see that the mean travel time computed from the BMTC (resp. Driveri) dataset has reduced by 16.13% (resp. 27.9%), the median has reduced by 13.84% (resp. 27.98%), the standard devi-

Table 8
A table of the alert rates and the values of S_{ns} for each segment and for the full stretch of the BPL, for comparing the driver stress levels between the northward trips and the southward trips.

Alert type (a)	Seg. 1		Seg. 2		Seg. 3		Seg. 4		Seg. 5		Seg. 6		Full BPL	
	h^n	h^s	h^n	h^s	h^n	h^s	h^n	h^s	h^n	h^s	h^n	h^s	h^n	h^s
	1942.97	2034.71	3847.28	3676.49	1711.50	1850.69	2256.13	2436.72	603.08	778.47	897.72	950.59	$11.26k$	$11.73k$
	$S_{ns}=21$		$S_{ns}=12$		$S_{ns}=108$		$S_{ns}=29$		$S_{ns}=51$		$S_{ns}=59$		$S_{ns}=36.94$	
	$\frac{n_a^n}{h^n}$	$\frac{n_a^s}{h^s}$	$\frac{n_a^n}{h^n}$	$\frac{n_a^s}{h^s}$	$\frac{n_a^n}{h^n}$	$\frac{n_a^s}{h^s}$	$\frac{n_a^n}{h^n}$	$\frac{n_a^s}{h^s}$	$\frac{n_a^n}{h^n}$	$\frac{n_a^s}{h^s}$	$\frac{n_a^n}{h^n}$	$\frac{n_a^s}{h^s}$	$\frac{n_a^n}{h^n}$	$\frac{n_a^s}{h^s}$
Collision-warning	0.39	0.41	0.84	0.86	1.47	1.91	1.47	1.91	2.14	2.92	1.05	0.69	40.68	40.3
Driver-distraction	0.14	0.22	0.17	0.19	0.37	0.57	0.37	0.57	0.34	0.46	0.23	0.23	0.30	0.33
Driver-drowsiness	0.06	0.06	0.04	0.04	0.08	0.09	0.08	0.09	0.08	0.13	0.03	0.10	0.11	0.12
Following-distance	0.04	0.04	0.09	0.09	0.19	0.28	0.19	0.28	0.20	0.22	0.09	0.06	0.19	0.20
Hard-braking	0.04	0.04	0.04	0.05	0.04	0.06	0.04	0.06	0.05	0.06	0.02	0.04	0.05	0.05
Hard-turn	–	–	0.02	0.02	–	–	–	–	–	–	–	–	0.007	0.007
Seatbelt-compliance	0.14	0.17	0.17	0.06	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.02	0.008	0.006

Table A.9
Travel times (in minutes) before and after the implementation of the BPL for Segment 1 (between Tin Factory and Mahadevapura).

Duration	CDF tail	Northwards					Southwards				
		Before BPL	After BPL		Improvements (%)		Before BPL	After BPL		Improvements (%)	
			BMTC	Driveri	BMTC	Driveri		BMTC	Driveri	BMTC	Driveri
	50%	9.26	8.61	6.59	7.1	28.86	8.62	8.43	7.31	2.27	15.21
	60%	10.1	9.16	7.24	9.3	28.28	9.1	8.96	7.7	1.56	15.47
Morning peak hours	70%	10.95	9.87	8.14	9.88	25.67	9.58	9.56	8.3	0.3	13.37
	80%	12.26	10.75	9.33	12.27	23.85	10.44	10.44	9.09	−0.07	12.9
	90%	14.75	12.24	11.07	17.04	24.98	11.93	11.93	10.53	0.02	11.72
	Mean	10.3	9.53	7.46	7.51	27.59	9.4	9.28	7.77	1.25	17.38
	Median	9.28	8.65	6.6	6.82	28.9	8.63	8.47	7.33	1.93	15.06
	Std dev	3.44	3.84	3.7	−11.69	−7.73	3.56	3.98	2.25	−11.91	36.63
	50%	14.09	14.58	9.71	−3.53	31.09	8.59	8.31	5.62	3.31	34.56
	60%	15.43	16.37	11.56	−6.1	25.09	9.12	8.81	6.24	3.38	31.51
Morning peak hours	70%	17.21	18.15	14.3	−5.46	16.92	9.78	9.42	6.97	3.72	28.71
	80%	19.4	20.51	17.58	−5.73	9.38	10.59	10.25	7.65	3.22	27.77
	90%	22.88	23.82	22.02	−4.09	3.75	12.58	11.58	8.86	7.99	29.62
	Mean	15.28	15.42	11.75	−0.96	23.07	9.66	8.97	6.14	7.19	36.48
	Median	14.12	14.62	9.64	−3.54	31.7	8.62	8.33	5.63	3.29	34.62
	Std dev	6.51	6.08	6.55	6.58	−0.57	4.32	2.9	2.08	32.88	51.82
	50%	9.25	9.04	7.35	2.34	20.6	8.59	8.44	7.18	1.72	16.33
	60%	9.96	9.69	8.14	2.65	18.26	8.97	8.97	7.79	−0.09	13.17
Morning peak hours	70%	10.95	10.57	9.13	3.42	16.63	9.62	9.75	8.5	−1.37	11.57
	80%	12.74	12.17	10.83	4.49	15.02	10.59	11.0	9.61	−3.83	9.27
	90%	16.08	15.57	14.66	3.19	8.84	12.59	13.61	11.45	−8.08	9.08
	Mean	10.86	10.41	8.62	4.1	20.64	9.53	9.88	7.63	−3.64	19.93
	Median	9.28	9.06	7.35	2.42	20.83	8.62	8.47	7.2	1.74	16.44
	Std dev	5.25	4.47	4.5	14.86	14.24	3.86	5.46	2.94	−41.24	23.83
	50%	10.6	9.76	7.57	7.88	28.61	8.6	8.41	7.03	2.21	18.24
	60%	11.92	10.92	8.43	8.42	29.27	9.1	8.95	7.53	1.63	17.18
Morning peak hours	70%	13.77	12.57	9.7	8.7	29.57	9.59	9.6	8.15	−0.14	15.03
	80%	16.08	15.43	11.68	4.06	27.38	10.41	10.56	9.01	−1.38	13.44
	90%	19.58	19.67	15.9	−0.43	18.79	12.28	12.59	10.65	−2.47	13.25
	Mean	12.5	11.82	9.09	5.42	27.31	9.48	9.51	7.39	−0.41	21.98
	Median	10.62	9.8	7.58	7.69	28.57	8.63	8.47	7.03	1.93	18.53
	Std dev	5.82	5.43	5.14	6.55	11.63	3.76	4.64	2.64	−23.56	29.74

ation has reduced by 22.33% (resp. 12.61%), and the smallest travel time among the worst 50% of the travel times has reduced by 15% (resp. 27.79%) after the implementation of the BPL.

Off-peak hours: For southward trips undertaken during the off-peak hours, we see that the mean travel time has increased by 5.93% (resp. 6.09%), the median has increased by 17.12% (resp. 19.4%), the standard deviation has reduced by 28.47% (resp. 34.47%), and the smallest travel time among the worst 10% of the travel times has reduced by 13.36% (resp. 11.37%) after the implementation of the BPL.

All-day: Finally, when all the southward trips are taken into account, we see that the mean travel time has reduced by 5.35% (resp. 6.65%), the median has reduced by 1.45% (resp. 0.73%), the standard deviation has reduced by 28.3% (resp. 32.57%), and the smallest travel time among the worst 20% of the travel times has reduced by 11.9% (resp. 14.83%) after BPL implementation.

A reduction in the standard deviation in each of the scenarios for the northward and southward trips indicates that the travel times have become more regular (less unpredictable) after BPL implementation.

Table A.10
Travel times (in minutes) before and after the implementation of the BPL for Segment 2 (between Mahadevapura and Marathahalli).

Duration	CDF tail	Northwards					Southwards				
		Before BPL	After BPL		Improvements (%)		Before BPL	After BPL		Improvements (%)	
			BMTC	Driveri	BMTC	Driveri		BMTC	Driveri	BMTC	Driveri
Morning peak hours	50%	8.32	7.95	6.31	4.38	24.12	15.09	12.79	12.71	15.23	15.79
	60%	8.91	8.44	6.95	5.26	22.07	16.24	14.21	13.95	12.51	14.15
	70%	9.46	8.94	7.68	5.57	18.83	17.89	15.75	15.53	11.97	13.2
	80%	10.29	9.69	8.46	5.76	17.78	20.08	17.46	17.19	13.06	14.41
	90%	12.08	11.35	10.15	6.02	15.98	23.54	20.71	20.97	12.01	10.9
	Mean	9.0	8.46	6.81	5.98	24.36	15.78	13.66	13.71	13.38	13.12
	Median	8.32	7.97	6.32	4.21	24.05	15.1	12.8	12.73	15.23	15.67
	Std dev	3.31	2.56	2.29	22.8	30.95	6.85	6.12	5.75	10.74	16.05
Morning peak hours	50%	9.78	9.09	7.9	7.02	19.26	12.43	10.6	8.84	14.68	28.84
	60%	10.29	9.63	8.24	6.4	19.92	13.59	11.44	10.26	15.81	24.55
	70%	10.94	10.27	8.66	6.06	20.82	14.92	12.44	11.67	16.59	21.78
	80%	11.91	11.1	9.09	6.82	23.66	16.4	13.75	13.11	16.13	20.04
	90%	13.58	12.42	10.06	8.51	25.91	19.9	15.91	16.0	20.04	19.57
	Mean	10.31	9.42	8.07	8.69	21.77	13.58	11.54	10.29	14.98	24.22
	Median	9.78	9.12	7.9	6.81	19.25	12.45	10.63	8.85	14.59	28.92
	Std dev	3.73	2.5	1.72	32.83	53.87	5.98	4.61	5.61	22.98	6.31
Morning peak hours	50%	7.27	7.28	7.01	−0.03	3.66	8.62	8.03	7.97	6.77	7.45
	60%	7.79	7.59	7.35	2.57	5.71	9.26	8.54	8.58	7.72	7.34
	70%	8.12	8.08	7.78	0.44	4.2	10.12	9.11	9.52	9.98	5.87
	80%	8.92	8.62	8.31	3.32	6.86	11.56	9.93	11.1	14.17	3.97
	90%	10.09	9.56	9.23	5.24	8.58	14.57	11.72	14.91	19.56	−2.36
	Mean	7.82	7.49	7.15	4.26	8.62	9.74	8.67	9.24	10.99	5.16
	Median	7.32	7.28	7.02	0.46	4.1	8.63	8.03	8.0	6.95	7.34
	Std dev	2.62	1.78	1.68	31.96	35.92	4.17	3.3	4.63	20.88	−10.93
Morning peak hours	50%	7.98	7.63	7.13	4.31	10.66	10.41	9.03	9.07	13.28	12.91
	60%	8.59	8.13	7.51	5.37	12.51	12.09	9.93	10.28	17.85	14.93
	70%	9.25	8.67	8.05	6.28	12.95	13.93	11.25	12.08	19.25	13.24
	80%	10.09	9.43	8.56	6.58	15.23	16.1	13.28	14.16	17.52	12.07
	90%	11.74	10.77	9.64	8.2	17.86	19.61	16.39	17.21	16.42	12.25
	Mean	8.67	8.09	7.27	6.74	16.19	12.28	10.46	10.72	14.79	12.74
	Median	7.98	7.67	7.13	3.97	10.65	10.47	9.08	9.08	13.22	13.22
	Std dev	3.15	2.26	1.89	28.27	40.06	6.07	4.9	5.49	19.24	9.63

3.4. Segment-wise travel times

We now present the segment-wise results on the travel times.[7] For each segment, the improvements in the travel times after the implementation of the BPL using only the data from the proprietary devices are summarised in Table 6. We find that the travel times have generally improved (reduced) in all the segments, especially during the peak hours. More details are given below.

Improvements in travel times: During the peak hours, we see that segment 5 (between Ibbaluru and Agara) exhibits the largest improvement in the mean travel times. For instance, during the evening peak hours, we see an improvement of 32.26% for the northward trips and 18.13% for the southward trips. Also, in many instances, segment 5 shows the largest improvement in the CDF tails. We therefore conclude that the implementation of the BPL has been most effective in segment 5.

Degradation in travel times: During the morning peak hours, we see that there is a degradation (increase) in the mean travel times and the CDF tails for the southward trips in segment 4 (between Bellandur and Ibbaluru). This explains the observed degradation in the mean travel times (by 1.35%) for the southward trips along the full stretch of the BPL during the morning peak hours (see Table 2). Interestingly, the northward trips in segment 4 do not suffer from a similar degradation. We also see that during the evening peak hours, the travel times for northward trips in segment 1 (between Tin Factory and Mahadevapura) have worsened. It will be interesting to closely examine the vehicular traffic in the above scenarios in segments 1 and 4, implement polices for better traffic management, and study the effect of such policies on the mean travel times. Finally, we record here that the southward trips in segment 4 see a degradation in the mean travel times during all times of the day after the implementation of the BPL.

For more details on the segment-wise results before and after the implementation of the BPL, see Appendix A.1. For the CDFs, see Appendix A.2.

3.5. Results of the *D*-test

Morning peak hours versus evening peak hours: Table 7 summarises the results of the *D*-test for comparing the levels of stressful driving between the morning peak hours and the evening peak hours. Here, we observe that for the full stretch of the BPL, $h^{\mathrm{m}} = 4649.18$ hours and $h^{\mathrm{e}} = 4842.81$ hours between November 15, 2019 and March 20, 2020. The value of S_{me} for the full stretch of the BPL is observed to be 175.95. From the values in Table 7, we find that for most of the alert types, the value of $n_a^{\mathrm{m}}/h^{\mathrm{m}}$ is *larger* than the value of $n_a^{\mathrm{e}}/h^{\mathrm{e}}$ in a majority of the segments (exceptions are collision-warning and following-distance alerts in segments 2 and 5). Also, a similar pattern holds for the full stretch of the BPL as exemplified by the last column of Table 7. Based on the preceding observations, on a majority of segments of the BPL and on the full BPL, we infer that the drivers are generally *more stressed during the morning peak hours than in the evening peak hours*.

Northward trips versus southward trips: Table 8 summarises the results of the *D*-test for comparing the levels of stressful driving between the northward trips and southward trips on the BPL. Here, we observe that for the full stretch of the BPL, $h^{\mathrm{n}} = 11{,}258$ hours and $h^{\mathrm{s}} = 11{,}728$ hours between November 15, 2019 and March 20, 2020. The value of S_{ns} for

[7] Recall the segments of the BPL (see Fig. 1): Tin Factory to Mahadevapura (Segment 1), Mahadevapura to Marathahalli (Segment 2), Marathahalli to Bellandur (Segment 3), Bellandur to Ibbaluru (Segment 4), Ibbaluru to Agara (Segment 5), and Agara to Central Silk Board (Segment 6).

Table A.11
Travel times (in minutes) before and after the implementation of the BPL for Segment 3 (between Marathahalli and Bellandur).

Duration	CDF tail	Northwards					Southwards				
		Before BPL	After BPL		Improvements (%)		Before BPL	After BPL		Improvements (%)	
			BMTC	Driveri	BMTC	Driveri		BMTC	Driveri	BMTC	Driveri
Morning peak hours	50%	12.75	12.06	10.28	5.44	19.4	16.25	13.87	14.74	14.65	9.32
	60%	13.43	12.86	11.48	4.26	14.54	18.07	15.24	15.75	15.67	12.85
	70%	14.4	13.75	12.72	4.56	11.65	20.06	16.86	17.81	15.96	11.21
	80%	15.46	14.9	14.04	3.63	9.17	22.23	19.59	21.17	11.87	4.8
	90%	17.07	16.55	16.49	3.08	3.4	25.82	24.21	26.35	6.26	−2.06
	Mean	13.24	12.39	11.07	6.47	16.44	17.0	15.5	16.56	8.87	2.61
	Median	12.78	12.08	10.3	5.41	19.37	16.27	13.95	14.75	14.24	9.32
	Std dev	4.05	3.65	4.06	9.79	−0.23	6.81	6.93	6.71	−1.77	1.45
Morning peak hours	50%	20.71	17.57	18.38	15.15	11.23	14.42	12.87	11.1	10.77	23.03
	60%	21.85	18.56	19.74	15.06	9.67	16.37	14.57	12.64	10.96	22.78
	70%	23.07	19.59	20.82	15.11	9.74	19.21	17.1	15.11	10.98	21.31
	80%	24.87	20.74	22.1	16.6	11.13	22.54	20.03	18.52	11.11	17.8
	90%	27.81	22.55	23.83	18.9	14.31	27.33	24.4	23.42	10.7	14.29
	Mean	21.75	17.62	18.3	18.97	15.88	17.16	15.33	13.5	10.67	21.37
	Median	20.79	17.6	18.39	15.35	11.54	14.45	12.94	11.15	10.44	22.84
	Std dev	6.8	4.01	4.63	41.06	31.91	8.69	7.44	7.32	14.33	15.77
Morning peak hours	50%	11.6	10.76	11.68	7.21	−0.72	9.6	9.74	9.83	−1.41	−2.39
	60%	13.11	11.67	12.84	10.99	2.02	10.26	10.61	11.0	−3.34	−7.13
	70%	15.3	12.73	14.29	16.8	6.58	11.42	11.56	12.55	−1.24	−9.86
	80%	17.9	14.16	15.91	20.89	11.14	13.4	13.73	15.54	−2.46	−15.92
	90%	21.23	16.2	18.37	23.7	13.47	17.28	18.77	21.79	−8.58	−26.09
	Mean	13.34	11.33	12.4	15.07	7.03	11.3	11.54	12.3	−2.13	−8.92
	Median	11.63	10.8	11.7	7.16	−0.57	9.63	9.8	9.88	−1.73	−2.6
	Std dev	5.78	3.62	4.37	37.33	24.49	6.64	5.95	6.52	10.39	1.76
Morning peak hours	50%	13.38	11.89	12.31	11.1	7.99	11.75	11.04	11.16	6.04	5.01
	60%	15.24	13.1	13.79	14.02	9.52	13.4	12.26	12.43	8.55	7.21
	70%	17.18	14.39	15.32	16.27	10.83	15.71	13.9	14.48	11.51	7.83
	80%	19.72	16.05	17.51	18.61	11.2	18.69	16.6	17.53	11.19	6.2
	90%	23.02	18.55	20.33	19.44	11.7	23.23	21.02	22.4	9.5	3.57
	Mean	14.96	12.65	13.16	15.41	12.02	13.98	12.93	13.21	7.49	5.5
	Median	13.45	11.95	12.32	11.15	8.43	11.78	11.1	11.21	5.8	4.88
	Std dev	6.64	4.38	4.99	34.02	24.77	7.33	6.38	6.59	12.93	10.06

the full stretch of the BPL is observed to be 36.94. From the values in Table 8, we find that for most of the alert types, the value of $n_a^{\mathrm{n}}/h^{\mathrm{n}}$ is *smaller* than the value of $n_a^{\mathrm{s}}/h^{\mathrm{s}}$ in a majority of the segments. Also, a similar pattern holds for the full stretch of the BPL as exemplified by the last column of Table 8. Based on the preceding observations, on a majority of the segments of the BPL and on the full BPL, we infer that the drivers are generally *more stressed during the southward trips than during the northward trips*.

For more detailed *D*-Test results, see Appendix B.

4. Study insights and policy interventions

We now present some insights from our study and also present some policy interventions for the fleet manager (BMTC). For the southward trips on the BPL undertaken during the morning peak hours, we see that after the implementation of the BPL, there is an increase in the mean travel time and a decrease in the travel times of the worst affected trips. This trend can be seen from the CDF tails (see Table 5). This underscores the importance of reporting the CDF tails in addition to reporting mean, median, and standard deviation values. Fig. 3 shows the histogram of travel times computed by taking into account *all* the trips before and after the implementation of the BPL. Notice the presence of two peaks in the histogram before the implementation of the BPL, versus a single peak after the implementation of the BPL. A comparison of the curves in purple and orange reveals that trips that took 70 or more minutes before the implementation of the BPL take lesser time after the implementation of the BPL. This asserts the overall effectiveness of the BPL. A closer look at Fig. 2 shows that the CDFs of the travel times computed using the data obtained from the Driveri devices match closely with the CDFs computed using the data from the proprietary devices. Also worth noting is the similarity in the 'Before BPL BMTC' and the 'After BPL Driveri' curves in Fig. 3. These figures provide an affirmation that the data collected from the Driveri devices validates the data collected from the proprietary devices.

The travel times for the northward trips undertaken during the morning peak hours and the southward trips undertaken during the evening peak hours, as measured by the data collected from the Driveri devices, see considerable reduction (between 19% and 27%) after the implementation of the BPL, compared to the data collected from the proprietary devices. Recall that the Driveri devices are mounted on Vajra A/C type buses only. This indicates that the BPL in the above scenarios is more effective for Vajra A/C buses than for non-A/C buses. The fleet manager (i.e., BMTC) may apply this insight to bus allotment on the BPL routes. Also, for many situations (e.g., northward trips during the evening peak hours), the travel times obtained using the data coming from the Driveri devices exhibit lesser standard deviation than those obtained using the data coming from the proprietary devices. We anticipate that this may be because (a) the average speed of a Vajra A/C type bus exhibits less variation, or (b) because fewer data points are available for the Vajra A/C type buses (recall that the Driveri devices were mounted on only 40 Vajra A/C type buses). This may be worth exploring further.

The travel times of the trips undertaken during the off-peak hours see an increase after the implementation of the BPL in both the northward and the southward directions, with the southward trip travel times being slightly larger. This suggests that the BPL may not be effective during the off-peak hours, particularly in the southward direction. We observe identical trends for the travel times measured in both the northward and the southward directions (i.e., Fig. 2(G) and (H)): the tails of the CDFs have improved after the implementation of the BPL, which indicates that the BPL has generally improved the travel times in both the directions of travel. The bottom portions of the CDFs have

Table A.12
Travel times (in minutes) before and after the implementation of the BPL for Segment 4 (between Bellandur and Ibbaluru).

Duration	CDF tail	Northwards					Southwards				
		Before BPL	After BPL		Improvements (%)		Before BPL	After BPL		Improvements (%)	
			BMTC	Driveri	BMTC	Driveri		BMTC	Driveri	BMTC	Driveri
Morning peak hours	50%	7.12	6.44	4.11	9.57	42.21	5.82	6.14	3.54	−5.57	39.07
	60%	7.45	6.97	4.93	6.44	33.84	5.97	6.5	3.78	−8.77	36.76
	70%	8.13	7.46	5.61	8.19	31.02	6.31	6.96	4.37	−10.27	30.83
	80%	9.1	8.2	6.51	9.96	28.52	6.79	7.78	5.06	−14.59	25.43
	90%	10.57	9.42	7.45	10.84	29.5	7.79	9.07	5.61	−16.44	27.94
	Mean	7.75	7.12	4.83	8.09	37.69	6.29	6.77	3.98	−7.68	36.71
	Median	7.13	6.48	4.14	9.11	41.94	5.82	6.15	3.55	−5.73	38.97
	Std dev	3.13	2.75	2.19	11.93	29.79	1.55	2.28	1.08	−46.83	30.42
Morning peak hours	50%	8.78	8.26	7.33	5.92	16.48	11.74	11.62	10.57	1.04	9.92
	60%	9.73	9.09	8.18	6.59	15.96	12.57	12.6	11.85	−0.22	5.74
	70%	10.97	10.23	8.97	6.68	18.21	13.4	13.58	12.93	−1.32	3.52
	80%	12.76	11.64	10.38	8.81	18.65	14.44	14.9	14.01	−3.19	2.97
	90%	15.4	14.13	12.72	8.22	17.37	16.05	16.57	15.37	−3.22	4.29
	Mean	10.05	9.24	7.97	8.08	20.69	11.95	11.79	10.23	1.29	14.4
	Median	8.8	8.3	7.35	5.68	16.48	11.78	11.62	10.58	1.41	10.25
	Std dev	4.77	3.88	3.51	18.51	26.42	3.51	3.85	4.4	−9.78	−25.54
Morning peak hours	50%	7.47	6.99	5.41	6.46	27.57	7.44	8.46	3.69	−13.61	50.42
	60%	8.28	7.79	6.08	5.94	26.62	8.44	9.47	4.1	−12.22	51.44
	70%	8.96	8.59	7.08	4.13	21.02	10.26	10.76	4.91	−4.89	52.14
	80%	10.12	9.93	8.44	1.82	16.55	11.97	12.16	5.67	−1.63	52.57
	90%	12.24	12.13	11.29	0.92	7.84	14.12	13.9	7.88	1.53	44.15
	Mean	8.3	8.02	6.43	3.33	22.53	8.91	9.23	4.77	−3.58	46.47
	Median	7.48	7.03	5.43	6.01	27.51	7.47	8.47	3.7	−13.39	50.45
	Std dev	3.09	3.46	3.79	−11.87	−22.45	4.3	3.86	3.29	10.29	23.55
Morning peak hours	50%	7.46	7.09	5.52	4.93	26.0	8.99	9.27	4.28	−3.14	52.42
	60%	8.09	7.74	6.3	4.38	22.16	10.42	10.56	5.22	−1.35	49.88
	70%	9.01	8.59	7.19	4.58	20.17	11.74	11.8	6.49	−0.45	44.77
	80%	10.27	9.77	8.46	4.8	17.62	13.07	13.26	9.46	−1.45	27.59
	90%	12.56	12.08	10.99	3.8	12.47	14.94	15.22	12.89	−1.87	13.74
	Mean	8.5	8.02	6.4	5.68	24.77	9.7	9.93	6.17	−2.32	36.42
	Median	7.47	7.12	5.53	4.69	25.89	9.01	9.3	4.32	−3.24	52.08
	Std dev	3.72	3.39	3.59	8.84	3.61	4.05	4.0	4.25	1.1	−5.03

become worse after the implementation of the BPL, mainly due to the travel times measured during the off-peak hours.

Fig. 4(A)–(F) depict the histogram of the alert counts measured during the morning peak, evening peak and off-peak hours. The tall bars corresponding to the collision-warning alerts are likely due to the relatively large traffic density in Bengaluru, especially on the BPL segment where many business parks and corporate offices are located. In a neighbourhood of Tin Factory, the density of alert counts during the morning peak hours is high, as evident from Fig. 4(D). However, this is not the case in Fig. 4(A). We anticipate that this is because of the presence of a bus station (in close proximity to the KR Puram railway station) in the southward direction. Comparing Fig. 4(A)–(C) with Fig. 4(D)–(F), we see that in a neighbourhood of Ibbaluru, the concentration of alerts is higher in the northward direction than that in the southward direction. This may be attributed to the presence of a traffic junction in the northward direction. While Fig. 4(A)–(F) are indicative of the presence of traffic junctions or bus stations as discussed above, they do not reveal any direct relationship between the concentration of alert counts and the travel times. Does a large concentration of alert counts in a certain region imply more crowding, and therefore larger travel times along that direction of travel? We postpone a detailed investigation of such questions to the future.

Policy interventions for BMTC: We now present some policy interventions for BMTC that emerge from our study.

First, our study brings out the overall effectiveness of the BPL through the reduction in the bus trip travel times. In addition to the observed improvements in the mean travel times during the peak hours in both directions across the full stretch of the BPL, there is also improvement in all but two segments and directions. The segments and directions that run counter to the broad conclusion are (a) segment 1, northward direction, evening peak hours, and (b) segment 4, southward direction, all hours. BMTC may therefore continue to have the BPL in operation for exclusive use by its buses, and an effort should be made to understand and mitigate the issues in segments 1 and 4.

Second, segments of the travel route could be identified and examined for bottlenecks in traffic. The glaring negative % improvement values in Table 6 corresponding to the southward trips in segment 4 (between Bellandur and Ibbaluru) indicate a degradation in the mean travel times in this segment after the introduction of the BPL. Either a careful restructuring of the bus schedules to regulate bus traffic or infrastructural upgrades or better regulation of traffic to minimise BPL violations in segment 4 along the southward direction (i.e., from Bellandur to Ibbaluru) can possibly lead to an overall further improvement in the mean travel times for this segment and also for the full stretch of the BPL.

Third, our results on the driver stress levels indicate that the drivers operating buses along the southward direction of the BPL during the morning peak hours are the most stressed. In view of this observation, the drivers' work hours (termed *shift*[8]) can possibly be reorganised so that the drivers operating buses during the morning peak hours on a given day, operate during the evening/off-peak hours on the following day. A similar rule may be applied to reorganise the driver shifts between northward and southward trips.

[8] Driver shifts are of three types: (a) general shift, (b) night out, and (c) day shift. A driver on general shift operates the bus from 07:00 h to 19:00 h, with breaks at the destination bus stations. A driver on night out shift operates the bus from 22:00 h to 03:00 h, and again from 05:00 h to 22:00 h, and repeats this every alternate day. A driver on day shift operates the bus between 06:00 h to 14:00 h.

Table A.13
Travel times (in minutes) before and after the implementation of the BPL for Segment 5 (between Ibbaluru and Agara).

Duration	CDF tail	Northwards					Southwards				
		Before BPL	After BPL		Improvements (%)		Before BPL	After BPL		Improvements (%)	
			BMTC	Driveri	BMTC	Driveri		BMTC	Driveri	BMTC	Driveri
Morning peak hours	50%	10.1	8.77	7.12	13.23	29.53	11.08	6.31	3.42	42.99	69.16
	60%	10.77	9.28	7.7	13.81	28.5	14.09	7.92	3.51	43.77	75.11
	70%	11.46	9.8	8.38	14.49	26.87	16.08	9.94	3.66	38.14	77.22
	80%	12.29	10.62	9.1	13.58	25.91	16.75	12.24	3.83	26.91	77.12
	90%	13.6	12.06	10.27	11.32	24.51	19.87	15.42	4.14	22.39	79.18
	Mean	10.36	9.33	7.42	9.91	28.39	12.18	8.08	3.72	33.68	69.46
	Median	10.12	8.82	7.15	12.85	29.32	10.22	6.32	3.42	38.09	66.56
	Std dev	2.46	3.16	3.29	−28.5	−33.55	6.96	5.68	1.34	18.34	80.69
Morning peak hours	50%	10.27	8.16	4.73	20.52	53.97	9.45	7.62	7.05	19.38	25.4
	60%	11.76	8.96	4.96	23.88	57.82	9.8	8.24	7.76	15.88	20.83
	70%	14.25	10.12	5.2	29.0	63.51	10.27	8.81	8.61	14.21	16.16
	80%	17.25	11.58	5.54	32.88	67.85	10.79	9.49	9.17	12.01	14.96
	90%	22.21	15.09	6.15	32.06	72.33	11.61	10.46	10.17	9.92	12.38
	Mean	13.53	9.16	4.94	32.26	63.44	9.51	7.78	7.11	18.13	25.18
	Median	10.38	8.17	4.73	21.29	54.38	9.45	7.63	7.05	19.22	25.4
	Std dev	8.96	4.41	1.06	50.8	88.2	1.74	2.38	2.4	−36.65	−37.91
Morning peak hours	50%	8.97	8.42	4.48	6.18	50.03	9.12	7.28	4.14	20.16	54.62
	60%	9.62	8.77	4.79	8.83	50.23	9.6	7.92	4.62	17.46	51.9
	70%	10.12	9.42	5.14	6.87	49.18	9.97	8.62	5.12	13.5	48.62
	80%	10.79	10.28	5.75	4.71	46.69	10.47	9.44	6.1	9.84	41.68
	90%	12.0	11.94	7.68	0.48	36.02	11.27	10.6	8.23	5.93	26.95
	Mean	9.36	9.13	5.31	2.54	43.25	9.21	7.44	4.96	19.25	46.11
	Median	8.98	8.45	4.52	5.94	49.72	9.13	7.32	4.15	19.89	54.56
	Std dev	2.28	4.24	3.29	−85.77	−44.25	2.04	2.75	2.14	−34.69	−4.99
Morning peak hours	50%	9.78	8.65	5.09	11.63	47.96	9.29	7.42	4.5	20.12	51.57
	60%	10.41	9.11	5.6	12.45	46.21	9.78	7.95	5.13	18.69	47.54
	70%	11.13	9.68	6.56	12.99	41.03	10.12	8.59	6.01	15.09	40.65
	80%	12.08	10.56	7.68	12.61	36.48	10.77	9.41	7.53	12.66	30.14
	90%	13.57	11.96	9.05	11.89	33.35	11.6	10.58	9.05	8.8	21.99
	Mean	10.26	9.17	6.01	10.64	41.47	9.44	7.56	5.39	19.83	42.86
	Median	9.78	8.68	5.12	11.24	47.61	9.3	7.43	4.52	20.07	51.43
	Std dev	3.22	3.16	2.78	1.89	13.71	2.06	2.74	2.39	−32.78	−16.11

The overall reduction in the bus travel times suggests that BPLs could first be tried out in other similar cities before making investments in more expensive tram, train, subway lines. The proposed method to analyse route segments enables targeted interventions for improvement, an idea which can be applied to other similar urban locations. Our approach to map hot-spots of increased driver stress is another contribution that can be carried over to other cities.

5. Summary, conclusions, and future directions

This paper dealt with a study of the effectiveness of the bus priority lane (BPL) in Bengaluru and its impact on travel times and driver stress levels. We analysed the GPS data coming from two sources: (a) proprietary devices mounted on every BMTC bus plying along the BPL, and (b) Netradyne's Driveri devices mounted on 40 Vajra A/C type buses plying along the BPL. We observed a considerable improvement (reduction) in the peak hour travel times (between 4% and 28%) after the implementation of the BPL in both the northward and the southward trips, and concluded that the BPL has been effective during the peak hours. One takeaway from our work is a scalable algorithm to compute the *path travel times* from a dataset of GPS coordinates. Our algorithm can also be easily implemented in other cities for which a similar dataset is available. Using the dataset of alerts generated by the Driveri devices, we proposed a novel test (the *D-test*) to compare the levels of stressful driving across two example scenarios: (a) morning peak hours versus evening peak hours, and (b) northward trips versus southward trips on the BPL. From the *D-test*, we were able to infer that the drivers are generally more stressed during the morning peak hours and along the southward trips on the BPL. Such insights may be used to allocate more buses to ply along the southward direction of the BPL during the morning peak hours. We segmented the BPL and ran our experiments on each segment to understand which segment(s) impact the travel times and the driver stress levels the most. Our segment-wise results indicate that corrective measures for the betterment of travel times and driver stress levels in some segments (for e.g., regulating traffic movement during the peak hours, introducing more buses subject to vehicle re-balancing constraints) can lead to further overall improvements in these quantities for the full stretch.

Some future directions of our study include assessing the effect of the BPL on (a) ridership in public transport, and (b) the change in the travel time distribution from the typical log-normal observed, for instance, in Dai et al. (2019). It will be interesting to obtain an empirical relationship between the improvements in the mean travel times and the driver stress levels with reference to other independent observables such as speed and acceleration of the buses, spatial and temporal attributes, etc. In fact, one might hypothesise that the BPL leads to reduced stress on the drivers, due to exclusive use of the lane for buses. The installation of the Driveri devices, which gathered the driver behaviour data, coincided with the start of the BPL in our work. So we have behavioural data only after the BPL was implemented. This only enabled comparison of stress levels across northward/southward trips and morning/evening peak hours for the full stretch of the BPL and across the segments, all after the implementation of the BPL. We leave it to the future to explore the possibility of conducting another trial to study the impact of BPL on driver stress levels and safety.

CRediT authorship contribution statement

P.N. Karthik: Formal analysis, Software, Investigation, Writing – original draft. **Nihesh Rathod:** Formal analysis, Software, Investigation, Visualization, Writing – review & editing. **Sarath Yasodharan:**

Table A.14
Travel times (in minutes) before and after the implementation of the BPL for Segment 6 (between Agara and Central Silk Board).

Duration	CDF tail	Northwards					Southwards				
		Before BPL	After BPL		Improvements (%)		Before BPL	After BPL		Improvements (%)	
			BMTC	Driveri	BMTC	Driveri		BMTC	Driveri	BMTC	Driveri
Morning peak hours	50%	15.39	13.13	10.65	14.7	30.81	11.91	11.71	11.2	1.75	6.01
	60%	17.42	14.92	11.83	14.36	32.1	12.77	12.42	12.0	2.75	6.01
	70%	19.4	16.77	13.52	13.55	30.3	13.93	13.43	12.81	3.58	8.03
	80%	22.24	19.21	15.88	13.59	28.6	15.25	14.74	13.61	3.4	10.75
	90%	27.2	23.51	19.1	13.58	29.78	18.08	17.41	15.57	3.72	13.89
	Mean	16.65	15.0	12.07	9.94	27.49	12.78	12.67	11.68	0.86	8.56
	Median	15.43	13.13	10.7	14.9	30.67	11.93	11.72	11.23	1.82	5.87
	Std dev	7.56	7.55	5.47	0.13	27.58	4.13	5.08	3.49	−22.88	15.5
Morning peak hours	50%	10.45	9.6	9.21	8.15	11.81	14.77	13.61	12.37	7.81	16.26
	60%	11.31	10.1	9.6	10.76	15.19	16.04	14.57	13.18	9.15	17.84
	70%	12.75	10.6	10.05	16.86	21.12	17.9	15.71	13.99	12.22	21.83
	80%	14.75	11.45	10.7	22.37	27.45	20.74	17.39	14.98	16.14	27.74
	90%	17.76	12.72	11.77	28.39	33.74	26.86	21.71	16.66	19.17	37.98
	Mean	11.88	9.97	9.57	16.02	19.4	16.79	15.21	13.05	9.39	22.25
	Median	10.45	9.62	9.22	7.97	11.8	14.77	13.63	12.4	7.67	16.03
	Std dev	4.59	2.44	1.99	46.81	56.54	7.02	6.59	4.56	6.23	35.16
Morning peak hours	50%	8.62	8.75	8.47	−1.43	1.8	10.78	11.1	10.16	−2.92	5.82
	60%	9.12	9.27	8.85	−1.74	2.93	11.59	11.93	10.98	−2.97	5.29
	70%	9.76	9.92	9.28	−1.68	4.91	12.75	12.89	11.85	−1.06	7.08
	80%	10.64	10.74	9.87	−0.92	7.24	14.1	14.08	13.0	0.1	7.79
	90%	12.42	12.56	11.18	−1.16	9.94	16.29	16.05	14.8	1.47	9.14
	Mean	9.41	9.5	8.81	−0.99	6.36	11.43	11.68	10.71	−2.15	6.32
	Median	8.63	8.8	8.48	−1.93	1.74	10.78	11.1	10.17	−2.94	5.72
	Std dev	3.78	3.62	2.24	4.33	40.64	4.44	4.85	4.21	−9.17	5.24
Morning peak hours	50%	9.77	9.47	8.93	3.06	8.61	11.78	11.57	10.87	1.74	7.74
	60%	10.8	10.25	9.4	5.07	12.97	12.75	12.53	11.69	1.72	8.37
	70%	12.6	11.27	10.13	10.52	19.6	14.09	13.49	12.61	4.21	10.44
	80%	15.73	13.01	11.17	17.29	29.0	15.57	14.75	13.6	5.28	12.68
	90%	20.56	16.91	13.88	17.75	32.51	18.86	17.21	15.46	8.72	18.03
	Mean	12.04	11.02	9.83	8.45	18.37	12.87	12.48	11.37	3.06	11.7
	Median	9.8	9.48	8.97	3.23	8.5	11.8	11.63	10.88	1.41	7.77
	Std dev	6.23	5.4	3.65	13.46	41.5	5.35	5.3	4.17	1.09	22.1

Table B.15
$h^m = 818.78$, $h^e = 881.35$, $S_{me} = 172$, Segment 1.

Alert type (a)	$\frac{n_a^m}{h^m}$	$\frac{n_a^e}{h^e}$	$(n_a^m + n_a^e)\, D_{KL}(p_{a,me} \parallel q_{me})$
Collision-warning	0.68	0.46	18.18
Driver-distraction	0.34	0.13	41.50
Driver-drowsiness	0.09	0.02	20.62
Following-distance	0.07	0.04	3.53
Hard-braking	0.06	0.04	1.71
Hard-turn	0.00	0.00	0.00
Seatbelt-compliance	0.28	0.04	86.82

Table B.16
$h^m = 1069.83$, $h^e = 939.66$, $S_{me} = 118$, Segment 2.

Alert type (a)	$\frac{n_a^m}{h^m}$	$\frac{n_a^e}{h^e}$	$(n_a^m + n_a^e)\, D_{KL}(p_{a,me} \parallel q_{me})$
Collision-warning	2.05	2.23	3.79
Driver-distraction	0.47	0.24	37.69
Driver-drowsiness	0.13	0.03	33.23
Following-distance	0.23	0.28	2.46
Hard-braking	0.10	0.06	5.03
Hard-turn	0.03	0.01	5.18
Seatbelt-compliance	0.18	0.06	31.06

Table B.17
$h^m = 727.83$, $h^e = 1001.69$, $S_{me} = 382$, Segment 3.

Alert type (a)	$\frac{n_a^m}{h^m}$	$\frac{n_a^e}{h^e}$	$(n_a^m + n_a^e)\, D_{KL}(p_{a,me} \parallel q_{me})$
Collision-warning	3.09	1.78	152.59
Driver-distraction	0.89	0.26	158.68
Driver-drowsiness	0.17	0.03	47.54
Following-distance	0.44	0.25	22.68
Hard-braking	0.06	0.05	0.38
Hard-turn	0.00	0.00	0.00
Seatbelt-compliance	0.06	0.05	0.38

Table B.18
$h^m = 1059.89$, $h^e = 1231.54$, $S_{me} = 232$, Segment 4.

Alert type (a)	$\frac{n_a^m}{h^m}$	$\frac{n_a^e}{h^e}$	$(n_a^m + n_a^e)\, D_{KL}(p_{a,me} \parallel q_{me})$
Collision-warning	2.26	1.62	60.66
Driver-distraction	0.54	0.21	86.59
Driver-drowsiness	0.16	0.02	72.18
Following-distance	0.24	0.18	4.92
Hard-braking	0.06	0.04	2.30
Hard-turn	0.00	0.00	0.00
Seatbelt-compliance	0.03	0.01	6.04

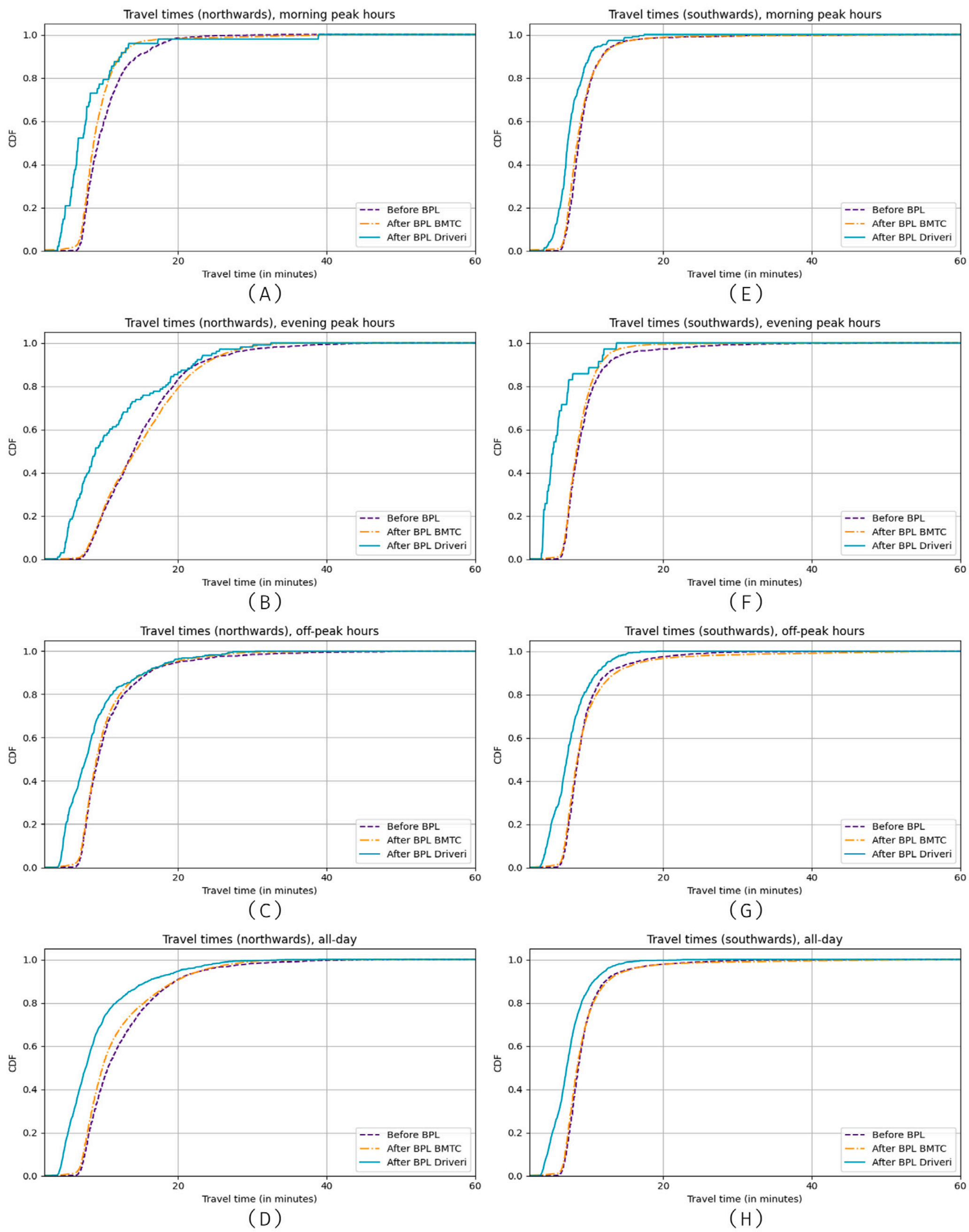

Fig. A.5. CDFs of the travel times for Segment 1.

Table B.19

$h^{\mathrm{m}} = 421.28,\ h^{\mathrm{e}} = 328.06,\ S_{\mathrm{me}} = 60$, Segment 5.

Alert type (a)	$\frac{n_a^{\mathrm{m}}}{h^{\mathrm{m}}}$	$\frac{n_a^{\mathrm{e}}}{h^{\mathrm{e}}}$	$(n_a^{\mathrm{m}} + n_a^{\mathrm{e}})\, D_{\mathrm{KL}}(p_{a,\mathrm{me}} \parallel q_{\mathrm{me}})$
Collision-warning	2.91	3.76	20.14
Driver-distraction	0.58	0.33	12.69
Driver-drowsiness	0.18	0.03	21.25
Following-distance	0.24	0.34	3.22
Hard-braking	0.07	0.04	1.51
Hard-turn	0.00	0.00	0.00
Seatbelt-compliance	0.03	0.01	1.89

Table B.20

$h^{\mathrm{m}} = 551.57,\ h^{\mathrm{e}} = 460.51,\ S_{\mathrm{me}} = 34$, Segment 6.

Alert type (a)	$\frac{n_a^{\mathrm{m}}}{h^{\mathrm{m}}}$	$\frac{n_a^{\mathrm{e}}}{h^{\mathrm{e}}}$	$(n_a^{\mathrm{m}} + n_a^{\mathrm{e}})\, D_{\mathrm{KL}}(p_{a,\mathrm{me}} \parallel q_{\mathrm{me}})$
Collision-warning	1.33	1.15	3.27
Driver-distraction	0.32	0.18	9.89
Driver-drowsiness	0.09	0.01	17.99
Following-distance	0.14	0.09	2.73
Hard-braking	0.04	0.03	0.36
Hard-turn	0.00	0.00	0.00
Seatbelt-compliance	0.03	0.03	0.00

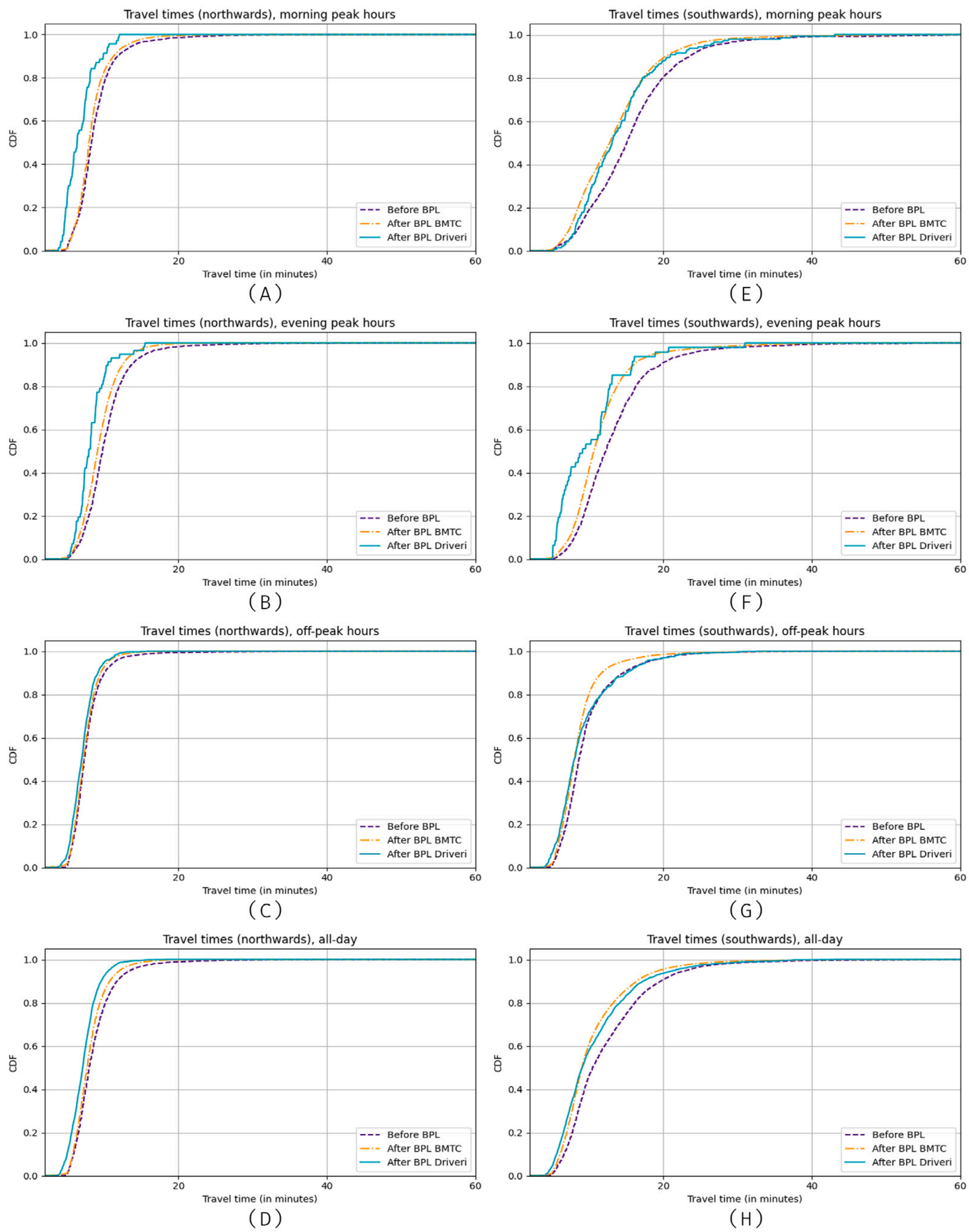

Fig. A.6. CDFs of the travel times for Segment 2.

Table B.21
$h^{\mathrm{m}} = 4649.18,\ h^{\mathrm{e}} = 4842.81$, full BPL.

Alert type (a)	$\frac{n_a^{\mathrm{m}}}{h^{\mathrm{m}}}$	$\frac{n_a^{\mathrm{e}}}{h^{\mathrm{e}}}$	$(n_a^{\mathrm{m}} + n_a^{\mathrm{e}})\, D_{\mathrm{KL}}(p_{a,\mathrm{me}} \parallel q_{\mathrm{me}})$
Collision-warning	0.84	0.71	21.45
Driver-distraction	0.17	0.08	75.77
Driver-drowsiness	0.03	0.008	42.15
Following-distance	0.06	0.06	0.97
Hard-braking	0.03	0.02	5.41
Hard-turn	0.006	0.002	0.21
Seatbelt-compliance	0.04	0.01	28.99

Table B.22
$h^{\mathrm{n}} = 1942.97,\ h^{\mathrm{s}} = 2034.71,\ S_{\mathrm{ns}} = 21$, Segment 1.

Alert type (a)	$\frac{n_a^{\mathrm{s}}}{h^{\mathrm{s}}}$	$\frac{n_a^{\mathrm{n}}}{h^{\mathrm{n}}}$	$(n_a^{\mathrm{n}} + n_a^{\mathrm{s}})\, D_{\mathrm{KL}}(p_{a,\mathrm{ns}} \parallel q_{\mathrm{ns}})$
Collision-warning	0.39	0.41	0.49
Driver-distraction	0.22	0.14	17.85
Driver-drowsiness	0.06	0.06	0.00
Following-distance	0.04	0.04	0.00
Hard-braking	0.04	0.04	0.00
Hard-turn	0.00	0.00	0.00
Seatbelt-compliance	0.17	0.14	2.89

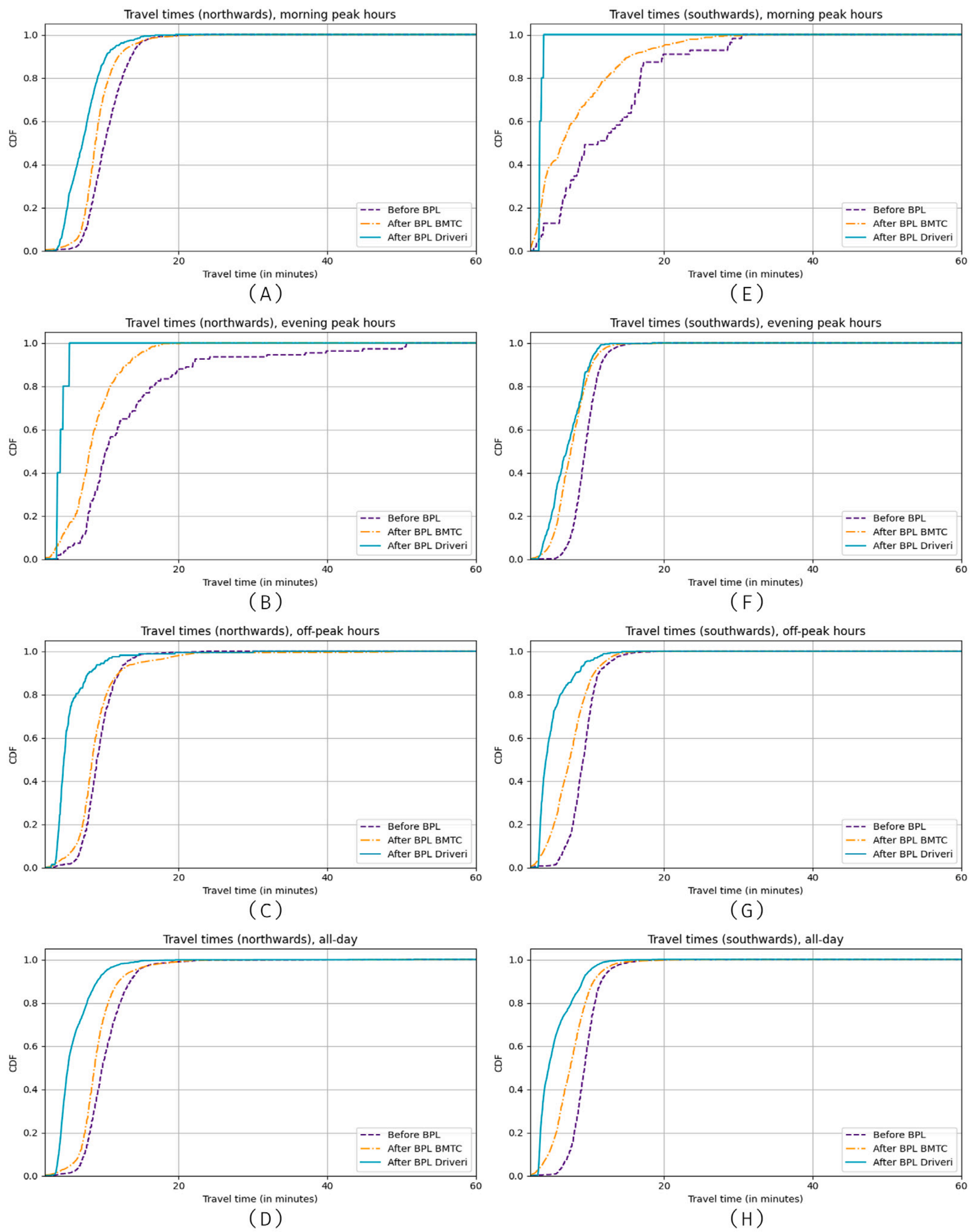

Fig. A.7. CDFs of the travel times for Segment 3.

Table B.23
$h^{\mathrm{n}} = 3847.28$, $h^{\mathrm{s}} = 3676.49$, $S_{\mathrm{ns}} = 12$, Segment 2.

Alert type (a)	$\frac{n_a^{\mathrm{s}}}{h^{\mathrm{s}}}$	$\frac{n_a^{\mathrm{n}}}{h^{\mathrm{n}}}$	$(n_a^{\mathrm{n}} + n_a^{\mathrm{s}})\, D_{\mathrm{KL}}(p_{a,\mathrm{ns}} \parallel q_{\mathrm{ns}})$
Collision-warning	0.86	0.84	0.44
Driver-distraction	0.19	0.17	2.08
Driver-drowsiness	0.04	0.04	0.00
Following-distance	0.09	0.09	0.00
Hard-braking	0.05	0.04	2.09
Hard-turn	0.02	0.02	0.00
Seatbelt-compliance	0.17	0.21	7.94

Table B.24
$h^{\mathrm{n}} = 1711.50$, $h^{\mathrm{s}} = 1850.69$, $S_{\mathrm{ns}} = 108$, Segment 3.

Alert type (a)	$\frac{n_a^{\mathrm{s}}}{h^{\mathrm{s}}}$	$\frac{n_a^{\mathrm{n}}}{h^{\mathrm{n}}}$	$(n_a^{\mathrm{n}} + n_a^{\mathrm{s}})\, D_{\mathrm{KL}}(p_{a,\mathrm{ns}} \parallel q_{\mathrm{ns}})$
Collision-warning	1.91	1.47	50.98
Driver-distraction	0.57	0.37	38.02
Driver-drowsiness	0.09	0.08	0.52
Following-distance	0.28	0.19	15.38
Hard-braking	0.06	0.04	3.57
Hard-turn	0.00	0.00	0.00
Seatbelt-compliance	0.04	0.04	0.00

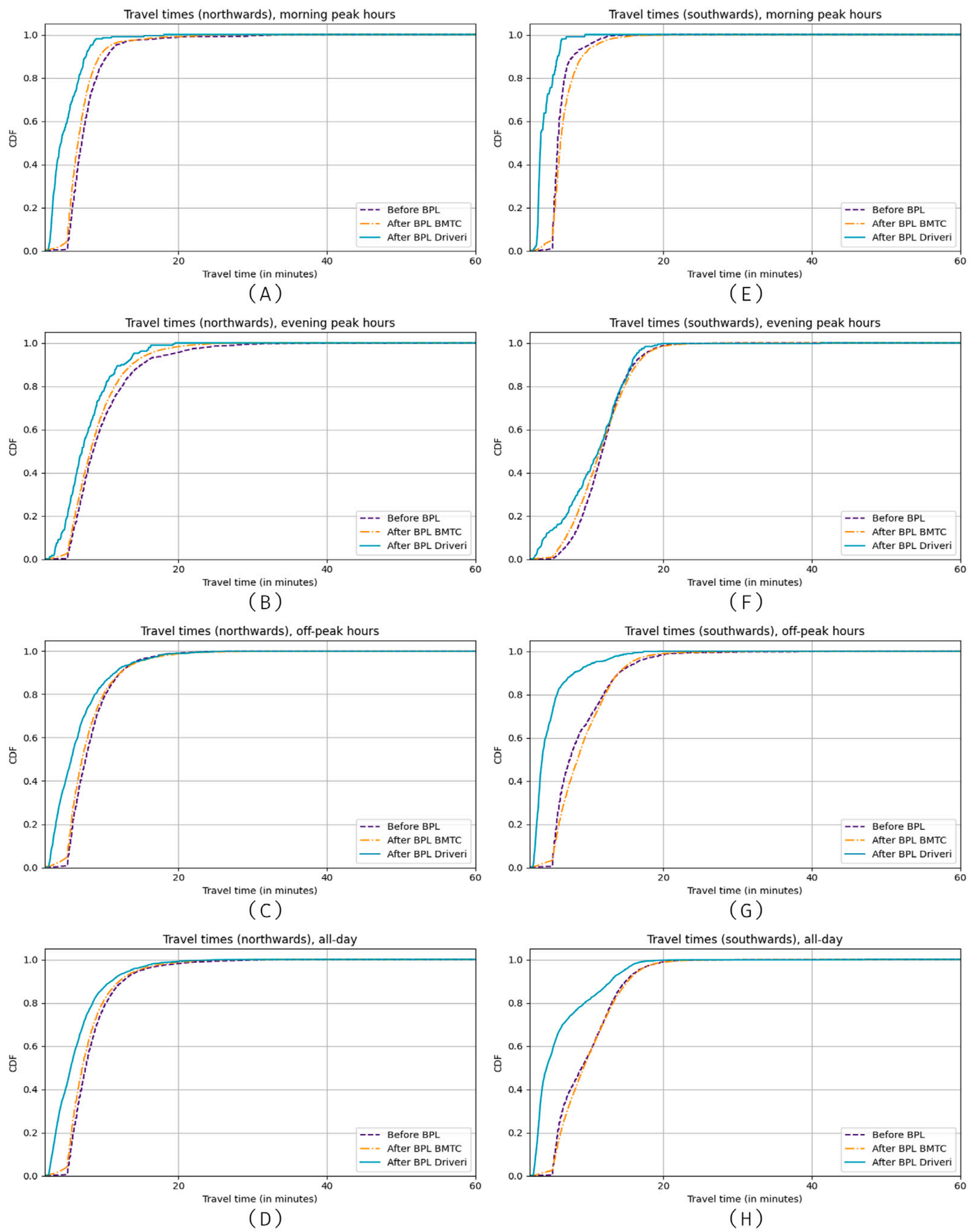

Fig. A.8. CDFs of the travel times for Segment 4.

Table B.25
$h^{\mathrm{n}} = 2256.13,\ h^{\mathrm{s}} = 2436.72,\ S_{\mathrm{ns}} = 29$, Segment 4.

Alert type (a)	$\frac{n_a^{\mathrm{s}}}{h^{\mathrm{s}}}$	$\frac{n_a^{\mathrm{n}}}{h^{\mathrm{n}}}$	$(n_a^{\mathrm{n}} + n_a^{\mathrm{s}})\, D_{\mathrm{KL}}(p_{a,\mathrm{ns}} \parallel q_{\mathrm{ns}})$
Collision-warning	1.47	1.28	15.38
Driver-distraction	0.35	0.31	2.84
Driver-drowsiness	0.09	0.08	0.69
Following-distance	0.16	0.12	6.70
Hard-braking	0.04	0.04	0.00
Hard-turn	0.00	0.001	0.00
Seatbelt-compliance	0.01	0.02	3.99

Table B.26
$h^{\mathrm{n}} = 603.08,\ h^{\mathrm{s}} = 778.47,\ S_{\mathrm{ns}} = 51$, Segment 5.

Alert type (a)	$\frac{n_a^{\mathrm{s}}}{h^{\mathrm{s}}}$	$\frac{n_a^{\mathrm{n}}}{h^{\mathrm{n}}}$	$(n_a^{\mathrm{n}} + n_a^{\mathrm{s}})\, D_{\mathrm{KL}}(p_{a,\mathrm{ns}} \parallel q_{\mathrm{ns}})$
Collision-warning	2.92	2.14	40.76
Driver-distraction	0.46	0.34	6.10
Driver-drowsiness	0.13	0.08	4.04
Following-distance	0.22	0.20	0.32
Hard-braking	0.06	0.05	0.31
Hard-turn	0.00	0.00	0.00
Seatbelt-compliance	0.04	0.04	0.00

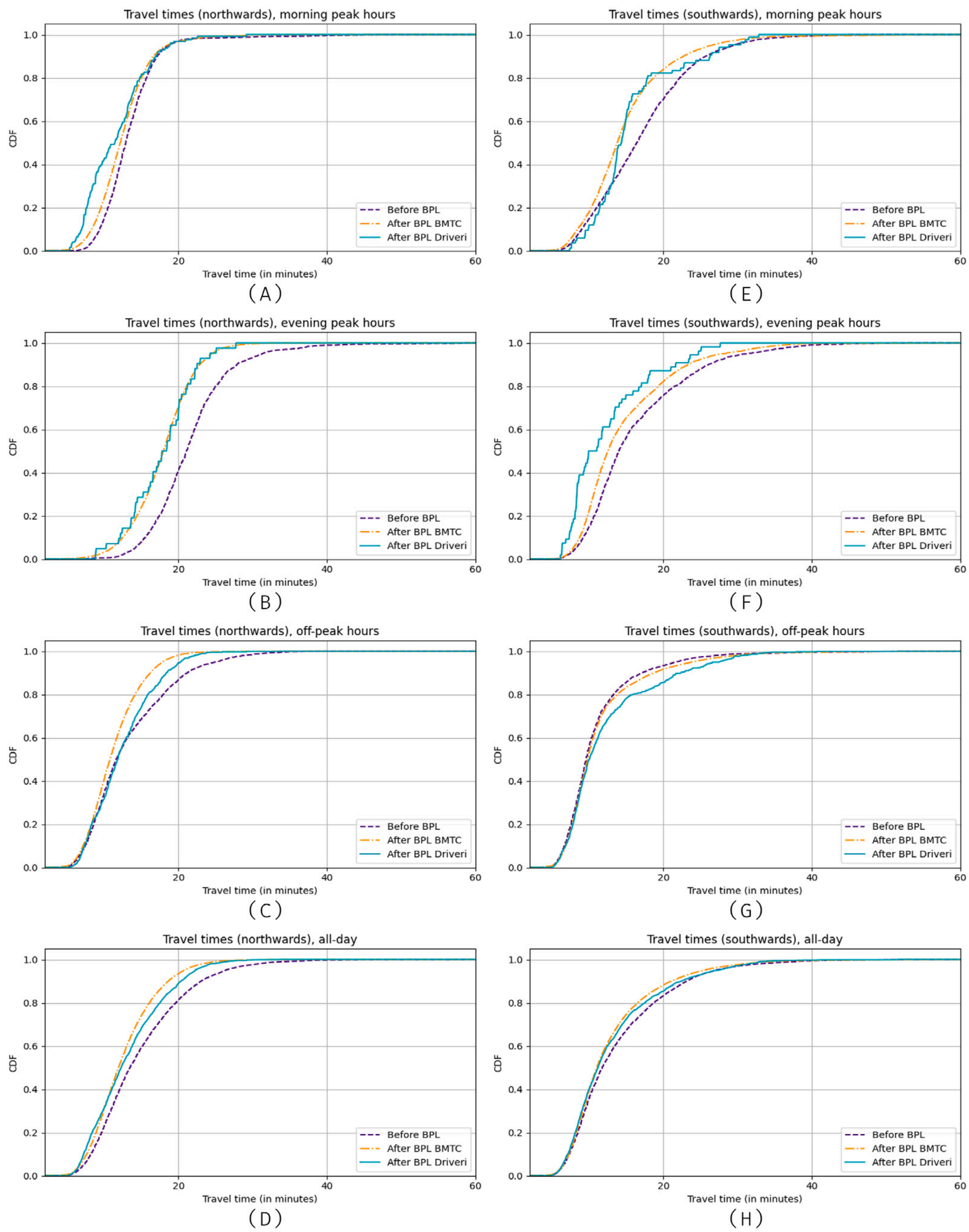

Fig. A.9. CDFs of the travel times for Segment 5.

Table B.27
$h^{n} = 897.72,\ h^{s} = 950.59,\ S_{ns} = 59$, Segment 6.

Alert type (a)	$\frac{n_a^s}{h^s}$	$\frac{n_a^n}{h^n}$	$(n_a^n + n_a^s)\, D_{KL}(p_{a,ns} \parallel q_{ns})$
Collision-warning	0.69	1.05	34.71
Driver-distraction	0.23	0.23	0.00
Driver-drowsiness	0.10	0.03	18.26
Following-distance	0.06	0.09	2.79
Hard-braking	0.04	0.02	3.13
Hard-turn	0.00	0.00	0.00
Seatbelt-compliance	0.02	0.03	0.93

Table B.28
$h^{n} = 11{,}258,\ h^{s} = 11{,}728$, full BPL.

Alert type (a)	$\frac{n_a^s}{h^s}$	$\frac{n_a^n}{h^n}$	$(n_a^n + n_a^s)\, D_{KL}(p_{a,ns} \parallel q_{ns})$
Collision-warning	40.3	40.68	12.76
Driver-distraction	0.33	0.30	14.90
Driver-drowsiness	0.12	0.11	2.18
Following-distance	0.20	0.19	3.70
Hard-braking	0.06	0.05	2.32
Hard-turn	0.007	0.006	0.32
Seatbelt-compliance	0.006	0.008	0.76

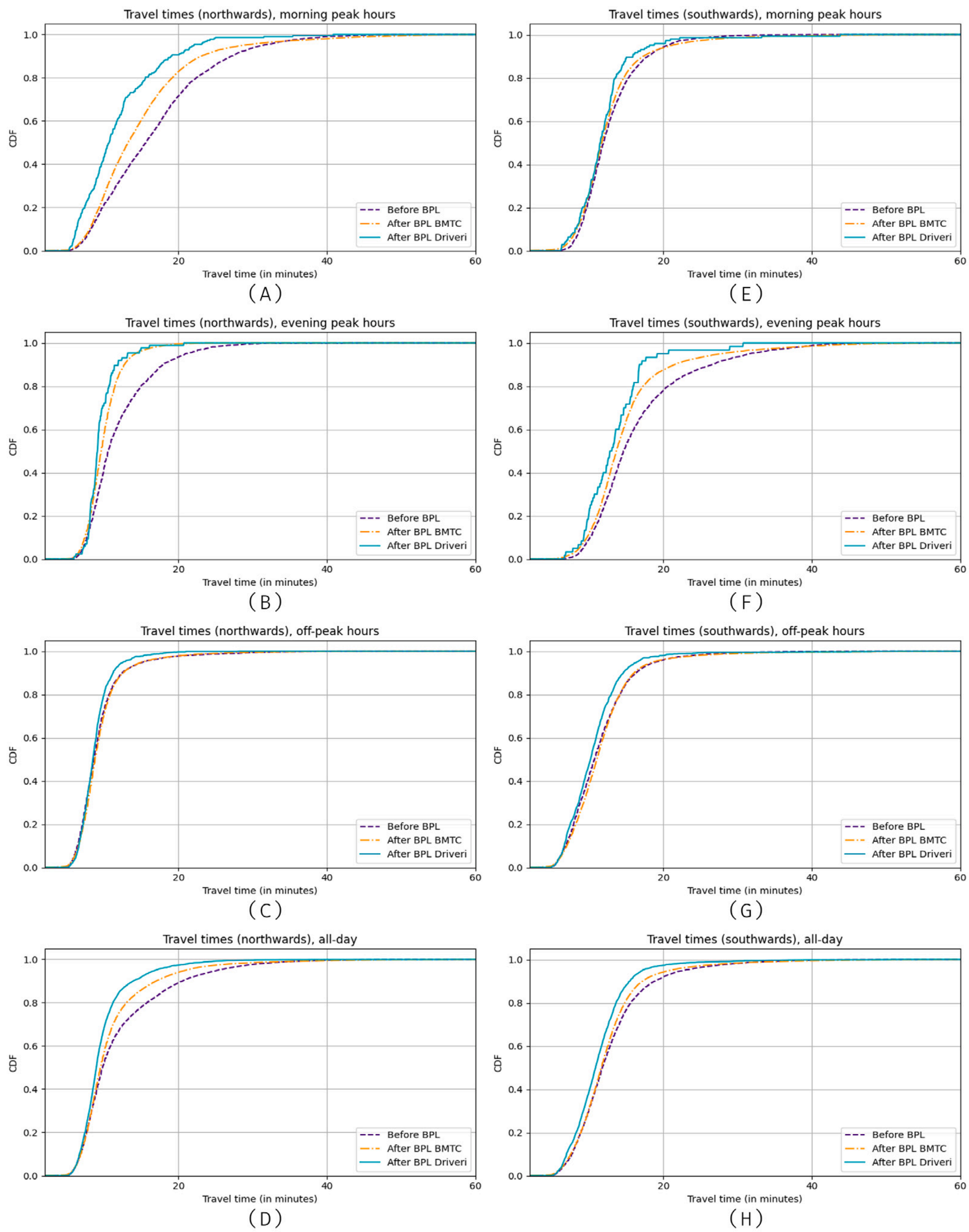

Fig. A.10. CDFs of the travel times for Segment 6.

Formal analysis, Software, Investigation, Validation, Writing – original draft. **Wilson Lobo:** Investigation, Resources. **Ajeesh Sahadevan:** Project administration, Data curation, Funding acquisition, Conceptualization, Writing – review & editing. **Rajesh Sundaresan:** Conceptualization, Funding acquisition, Supervision, Project administration, Methodology, Formal analysis, Writing – review & editing. **Pratik Verma:** Data curation, Investigation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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Appendix A. Segment-wise travel times

A.1. Segment-wise tables of the mean, median, standard deviation, and CDF tails

See Tables A.9–A.14.

A.2. CDF plots

See Figs. A.5–A.10.

Appendix B. *D*-Test results

B.1. Morning peak hours versus evening peak hours

See Tables B.15–B.21.

B.2. *D*-Test results: Northward trips versus southward trips

See Tables B.22–B.28.

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