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Analysis of Bus Travel Time variability Using Automatic Vehicle Location Data

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Abstract

Transit service reliability is a measure of the quality of service offered by the public transit systems. The nature and pattern of the travel time variability can be described by the travel time distribution and it is the prerequisite in the reliability analysis. Many research works have been carried out to understand the travel time distribution, but there are very few studies on the heterogeneous traffic in developing countries like India. In this study, an attempt has been made to analyze the travel time distribution at different spatial and temporal aggregation scales using Automatic Vehicle Location (AVL) data of public bus route in Mysore city. The results suggest that, Generalized extreme value (GEV) distribution is the better fit for travel times at both route and segment levels and the performance of the Generalized extreme value (GEV) distribution is comparatively better in both temporal and spatial aggregation compared to other distributions. This distribution can be utilized by the transit operators in the operation and performance evaluation of transit systems.

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Keywords: Transit reliability; Travel time variability; Generalised Extreme Value (GEV) Distribution; Intelligent Transport System (ITS); Automatic Vehicle Location (AVL)

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1. Introduction

In present days, sustainable transportation is a key issue being studied by most of the traffic engineers and transport planners. The traffic congestion due to the increasing private vehicle usage in Indian metropolitan cities is forcing people to focus on public transit systems which are sustainable in nature. The idealization and implementation of Intelligent Transport Systems (ITS) and Bus Rapid Transit Systems are the attempts being made to attract the commuters towards public transport systems and to solve the problem of traffic congestion to some extent.

Transit service reliability is a measure of the quality of service offered by the public transit systems Mazloumi (2009) and it also evaluates the system performance better at different traffic conditions over a time and space Chepuri et.al (2018). The idea of comparing the travel time with that of travelers' expectations forms the basis of travel time reliability Small (1982). The transport systems probably fail to attract potential travelers when the service provided by the routes becomes unreliable Ma et.al (2016). Passengers lose their confidence in making travel decisions such as choices on departure time, routes, modes of transport etc., due to day to day travel time variability in transport systems resulting in unpredictable waiting time, in-vehicle time, transfer time etc. The reduction in travel time variability is similar to or more valuable than reducing the average travel time Van Oort (2011). Transit operators who schedule the routes and vehicles are also helped by the knowledge of travel time variability in the optimization of performance and operating costs. The optimal slack times can be defined by understanding the travel time variability during scheduling process Kimpel et al. (2004).

The nature and pattern of the travel time variability can be described by the travel time distribution and it is the prerequisite in the reliability analysis Sumalee A et.al (2006). Travel time distribution has been given due importance from researchers and suggested Normal, Lognormal, Gamma, Logistic, Log logistic, Weibull and Burr distributions with respect to different operating condition, spatial and temporal scales time components. There are only a few studies which concentrated on the travel time distribution in developing country like India with heterogeneous, lane less movement of traffic conditions. The travel time reliability study was carried out by Chepuri et.al. (2017) using travel time data of cars collected by license plate matching in Surat city and Burr distribution has been suggested. Chepuri et.al. (2018) also made an attempt to examine the travel time distribution of bus travel time for bus routes in Chennai city using the Automatic Vehicle Location data (AVL) and found that GEV distribution is the best fit for both morning and evening off-peak and peak hours.

An attempt has been made in this study to understand the travel time variability of bus routes by fitting the various distributions suggested in the literature. The AVL data of buses collected by the Mysore ITS using Global Positioning System (GPS) devices was used for the analysis of travel time variability. The width of DTW (Departure Time Window) influences the shape of travel time distribution Li et.al. (2006), therefore data were analyzed to understand the travel time distribution in different temporal aggregation levels. The temporal aggregation has been done by considering different DTWs for peak and off-peak periods. Intersection and bus stops are the major sources for the travel time variability and hence the analysis of travel time was also carried out by considering spatial aggregation. The spatial aggregation was done based on the spacing of bus stops and intersections separately. The goodness of fit was analyzed by the Kolmogorov-Smirnov (KS) test and top 3 distributions were selected.

The next section briefs the literature review of previous researches which is followed by the details of data used for the present study. The methodology and the analysis are described in sections 4 and section 5 respectively. In section 6, the results have been discussed and conclusions are provided in section 7.

2. Literature Review

Previous studies have been carried out on the travel time variability of vehicles in the traffic stream. Bates et.al., (1987); Noland and Polak, (2002) suggested that the travel time variability of vehicles had to be studied in different ways such as inter vehicle, inter period and inter day variabilities. The variations in traffic flow, different driving behaviors, changes in weather conditions and accidents were the factors causing variability in travel time as described by Mazloumi et.al. (2009).

By previous researchers, several methods have been proposed for modeling and quantifying travel time variability. Among them, the probability distribution approach was said to be more comprehensive and the one which describes the nature of travel time variations more realistically Rahman et.al. (2018). The travel times were said to follow a skewed distribution by Wardrop (1952). Later Gamma and Log-normal distributions were proposed for travel time variations by Herman and Lam (1974). Richardson and Taylor (1978) also said that Log-normal fitted the travel times better. Due to its simplicity and goodness of fit, log-normal distribution was used for recent travel time studies done by Clark and Walting (2005), Sumalee et.al. (2006) and Hollander and Liu (2008). The use of other distribution models was also observed in previous as well as recent research studies on travel time variability. A Log logistic distribution for travel times was made use by Chu (2010) for estimating travel time reliability in freight corridors, Polus (1979) used Gamma distribution for travel times in arterials and Weibull distribution in travel time reliability studies by Al-Deek and Emam (2006). Susilawati et.al, (2013) in their work on modeling travel time distributions in urban roads said that Burr Type XII distribution by Burr (1942) was found to be appropriate for travel times at both link and route levels. They also mentioned that it was more suitable for life-test (real life) data than the other distributions.

Though there were many studies on travel time variability of vehicles, the research on travel time variability of public transit was limited due to unavailability of time-space data of public transit vehicles. Earlier studies on bus travel time distributions conducted by Jordan and Turnquist (1979) and Taylor (1982) showed that, Gamma and Normal distributions are the suitable fit for running time at morning peak and travel time of buses respectively. The recent studies on travel time variability of buses by Uno et.al. (2009) and Kieu et.al (2014) observed that Lognormal was the better fit for the bus running time. Xue et.al. (2011) revealed that bus travel times followed a Log logistic distribution at peak periods. Ma et.al. (2016) carried out studies on travel time distributions for bus operations by spatial and temporal aggregation of data. The travel time distribution studies were conducted for different Departure Time Windows (DTW) and at route and link levels. They found Gaussian Mixture Models (GMM) as better fit for bus travel times. It was also said that the Burr distribution was able to fit as accurately as GMMs under certain conditions. Rehman et.al.(2018) carried out a study on bus travel time distributions for different horizons. The distance between the bus stop for which the real time estimation of travel had to be made and the real time location of the bus at the time of estimation was known as horizon. This study used pseudo-horizon (the distance between a GPS point to an upstream GPS point) for travel time analysis and it was shown that the lognormal was a better fit before the cut-off horizon whereas normal distribution was suitable after the cut-off horizon of 7 to 8 Kms. Chepuri et.al. (2018) mentioned in their study that the bus travel times follow Generalized Extreme Value (GEV) distribution.

Study of bus travel time variation and their reliability requires sufficient data regarding the movement of buses in the network. Automatic Vehicle Location (AVL) data of buses obtained using GPS devices form a suitable data set for the travel time studies of buses. Mazloumi et.al (2009) used GPS data to study the travel time variability of buses collected at Melbourne, Australia. Study on travel time variability distribution was carried out using Automatic Vehicle Location data of 6 months collected at Brisbane, Australia by Ma et.al. (2016). Rahman et.al (2018) also used the GPS data of public transit vehicles in Calgary, Alberta, Canada for their study. Most of the studies mentioned above were carried out in countries having nearly homogeneous traffic conditions with lane discipline.

Studies on travel time have been carried out in heterogeneous traffic having weak lane discipline in Indian cities. Vanajakshi et al. (2009), Kumar et al. (2013) and Kumar et.al. (2017) carried out research studies on bus travel time estimation and bus arrival time prediction using the GPS data of bus in Chennai city, India. Some recent studies on travel time variability and reliability in India were also found. Chepuri et.al. (2017) studied variability in travel time using two wheelers as probes in Surat, India. A study on travel time reliability was carried out by Chepuri et.al. (2018) using travel time data of cars collected by license plate matching in Surat city. Chepuri et.al. (2018) also made an attempt to examine the reliability of bus travel time for bus routes in Chennai city using the Automatic Vehicle Location data of buses collected by GPS devices. Kumar et.al (2018) studied bus travel time data of three Indian cities and suggested that GEV distribution is the best fit for travel time variability. There are very few researches have been carried out on travel time variability and its distributions in heterogeneous traffic conditions like India. Hence there is a need to explore more about the variability of travel time in different temporal and spatial aggregation.

3. Data

3.1. Description

Mysore city public transportation buses are facilitated with the GPS units under the project of Mysore Intelligent Transport System (MITRA) which provides Automatic Vehicle Location data of buses. In the present study, Mysore city transit route 119 has been selected which connects the industrial area to CBD (Figure 1). The study length 13km connects City Bus Stand (CBS) to Infosys bus stop which includes 24 bus stops in between with spacing of 310m to 1270m and the one-way trips from Infosys bus stop to CBS has been considered. This route covers different types of urban roads with diverse traffic, geometric and land use characteristics. The weekdays data of the month February (2018) with service operating from 5.30 AM to 10 PM has been used in the analysis. The Automatic Vehicle Location data includes information about schedule date, schedule ID, route ID, trip ID, latitude, longitude and GPS timestamp which updates for every 10 sec and the sample data is shown in Table 1.

Table 1 Sample Automatic Vehicle Location data of route 119

Schedule date	Schedule ID	Route ID	Trip ID	Latitude	Longitude	Time stamp
01-02-2018	468	1927	2	12.35789	76.60214	01-02-2018 06:20
01-02-2018	468	1927	2	12.35795	76.60299	01-02-2018 06:30
01-02-2018	468	1927	2	12.35786	76.6032	01-02-2018 06:40
01-02-2018	468	1927	2	12.35762	76.60329	01-02-2018 06:50
01-02-2018	468	1927	2	12.35719	76.60351	01-02-2018 07:00
01-02-2018	468	1927	2	12.35646	76.60399	01-02-2018 07:10
01-02-2018	468	1927	2	12.35568	76.60477	01-02-2018 07:20
01-02-2018	468	1927	2	12.35514	76.60542	01-02-2018 07:30
01-02-2018	468	1927	2	12.35509	76.60546	01-02-2018 07:40
01-02-2018	468	1927	2	12.35464	76.60597	01-02-2018 07:50

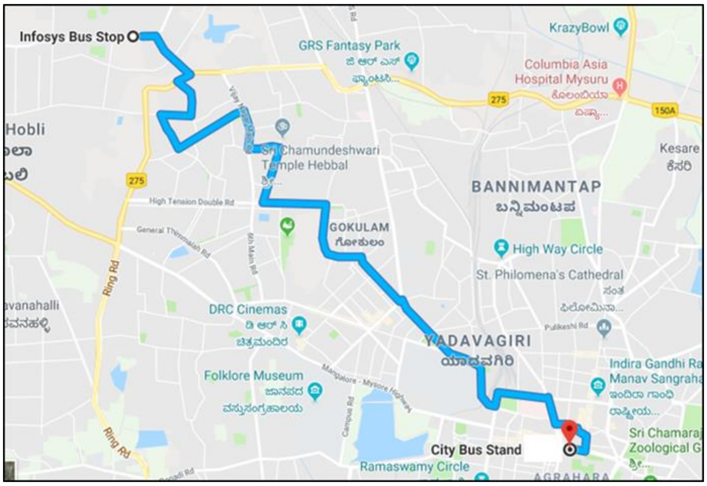

Figure 1 Route 119 (© google maps)

3.2. Preliminary Analysis

The data points were plotted on to the respective bus route map by using ArcGIS software. The data points that were 100m away from the central line of bus route were deleted. These erroneous points might have been occurred due to the communication error in the network or functional problem in the GPS units. The trips that were deviated from the allotted route have not been considered in the analysis, since the characteristics of the diverted route might be having different characteristics than the allotted route. The distance between each data point was calculated using Haversine formulae, which provides the great circle distance (d) between two data points on a sphere. The cumulative distance and cumulative time between starting and ending point of the trip were calculated and the trips which were having abnormal trip distance were removed. For the elimination of outliers from the travel time data set, the median absolute deviation (MAD) technique Ma et.al. (2015) was adopted which removes very large and very small travel time trips. The travel time of each trip is grouped into 30 min departure time window and the average travel time in each departure time window was calculated. The average travel time vs departure time was plotted as shown in Figure 2 and from the figure, distinguished periods are taken as, morning peak as 8.30 to 10.30, interpeak as 13 to 14, evening peak as 17.30 to 19.30 and off-peak as 5.30 to 7.30.

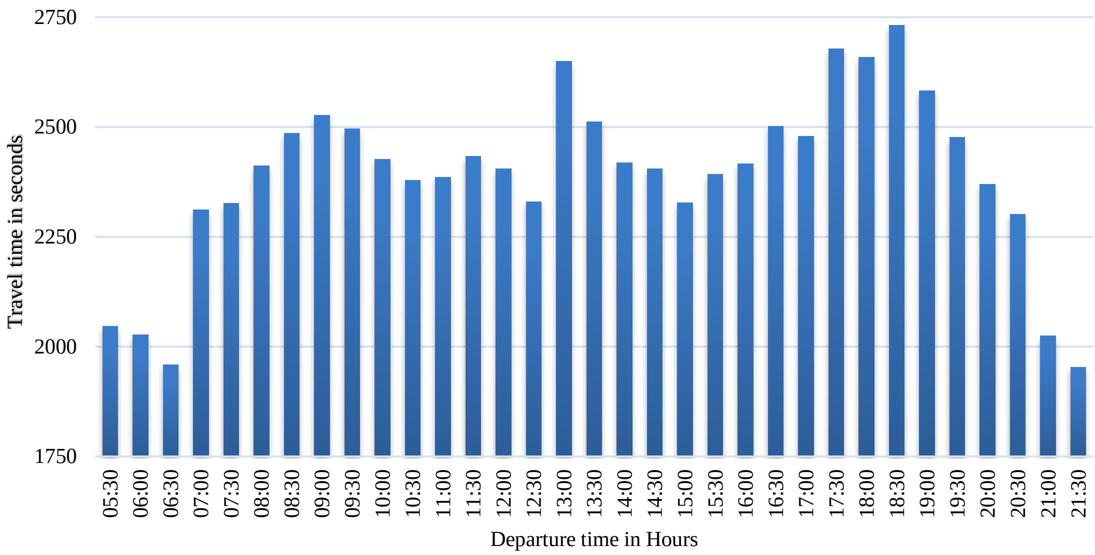

Figure 2 Average travel time of buses with respect to departure time

4. Methodology

The main objective of this study is to explore the variability of travel time of public transit by analyzing travel time distribution. The aggregation attributes (temporal and spatial) significantly influence the travel time distribution Li et al. (2006). Travel time data is aggregated into three different scales such as temporal (period, 60 minutes, 45 minutes and 30 minutes), spatial (route level and segment level) and time components (morning peak, interpeak, evening peak and off-peak periods). Each case of aggregations was considered separately for the travel time distribution analysis.

Two types of spatial aggregation analysis were carried out, the route was divided into segments based on the spatial separation between bus stops and spatial separation between intersections. The number of segments formed by considering the spacing between bus stops were 25 and segments formed by considering the spacing between intersections were 7. In order to encircle the bus stop region, a radius of 50m was considered from the center of the bus stop. Each segment consisted of distance between the two consecutive bus stops up to the end of downstream bus stop. The spatial aggregation considering the intersections was also carried out in the same manner. In this case, the length of each segment was the distance between two consecutive intersections.

Based on the findings from the literature studies- normal, lognormal, logistic, log-logistic, Gamma, Weibull, Burr and Generalized extreme value distributions were considered in the analysis of travel time variability. Maximum likelihood estimation method was used for the estimation of probability density function parameters. For fitted distributions in each case, Kolmogorov-Smirnov (KS) test for goodness of fit was used to evaluate the performance of each distribution. Distributions were ranked based on Kolmogorov-Smirnov (KS) test for goodness of fit and in each case, the top three distributions were selected. Robustness of each distribution was analyzed based on the performance of the distributions in different temporal, spatial and time components.

5. Analysis

5.1. Route level

Analysis of travel time distributions at different Departure Time Windows (DTWs) was carried out at route level. The DTWs considered in the present study were peak, off-peak period, 60 minutes, 45 minutes, 30 minutes. The 15 minutes DTW was not considered due to lack of samples. The entire route from the origin to destination was considered which includes all the bus stops and intersections. The analysis was carried out separately for travel time and running times of buses. Bus stop delays and intersection delays were excluded in the analysis of running time.

5.2. Segment level

To further explore more about travel time distributions, the route was divided into segments based on the spacing of bus stops and spacing of intersections. The route travel time data may not be adequate in capturing the travel time variability under varying passenger demand (bus stop delays) and signalized intersection delays. The variability of segment level travel time distribution is more than the route level travel time distribution since the bus stop and intersection delays occupy more weightage in segment level. The characteristics of segments such as road type, geometric features, land use, passenger demand and presence of signalized intersection along with different signal timings vary along a bus route. Intersection and bus stops are major sources for the variability in travel time.

The segments were created based on the bus stops and intersections as described in the methodology. The analysis of travel time distribution was carried out for different DTWs. The DTWs considered at segment level analysis were peak, off-peak periods and 60 minutes.

6. Results and Discussions

The impact of temporal and spatial aggregation on the characteristics of travel time distribution was analyzed separately and the results obtained are discussed in the subsequent paragraphs.

The results of different levels of temporal aggregation at route level are tabulated in Table 2. As mentioned earlier, the top three fitted distributions were selected based on the Kolmogorov-Smirnov (KS) test results. In all the cases GEV distribution was among the top three positions and it was found to be the best fit in 12 cases out of 15 cases. In the off-peak and morning peak periods, GEV distribution was the best fit in all the temporal aggregation levels. But in the inter peak and evening peak periods the GEV distribution was the best fit in 4 cases out of 7 cases. Weibull and Burr distributions were found to be the best fit in 1 and 2 cases respectively. The sample plots of probability density function of GEV distribution for travel times at peak hour and off-peak hour are shown in Figure 4.

The temporal aggregation analysis of the running time illustrates almost similar results of that of travel time. The GEV distribution was seemed to be the best fit in almost 75% cases and also the best fit for all the DTWs of interpeak and off-peak periods. Burr, Weibull and logistic distribution have taken the top position in 2, 1 and 1 cases respectively.

The impact of bus stops and intersections on travel time distributions was analyzed by dividing the route into segments as explained earlier in section 4. Figure 3 shows the travel time coefficient of variation (COV) of respective segments. The influence of factors affecting the travel time, which are different for each segment can be visualized by the variation of COVs.

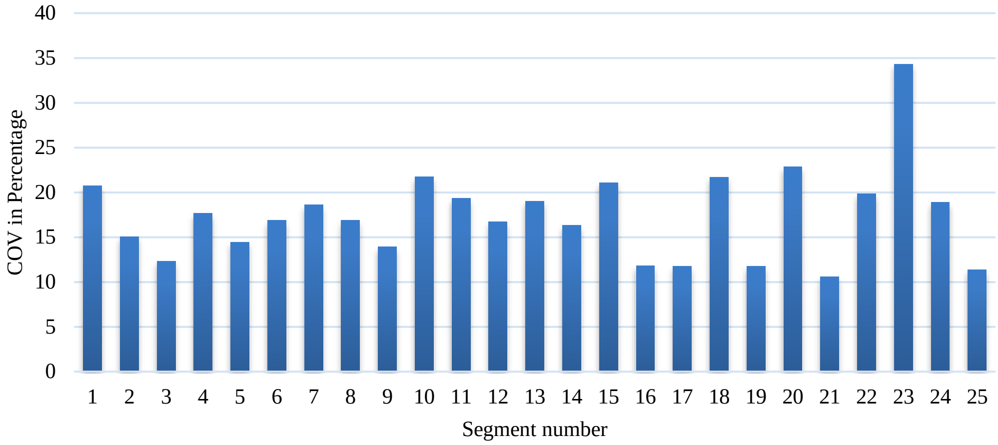

Figure 3 COV of Travel time of each segment

In the analysis of spatial aggregation, each segment was analyzed for morning peak period, morning peak 60 min DTW, evening peak period and evening peak 60 min DTW. The results of the goodness of fit test for different segments based on the bus stops for morning peak are shown in Table 4 and Table 6. The evening peak results based on the bus stop spacing are shown in Table 8 and Table 10. For morning peak period, GEV distribution outperforms the other distributions including Burr distribution, as GEV was the best fit in 33 cases out of 50. Burr distribution was the best fit in 7 cases only. Also, in the evening peak period, the number of best fit cases for GEV distribution (26 out of 50) was more than the Burr distribution (15 out of 50). Table 3 and Table 5 present the results of the goodness of fit test of different segments for morning peak based on the intersection spacing. The evening peak results based on the intersection spacing are shown in Table 7 and Table 9. In the analysis of segments based on the intersection, the GEV distribution was the best fit in 60% of the cases, whereas the next best distribution was Burr distribution with 21% of best fits. In both types of segment aggregation analysis, the best fit cases for other distributions (normal, lognormal, Weibull, log logistic, logistic and gamma distribution) were almost same for both evening and morning peak periods.

Figure 5 shows the summary of top three best fit distributions for all the cases. In the route level, GEV distribution has almost similar performance in both travel time and running time analysis. The results of route level suggest that the GEV distribution has the ability to capture the combined variability of delays (bus stop and intersection), traffic conditions and geometric conditions. It was also able to represent the variability of traffic and geometric conditions along the route without bus stop and intersection delays in terms of running time variability.

In the analysis of travel time variability of spatial aggregation based on the bus stops, the GEV distribution has higher number of cases with the best fit (59 out of 100 cases), than all the cases of Burr distribution being in top three positions (56 out of 100). The similar performance was seen in the segment level based on the intersections which suggest that GEV distribution was able to explain the travel time variability caused by bus stop delays and intersection delays.

GEV distribution has higher number of top 1 cases than the all top 3 cases of successive distributions in both route level and segment level travel time data which suggests that, the varying characteristics of different segments can be analyzed by this distribution.

The above results clearly illustrate that GEV distribution has all the capability to capture the variability of travel time at both route level and segment level in heterogeneous traffic conditions and it is consistent with the literature Chepuri et.al. (2018). This study also suggests that the performance of the GEV distribution is comparatively better in both temporal and spatial aggregation compared to other selected distributions. Generalized Extreme Value (GEV) distribution is a family of continuous probability distributions which combines the Gumbel (Type I), Frechet (Type

II) and Weibull (Type III) distributions developed within the extreme value theory and it has three parameters namely: location, scale and shape. In the analysis of travel time variability both smaller and larger travel times are equally important as that of the mean travel time. The better performance of GEV distribution compared to the other distributions might be due to the ability of the GEV distribution to capture the extreme events. In case of travel time variability analysis, it can address both the smaller and larger travel times of public transit.

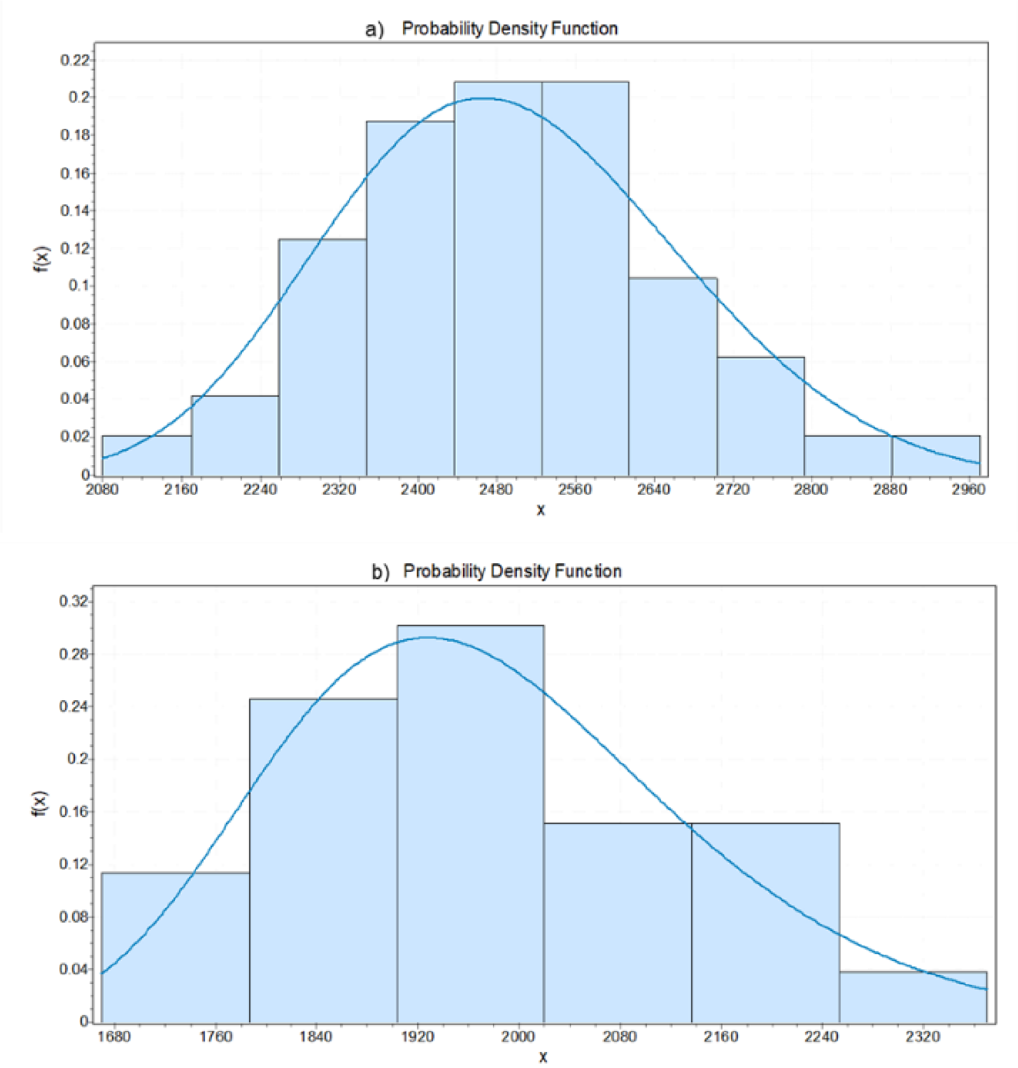

Figure 4 Probability density function GEV distribution a) Peak hour and b) Off Peak hour

Table 2 Kolmogorov-Smirnov (KS) test results at route level

	Time period	Aggregation level	Sample size	Goodness of fit (K S test)		
				Top 1	Top 2	Top 3
Travel time	Morning peak	peak period	193	GEV (0.998)	Burr (0.973)	Log logistic (0.958)
		60 minutes	109	GEV (0.999)	Lognormal (0.994)	Normal (0.993)
		45 minutes	77	GEV (0.989)	Burr (0.97)	Normal (0.966)
		30 minutes	45	GEV (0.982)	Lognormal (0.95)	Burr (0.938)
	Interpeak	60 minutes	82	GEV (0.553)	Weibull (0.547)	Burr (0.488)
		45 minutes	55	GEV (0.675)	Burr (0.545)	Weibull (0.462)
		30 minutes	45	Weibull (0.597)	Burr (0.59)	GEV (0.53)
	Evening peak	peak period	130	GEV (0.96)	Weibull (0.945)	Burr (0.935)
		60 minutes	91	GEV (0.988)	Log logistic (0.951)	Burr (0.917)
		45 minutes	69	Burr (0.918)	GEV (0.764)	Weibull (0.621)
		30 minutes	42	Burr (0.952)	GEV (0.716)	Logistic (0.663)
	Off-peak	period	70	GEV (0.999)	Normal (0.991)	gamma (0.989)
		60 minutes	55	GEV (0.998)	Normal (0.968)	Lognormal (0.962)
		45 minutes	41	GEV (0.995)	Gamma (0.972)	Log logistic (0.965)
		30 minutes	29	GEV (0.996)	Lognormal (0.982)	Normal (0.981)
Running time	Morning peak	peak period	193	Logistic (0.845)	Burr (0.843)	Lognormal (0.569)
		60 minutes	109	Weibull (0.912)	Burr (0.762)	GEV (0.757)
		45 minutes	77	GEV (0.912)	Burr (0.762)	Weibull (0.757)
		30 minutes	45	GEV (0.995)	Logistic (0.998)	Lognormal (0.998)
	Interpeak	60 minutes	82	GEV (0.93)	Weibull (0.903)	Burr (0.704)
		45 minutes	55	GEV (0.986)	Weibull (0.915)	Burr (0.787)
		30 minutes	45	GEV (0.586)	Weibull (0.584)	Burr (0.376)
	Evening peak	peak period	130	Burr (0.841)	Weibull (0.803)	GEV (0.588)
		60 minutes	91	GEV (0.985)	Burr (0.843)	Weibull (0.791)
		45 minutes	69	Burr (0.934)	GEV (0.899)	Weibull (0.652)
		30 minutes	42	GEV (0.86)	Burr (0.711)	Weibull (0.548)
	Off-peak	period	70	GEV (0.804)	Lognormal (0.723)	Normal (0.672)
		60 minutes	55	GEV (0.715)	Burr (0.613)	Normal (0.465)
		45 minutes	41	GEV (0.548)	Burr (0.48)	Log logistic (0.414)
		30 minutes	29	GEV (0.691)	Log logistic (0.563)	Burr (0.561)

Note: From Table 2 to Table 10, value within parenthesis is P-value

Table 3 Kolmogorov-Smirnov (KS) test results of morning peak period at segment level (based on the intersections)

Segment number	Length, m	Number of Bus stops	Morning peak period		
			Top 1	Top 2	Top 3
1	5380	14	Gamma (0.901)	Logistic (0.895)	Normal (0.873)
2	3000	5	GEV (0.358)	Burr (0.304)	Gamma (0.186)
3	625	1	GEV (0.378)	Lognormal (0.363)	Gamma (0.31)
4	1500	1	GEV (0.862)	Normal (0.596)	Weibull (0.474)
5	500	1	GEV (0.847)	Normal (0.595)	Weibull (0.594)
6	1200	2	Normal (0.989)	Burr (0.984)	GEV (0.981)
7	500	1	GEV (0.312)	Gamma (0.171)	Lognormal (0.147)

Table 4 Kolmogorov-Smirnov (KS) test results of morning peak period at segment level (based on the bus stops)

Segment Number	Land Use	Length, m	Morning Peak Period		
			Top 1	Top 2	Top 3
1	Industrial	520	Gamma (0.936)	Lognormal (0.874)	GEV (0.853)
2	Industrial	430	Gamma (0.903)	Normal (0.835)	Burr (0.801)
3	Industrial	330	GEV (0.774)	Lognormal (0.762)	Gamma (0.708)
4	Residential	300	Logistic (0.37)	Weibull (0.323)	Burr (0.306)
5	Residential	400	Burr (0.988)	Log logistic (0.98)	Lognormal (0.923)
6	Residential	640	GEV (0.937)	Normal (0.899)	Burr (0.897)
7	Residential	310	Log logistic (0.932)	GEV (0.888)	Burr (0.881)
8	Residential	340	GEV (0.91)	Burr (0.794)	Normal (0.784)
9	Residential	330	GEV (0.99)	Burr (0.978)	Normal (0.915)
10	Residential	280	Normal (0.858)	Burr (0.837)	GEV (0.806)
11	Residential	220	GEV (0.955)	Burr (0.954)	Weibull (0.953)
12	Commercial	510	GEV (0.997)	Weibull (0.943)	Normal (0.845)
13	Commercial	340	Logistic (0.707)	Burr (0.621)	Normal (0.488)
14	Commercial	430	GEV (0.937)	Normal (0.874)	Weibull (0.831)
15	Commercial	790	GEV (0.63)	Lognormal (0.589)	Gamma (0.512)
16	Residential	270	GEV (0.977)	Gamma (0.95)	Lognormal (0.917)
17	Residential	870	GEV (0.519)	Lognormal (0.472)	Gamma (0.413)
18	Commercial	250	GEV (0.58)	Normal (0.498)	Weibull (0.363)
19	Commercial	510	GEV (0.761)	Normal (0.726)	Gamma (0.582)
20	Commercial	750	GEV (0.773)	Lognormal (0.712)	Log logistic (0.654)
21	Commercial	750	Lognormal (0.971)	GEV (0.953)	Gamma (0.933)
22	Commercial	1340	Lognormal (0.977)	GEV (0.968)	Gamma (0.95)
23	CBD	320	GEV (0.47)	Gamma (0.437)	Lognormal (0.4)
24	CBD	670	Burr (0.979)	Log logistic (0.895)	GEV (0.812)
25	CBD	1270	GEV (0.737)	Lognormal (0.616)	Burr (0.581)

Table 5 Kolmogorov-Smirnov (KS) test results of morning peak 60 min at segment level (based on the intersections)

Segment number	Length, m	Number of Bus stops	Morning peak 60 min		
			Top 1	Top 2	Top 3
1	5380	14	GEV (0.316)	Weibull (0.288)	Burr (0.264)
2	3000	5	GEV (0.776)	Burr (0.629)	Gamma (0.443)
3	625	1	GEV (0.345)	Log logistic (0.269)	Gamma (0.253)
4	1500	1	Burr (0.977)	GEV (0.946)	Log logistic (0.925)
5	500	1	GEV (0.953)	Burr (0.746)	Weibull (0.647)
6	1200	2	Burr (0.995)	Normal (0.985)	GEV (0.952)
7	500	1	GEV (0.565)	Gamma (0.544)	Log logistic (0.445)

Table 6 Kolmogorov-Smirnov (KS) test results of morning peak 60 min at segment level (based on the bus stops)

Segment Number	Land Use	Length, m	Morning Peak 60 min		
			Top 1	Top 2	Top 3
1	Industrial	520	GEV (0.924)	Lognormal (0.877)	Gamma (0.831)
2	Industrial	430	Gamma (0.966)	Normal (0.916)	Lognormal (0.888)
3	Industrial	330	GEV (0.982)	Burr (0.939)	Log logistic (0.855)
4	Residential	300	Burr (0.46)	GEV (0.408)	Logistic (0.401)
5	Residential	400	Burr (0.965)	Log logistic (0.888)	GEV (0.841)
6	Residential	640	GEV (0.999)	Burr (0.951)	Gamma (0.803)
7	Residential	310	GEV (0.955)	Burr (0.953)	Log logistic (0.948)
8	Residential	340	GEV (0.951)	Burr (0.906)	Gamma (0.902)
9	Residential	330	GEV (0.999)	Gamma (0.992)	Normal (0.988)
10	Residential	280	GEV (0.883)	Lognormal (0.857)	Gamma (0.852)
11	Residential	220	GEV (0.958)	Burr (0.889)	Weibull (0.828)
12	Commercial	510	Burr (0.988)	Weibull (0.962)	GEV (0.906)
13	Commercial	340	GEV (0.661)	Burr (0.625)	Weibull (0.395)
14	Commercial	430	GEV (0.893)	Weibull (0.879)	Burr (0.859)
15	Commercial	790	GEV (0.745)	Lognormal (0.701)	Gamma (0.641)
16	Residential	270	GEV (0.726)	Log logistic (0.71)	Weibull (0.685)
17	Residential	870	GEV (0.479)	Log logistic (0.403)	Lognormal (0.366)
18	Commercial	250	GEV (0.962)	Burr (0.922)	Weibull (0.902)
19	Commercial	510	GEV (0.949)	Normal (0.894)	Weibull (0.882)
20	Commercial	750	GEV (0.927)	Lognormal (0.832)	Log logistic (0.82)
21	Commercial	750	GEV (0.982)	Weibull (0.97)	Normal (0.941)
22	Commercial	1340	Burr (0.995)	Lognormal (0.993)	GEV (0.987)
23	CBD	320	Burr (0.311)	GEV (0.248)	Normal (0.206)
24	CBD	670	Lognormal (0.955)	Gamma (0.913)	Burr (0.752)
25	CBD	1270	GEV (0.502)	Normal (0.496)	Gamma (0.468)

Table 7 Kolmogorov-Smirnov (KS) test results of Evening peak period at segment level (based on the intersections)

Segment number	Length, m	Number of Bus stops	Evening peak period		
			Top 1	Top 2	Top 3
1	5380	14	GEV (0.98)	Log logistic (0.897)	Lognormal (0.82)
2	3000	5	GEV (0.867)	Gamma (0.865)	Log logistic (0.864)
3	625	1	GEV (0.749)	Burr (0.669)	Gamma (0.602)
4	1500	1	GEV (0.942)	Burr (0.923)	Log logistic (0.251)
5	500	1	Gamma (0.991)	GEV (0.981)	Burr (0.981)
6	1200	2	Weibull (0.917)	Burr (0.83)	GEV (0.668)
7	500	1	Burr (0.871)	GEV (0.573)	Log logistic (0.075)

Table 8 Kolmogorov-Smirnov (KS) test results of evening peak period at segment level (based on the bus stops)

Segment Number	Land Use	Length, m	Evening Peak Period		
			Top 1	Top 2	Top 3
1	Industrial	520	GEV (0.762)	Weibull (0.584)	Normal (0.436)
2	Industrial	430	Gamma (0.853)	Lognormal (0.807)	GEV (0.736)
3	Industrial	330	GEV (0.908)	Normal (0.846)	Gamma (0.78)
4	Residential	300	GEV (0.872)	Gamma (0.783)	Lognormal (0.761)
5	Residential	400	Normal (0.864)	Weibull (0.784)	GEV (0.744)
6	Residential	640	GEV (0.746)	Gamma (0.701)	Lognormal (0.624)
7	Residential	310	GEV (0.907)	Burr (0.882)	Log logistic (0.833)
8	Residential	340	Burr (0.906)	Log logistic (0.762)	GEV (0.701)
9	Residential	330	GEV (0.841)	Normal (0.697)	Burr (0.654)
10	Residential	280	Burr (0.886)	Logistic (0.851)	Gamma (0.684)
11	Residential	220	Weibull (0.947)	Normal (0.925)	Burr (0.904)
12	Commercial	510	Burr (0.917)	Logistic (0.868)	GEV (0.782)
13	Commercial	340	GEV (0.885)	Normal (0.806)	Weibull (0.736)
14	Commercial	430	GEV (0.919)	Burr (0.857)	Weibull (0.803)
15	Commercial	790	GEV (0.666)	Burr (0.591)	Log logistic (0.459)
16	Residential	270	Logistic (0.852)	Normal (0.808)	Weibull (0.773)
17	Residential	870	GEV (0.938)	Weibull (0.827)	Normal (0.673)
18	Commercial	250	Burr (0.877)	GEV (0.829)	Normal (0.672)
19	Commercial	510	Weibull (0.94)	Normal (0.912)	Burr (0.886)
20	Commercial	750	GEV (0.946)	Gamma (0.906)	Lognormal (0.883)
21	Commercial	750	Burr (0.922)	GEV (0.884)	Log logistic (0.864)
22	Commercial	1340	Burr (0.938)	Gamma (0.855)	Normal (0.825)
23	CBD	320	Burr (0.912)	Normal (0.84)	Weibull (0.762)
24	CBD	670	Burr (0.817)	Logistic (0.755)	GEV (0.638)
25	CBD	1270	Gamma (0.836)	Lognormal (0.796)	GEV (0.758)

Table 9 Kolmogorov-Smirnov (KS) test results of evening peak 60 min at segment level (based on the intersections)

Segment number	Length, m	Number of Bus stops	Evening peak 60 min		
			Top 1	Top 2	Top 3
1	5380	14	GEV (0.991)	Lognormal (0.988)	Gamma (0.956)
2	3000	5	GEV (0.918)	Lognormal (0.907)	Gamma (0.886)
3	625	1	Burr (0.944)	Lognormal (0.913)	GEV (0.902)
4	1500	1	GEV (0.974)	Burr (0.922)	Log logistic (0.516)
5	500	1	GEV (0.973)	Burr (0.938)	Log logistic (0.928)
6	1200	2	Normal (0.904)	GEV (0.899)	Logistic (0.882)
7	500	1	Burr (0.986)	GEV (0.979)	Log logistic (0.802)

Table 10 Kolmogorov-Smirnov (KS) test results of evening peak 60 min at segment level (based on the bus stops)

Segment Number	Land Use	Length, m	Evening Peak 60 min		
			Top 1	Top 2	Top 3
1	Industrial	520	GEV (0.809)	Burr (0.714)	Weibull (0.646)
2	Industrial	430	GEV (0.842)	Weibull (0.836)	Normal (0.818)
3	Industrial	330	GEV (0.872)	Normal (0.857)	Gamma (0.849)
4	Residential	300	GEV (0.944)	Normal (0.912)	Burr (0.83)
5	Residential	400	GEV (0.843)	Weibull (0.838)	Burr (0.819)
6	Residential	640	GEV (0.862)	Normal (0.852)	Lognormal (0.832)
7	Residential	310	GEV (0.691)	Burr (0.542)	Lognormal (0.518)
8	Residential	340	Burr (0.873)	GEV (0.858)	Log logistic (0.821)
9	Residential	330	GEV (0.784)	Burr (0.711)	Normal (0.67)
10	Residential	280	Burr (0.817)	Lognormal (0.756)	GEV (0.721)
11	Residential	220	Burr (0.925)	Logistic (0.914)	GEV (0.862)
12	Commercial	510	Burr (0.858)	Logistic (0.846)	Normal (0.838)
13	Commercial	340	GEV (0.967)	Normal (0.828)	Weibull (0.789)
14	Commercial	430	GEV (0.815)	Weibull (0.775)	Normal (0.748)
15	Commercial	790	Burr (0.357)	GEV (0.304)	Log logistic (0.224)
16	Residential	270	Log logistic (0.563)	GEV (0.541)	Lognormal (0.374)
17	Residential	870	GEV (0.553)	Burr (0.521)	Weibull (0.298)
18	Commercial	250	GEV (0.986)	Normal (0.872)	Logistic (0.862)
19	Commercial	510	GEV (0.739)	Weibull (0.625)	Burr (0.614)
20	Commercial	750	Weibull (0.833)	Log logistic (0.797)	GEV (0.79)
21	Commercial	750	Weibull (0.91)	GEV (0.851)	Normal (0.845)
22	Commercial	1340	GEV (0.87)	Burr (0.815)	Normal (0.81)
23	CBD	320	GEV (0.89)	Gamma (0.889)	Burr (0.888)
24	CBD	670	Burr (0.881)	Logistic (0.838)	Normal (0.812)
25	CBD	1270	Burr (0.933)	Normal (0.83)	Weibull (0.819)

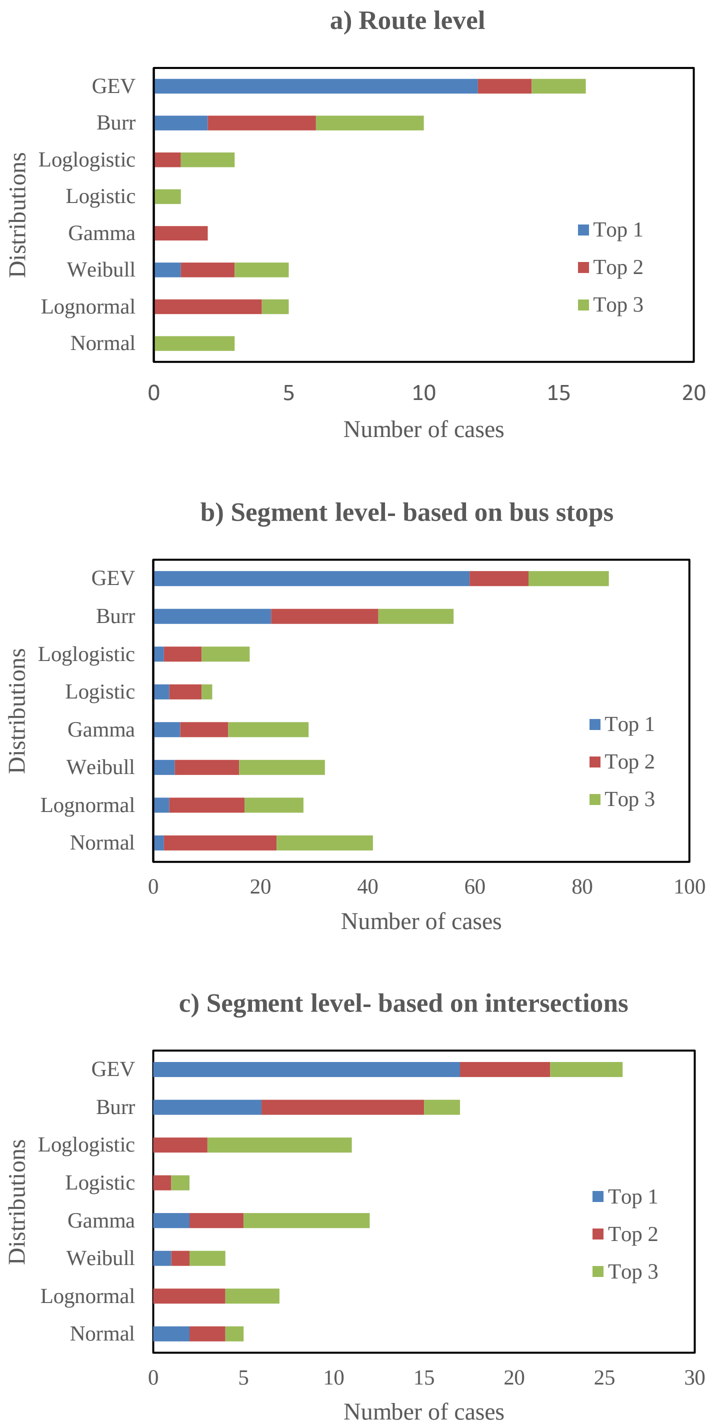

Figure 5 Summary of top three distributions in all the cases a) route level, b) segment level based on bus stops and c) segment level based on intersections

7. Conclusions

Travel time reliability is an important aspect in improving the quality of service in public transit system. The Understanding about the travel time distribution which explains the variability in travel times is necessary for analyzing the reliability of the system. In the present study, the influence of spatial and temporal aggregation on the travel time distribution was analyzed by using the one-month Automatic Vehicle Location data of a typical bus route of Mysore city, India. The different combinations of temporal and spatial aggregation were considered to examine the performance of alternative distributions. Kolmogorov-Smirnov (KS) test was used in the selection of top three fitted distributions in each case. Consistent with the literature, it is found that the GEV distribution fits the travel time better in heterogeneous traffic conditions, at both route level (both travel time and running time) and segment level (based on bus stop spacing and based on intersection spacing). The overall performance of this distribution was relatively superior compared to all other selected distributions. The GEV distribution can be used by the transit operators in travel time reliability analysis and travel time prediction studies to improve the transit performance.

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References

1. Al-Deek, H. and Emam, E.B., 2006. New methodology for estimating reliability in transportation networks with degraded link capacities. Journal of intelligent transportation systems, 10(3), pp.117-129.
2. Bates, J., Dix, M. and May, A.D., 1987. Travel time variability and its effect on time of day choice for the journey to work. Planning and transport research and computation.
3. Burr, I.W., 1942. Cumulative frequency functions. The Annals of mathematical statistics, 13(2), pp.215-232.
4. Chepuri, A., Borakanavar, M., Amrutsamanvar, R., Arkatkar, S. and Joshi, G., 2018. Examining Travel Time Reliability under Mixed Traffic Conditions: A Case Study of Urban Arterial Roads in Indian cities. Asian Transport Studies, 5(1), pp.30-46.
5. Chepuri, A., Ramakrishnan, J., Arkatkar, S., Joshi, G. and Pulugurtha, S.S., 2018. Examining Travel Time Reliability-Based Performance Indicators for Bus Routes Using GPS-Based Bus Trajectory Data in India. Journal of Transportation Engineering, Part A: Systems, 144(5), p.04018012.
6. Chepuri, A., Wagh, A., Arkatkar, S.S. and Joshi, G., 2017, June. Study of travel time variability using two-wheeler probe data–an Indian experience. In Proceedings of the Institution of Civil Engineers-Transport (pp. 1-17). Thomas Telford Ltd.
7. Chu, H.C., 2010. Estimating travel time reliability on freight corridors (No. 10-1322).
8. Clark, S. and Watling, D., 2005. Modeling network travel time reliability under stochastic demand. Transportation Research Part B: Methodological, 39(2), pp.119-140.
9. Herman, R. and Lam, T., 1974. Trip time characteristics of journeys to and from work. Transportation and traffic theory, 6, pp.57-86.
10. Hollander, Y. and Liu, R., 2008. Estimation of the distribution of travel times by repeated simulation. Transportation Research Part C: Emerging Technologies, 16(2), pp.212-231.
11. Jordan, W.C. and Turnquist, M.A., 1979. Zone scheduling of bus routes to improve service reliability. Transportation science, 13(3), pp.242-268.
12. Kieu, L.M., Bhaskar, A. and Chung, E., 2014. Establishing definitions and modeling public transport travel time variability.
13. Kimpel, T., Strathman, J.G. and Callas, S., 2004. Improving scheduling through performance monitoring using AVL/APC data. Submitted to University of Wisconsin-Milwaukee as a Local Innovations in Transit project report under the Great Cities University Consortium.
14. Kumar, B.A., Arkatkar, S.S. and Vanajakshi, L., 2018. Performance Comparison of Bus Travel Time Prediction Models across Indian Cities (No. 18-04897).
15. Kumar, B.A., Vanajakshi, L. and Subramanian, S.C., 2013. Pattern-based bus travel time prediction under heterogeneous traffic conditions. Transportation Research Record, Transportation Research Board, National Research Council, Washington, DC.
16. Kumar, B.A., Vanajakshi, L. and Subramanian, S.C., 2017. A hybrid model based method for bus travel time estimation. Journal of Intelligent Transportation Systems, pp.1-17.
17. Li, R., Rose, G. and Sarvi, M., 2006. Using automatic vehicle identification data to gain insight into travel time variability and its causes. Transportation Research Record: Journal of the Transportation Research Board, (1945), pp.24-32.
18. Ma, Z., Ferreira, L., Mesbah, M. and Zhu, S., 2016. Modeling distributions of travel time variability for bus operations. Journal of Advanced Transportation, 50(1), pp.6-24.

19. Mazloumi, E., Currie, G. and Rose, G., 2009. Using GPS data to gain insight into public transport travel time variability. Journal of Transportation Engineering, 136(7), pp.623-631.
20. Noland, R.B. and Polak, J.W., 2002. Travel time variability: a review of theoretical and empirical issues. Transport reviews, 22(1), pp.39-54.
21. Polus, A., 1979. A study of travel time and reliability on arterial routes. Transportation, 8(2), pp.141-151.
22. Rahman, M.M., Wirasinghe, S.C. and Kattan, L., 2018. Analysis of bus travel time distributions for varying horizons and real-time applications. Transportation Research Part C: Emerging Technologies, 86, pp.453-466.
23. Richardson, A.J. and Taylor, M.A.P., 1978. Travel time variability on commuter journeys. High Speed Ground Transportation Journal, 12(1).
24. Small, K.A., 1982. The scheduling of consumer activities: work trips. The American Economic Review, 72(3), pp.467-479.
25. Sumalee, A., Watling, D. and Nakayama, S., 2006. Reliable network design problem: case with uncertain demand and total travel time reliability. Transportation Research Record: Journal of the Transportation Research Board, (1964), pp.81-90.
26. Susilawati, S., Taylor, M.A. and Somenahalli, S.V., 2013. Distributions of travel time variability on urban roads. Journal of Advanced Transportation, 47(8), pp.720-736.
27. Taylor, M.A.P., 1982. Travel time variability—the case of two public modes. Transportation Science, 16(4), pp.507-521.
28. Uno, N., Kurauchi, F., Tamura, H. and Iida, Y., 2009. Using bus probe data for analysis of travel time variability. Journal of Intelligent Transportation Systems, 13(1), pp.2-15.
29. Van Oort, N., 2011. Service reliability and urban public transport design.
30. Vanajakshi, L., Subramanian, S.C. and Sivanandan, R., 2009. Travel time prediction under heterogeneous traffic conditions using global positioning system data from buses. IET intelligent transport systems, 3(1), pp.1-9.
31. Wardrop, J.G., 1952, January. Some theoretical aspects of road traffic research. In Inst Civil Engineers Proc London/UK/.
32. Xue, Y., Jin, J., Lai, J., Ran, B. and Yang, D., 2011. Empirical characteristics of transit travel time distribution for commuting routes (No. 11-2827).