

Comparative analysis of Urban Travel Time Reliability across Public Transit and Motorized Transport Modes

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ABSTRACT

Travel time reliability has become a key performance indicator in urban transportation planning as it captures the consistency and predictability of travel conditions beyond average travel time, directly influencing user satisfaction and system efficiency. This study presents a comparative analysis of travel time reliability between public transit and motorized transport modes operating along an urban corridor, using empirical travel time data collected during both peak and off-peak periods. The dataset reflects variations arising from traffic congestion, operational characteristics, mixed traffic interactions, and external disturbances typical of rapidly growing cities such as Pune, where increasing travel demand, accelerating motorization, heterogeneous vehicle composition, and limited roadway capacity place significant stress on transport networks. Reliability performance was evaluated using statistical measures including mean travel time, standard deviation, buffer time index, and percentile-based indicators, enabling a comprehensive assessment of travel time variability and uncertainty across modes. The analysis reveals distinct reliability patterns between public transport and motorized vehicles. In contrast, public transit systems demonstrate relatively stable travel time behavior under congestion, attributed to fixed routes, regulated operations, scheduled stops, and in some cases priority measures or partial right-of-way advantages. The results highlight the significant influence of stop frequency, traffic exposure, and right-of-way conditions on travel time performance. The study emphasizes that reliance on average travel time alone may lead to incomplete or misleading evaluations of corridor performance. Incorporating reliability-based metrics into transport planning and evaluation frameworks is therefore essential for informed decision-making. The findings offer valuable insights for transport planners and policymakers seeking to enhance operational efficiency, improve commuter travel experience, and support sustainable urban mobility strategies in congested urban environments.

Keywords: - Planning Time Index; Travel time reliability; Urban transportation systems; Public transit performance; Sustainable mobility planning

1. INTRODUCTION

Today's urban mobility is shaped more and more by the growing demand for travel, the quickening pace of motorization, and the growing concerns about sustainability and traffic. Mixed traffic operations, diverse vehicle compositions, and insufficient road capacity put a great deal of strain on the transportation network in urban areas like Pune. Because of this, commuters often experience erratic travel conditions, which makes it challenging to predict how long it will take them to get to their destinations. Understanding modal performance in this situation requires evaluating travel time reliability from a comparative standpoint between private motorized vehicles and public transportation. In the end, modal preference and mode shift behavior are influenced by commuters' perceptions of each mode's predictability and convenience, which can be better understood through such a comparison. A quantitative analysis of how travel time varies under various operational and traffic conditions is made possible by evaluating TTR using indices like the Travel Time Index (TTI), Buffer Time Index (BTI), and Planning Time Index (PTI). These indices provide a comprehensive picture of travel behavior along important Pune corridors by capturing variability across days, modes, and time periods (peak vs. off-peak).

Policymakers can identify operational shortcomings, prioritize corridor improvements, implement dedicated lanes, optimize signal timings, and strengthen transit management practices by understanding the differences in reliability

performance between buses and private vehicles. By providing a comparative evaluation of TTR across modes and concentrating on corridor-level analysis within Pune, this study thus adds to the larger conversation on urban transportation. The results are anticipated to strengthen the city's strategy for creating a dependable, predictable, and effective transportation system and to support evidence-based decision-making.

2. LITERATURE REVIEW

Li Baibing et al. (2019) The measurement of travel time reliability and risk is examined in this paper. The CVaR, a well-known risk metric in financial economics, is closely linked to the TTRR as a reliability metric. Total travel time reliability (TTTR), total travel time budget (TTTB), and mean-excess total travel time (METTT) are some of the reliability metrics found in the traffic literature. The relationships between the different travel time reliability metrics are established in this paper.

Sabyasachee Mishra et al. (2018) This paper states that reliability is one of the major parameters that can describe the performance of a transportation network. When the current state of the network is being tested, reliability should be one of the performance measures along with others, as traveler's value reliability, and factor it in to their choices. Moreover, when the benefits and costs of proposed or current projects are being analyzed, one should not disregard reliability, as the value of reliability savings may change the outcome.

Khorshidi Navid et al. (2025) This paper discusses the widespread use of travel time reliability in project performance reporting and assessment. However, the dynamic nature of traffic and the wide range of variables influencing travel time variability make it difficult to predict TTR metrics. Optimization is essential because hyper parameter tuning plays a major role in these models' accuracy.

Ricard, Lea. (2012) Reliability has become a major obstacle for public transportation operators looking to draw in new customers, as this article illustrates. In this work, we suggested a way to gauge bus schedule reliability in order to eventually improve it. In order to achieve this, we introduced a simulation model that uses the long-term conditional PDF of the TT to estimate a vehicle schedule's delay tolerance. The prediction of this conditional probability distribution, which we called the PDTT, was framed as a supervised learning problem.

3. STUDY AREA

The study corridor extends from Swargate Bus Stand to Shivajinagar Bus Stand, one of Pune's most important north-south urban transport links. This corridor passes through densely developed commercial and institutional zones including Sarasbaug, SP College Chowk, Shatihya parisad, Alka chawk, Deccan corner Stop approach, and the institutional administrative area. It carries a high volume of daily commuters traveling by PMPML buses, private vehicles, and intermediate public transport modes.

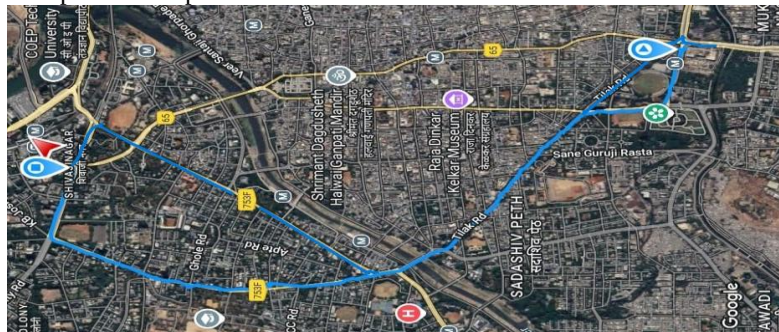


Fig -1: Aerial view of data collection Location (Swargate Bus Stand to Shivajinagar Bus Stand), Pune

Fig 1 indicate the tracked marked in blue color is used for studied area. The route experiences recurring congestion due to narrow road sections, multiple signalized intersections, roadside parking, pedestrian activity, and high bus stop density. As a major feeder to Pune Railway Station, Shivajinagar Court, educational institutes, and commercial markets, this corridor forms a critical mobility spine of the city. Its heterogenous traffic mix and varying demand patterns make it a suitable case for analyzing travel time reliability for both public transport and motorized vehicles.

4. FIELD DATA COLLECTION

The Data collection Travel time data was collected via on-board surveys from origin to destination along the selected corridor for morning peak and off-peak periods. The data was collected for 3 consecutive weeks, days of week are Tuesday, Wednesday, Thursday for the study. The data for peak hours was collected for morning time

from 10:00 AM to 12:00 AM and for evening from 4:00 PM to 6:00 PM. Data for off peak hour was collected from time 1:00 PM to 3:00 PM. Data was collected with the aid of a handheld GPS tracker and stopwatch. Between origin and destination points, the following information was collected: departure time from the origin, arrival and departure time at each stop along the route, number of stops made, arrival and departure times at intersections, and delays due to any road incidents such as roadwork's or accidents. Data was recorded separately for different vehicle.

Following Table -1 is standard/ reference value of TTR indices are considered for this study:-

Table -1: Standard / Reference Value Range

Index	Standard / Reference Value Range	Reference Source
Standard Deviation (SD)	< 3–5 min → Reliable > 10 min → Unreliable	Federal Highway Administration (FHWA) – Travel Time Reliability: Making It There on Time, All the Time (2006, 2013)
Coefficient of Variation (CV)	< 10% → Very reliable 10–20% → Moderate > 20% → Poor	Li et al. (2019), Asensio & Matas (2010)
Buffer Time (BT)	< 5 min → Reliable 5–10 min → Moderate > 10 min → Unreliable	Transportation Research Board (TRB Circular E-C118) – Travel Time Reliability: Measures, Analysis, and Applications (2007)
Buffer Time Index (BTI)	< 0.25 → Good reliability 0.25–0.5 → Moderate > 0.5 → Poor	FHWA (2013), Bates et al. (2001)
Planning Time Index (PTI)	1.0–1.5 → Good 1.5–2.0 → Moderate > 2.0 → Poor	FHWA (2013), Travel Time Reliability Framework
Misery Index (MI)	0.05–0.15 → Reliable 0.15–0.30 → Moderate > 0.30 → Poor	Lomax, T. et al. (2003) – Selecting Travel Time Reliability Measures, Texas Transportation Institute

5. DATA ANALYSIS AND PERFORMANCE EVALUATION

The analysis indicates that public transportation has a greater degree of variation than motorized vehicles based on the statistical measure of travel-time reliability (TTR). The variability of bus travel time across the days and during peak times is significantly determined by the effects of dwell time and traffic signal delay on bus travel time and also because buses operate in a mixed-traffic environment. This difference between these two types of travel has been confirmed by statistical testing to be statistically significant, therefore indicating that motor vehicles are more susceptible to congestion than public transport.

5.1 Travel Time Reliability (TTR) indices of Peak Hour data for particular vehicles

Table -2: TTR indices of Peak hour data for particular vehicles

Reliability (TTR) indices	Bus – Peak Hours	Car – Peak Hours	Two-Wheeler – Peak Hours
Mean Travel Time (min)	30.95	26.35	21.79
Standard Deviation (min)	2.03	1.44	1.51
Coefficient of Variation (CV)	6.57%	5.46%	6.93%
95th Percentile (T95)	33.59	28.9	24.3
Free Flow Time (min)	33.37	24.38	19.56
Buffer Time (BT)	2.64 min	2.55 min	2.51 min
Buffer Time Index (BTI)	0.09	0.097	0.115
Planning Time Index (PTI)	9.96	1.19	1.24
Misery Index (MI)	0.08	0.06	0.06

Based on the standard reference values, table 2 concluded that all three modes during peak hours show good travel time reliability. The standard deviation for bus (2.03 min), car (1.44 min), and two-wheeler (1.51 min) is well below the 3 to 5 minute threshold. This indicates reliable performance. The coefficient of variation (CV) for all modes is also below 10%, classifying them as very reliable. The buffer time, which is around 2.5 to 2.6 minutes, and the buffer time index (0.09 to 0.115) for all modes fall within the reliable or good range. This suggests that travelers need only a small extra time cushion. The planning time index (PTI) for cars is 1.19 and for two-wheelers, it is 1.24. This indicates good reliability. The bus has a higher PTI because of low free-flow time, but other indices still show stable performance. The misery index for all modes ranges from 0.06 to 0.08, which is within the reliable range. This means extreme delays are limited. Overall, cars and two-wheelers show slightly better reliability than buses, but peak-hour travel for all modes is dependable based on standard measures.

5.2 Travel Time Reliability (TTR) indices for Off Peak hour data for separate vehicles

Table -3: TTR indices for Off Peak hour data for particular vehicles

Reliability (TTR) indices	Bus – Off Peak Hours	Car – Off Peak Hours	Two-Wheeler – Off Peak Hours
Mean Travel Time (min)	29.68	25.52	18.82
Standard Deviation (min)	1.01	1.36	0.97
Coefficient of Variation (CV)	3.40%	5.33%	5.16%
95th Percentile (T95)	31.18	27.96	20.13
Free Flow Time (min)	20.91	19.37	17.27
Buffer Time (BT)	1.50 min	2.44 min	1.31 min
Buffer Time Index (BTI)	0.05	0.096	0.07
Planning Time Index (PTI)	10.72	1.2	1.17
Misery Index (MI)	0.05	0.06	0.06

Based on the standard reference values, table 3 concluded that travel time during off-peak hours shows very high reliability for all three modes. Additionally, the buffer time index, ranging from 0.05 to 0.096, also shows good reliability. The planning time index for cars (1.20) and two-wheelers (1.17) is in the good range. The higher PTI for buses shows its very low free-flow time instead of poor consistency. The misery index (0.05–0.06) for all modes is in the reliable range, indicating limited extreme delays. Overall, off-peak travel is more reliable than during peak hours. Two-wheelers and cars perform slightly better than buses when it comes to travel time consistency.

5.3 Travel Time Reliability (TTR) indices for the Peak Hour data

Table -4: TTR indices for the Peak Hour data

Metric	Value	Interpretation
Mean Travel Time (min)	25.93	Average time users spend traveling under observed conditions.
Standard Deviation (min)	4.53	Indicates moderate variability in travel time.
Minimum Travel Time (min)	16.56	Shows small spread → free variability present
Maximum Travel Time (min)	34.38	Shows large spread → congestion variability present.
95th Percentile Travel Time (min)	32.48	Time needed to ensure on-time arrival 95% of the time (worst-case reliable time).
Free Flow Time (min)	10 min	Fastest achievable time under minimal congestion
Travel Time Index (TTI)	2.59	Travel takes 2.59 times longer than free-flow travel. → Indicates substantial congestion even during the measurement period.
Planning Time Index (PTI)	3.25	Travellers should plan for 3.25× FFT to be 95% reliable. → High variability → Need extra buffer time.
Buffer Index (%)	25.27 %	Travellers must budget 25% extra time to maintain reliability. → Moderate unreliability; travel times fluctuate noticeably.
Misery Index	3.44	Worst travel times are 3.44× FFT, indicating occasional severe delays.

From table 4, the TTR values concluded that mean travel time of almost 26 minutes compared to an FFT of 10 minutes, the route exhibits moderate to high congestion. Travelers must budget for more than three times the free-flow time in order to be almost always on time, as indicated by $PTI = 3.25$, which highlights considerable variability. Buffer Index (25%) indicates a discernible reliability problem that necessitates additional buffer time. There are sporadic severe congestion events where travel times sharply increase, as indicated by the Misery Index (3.44). The corridor is generally unreliable, necessitating careful planning on the part of commuters to prevent delays.

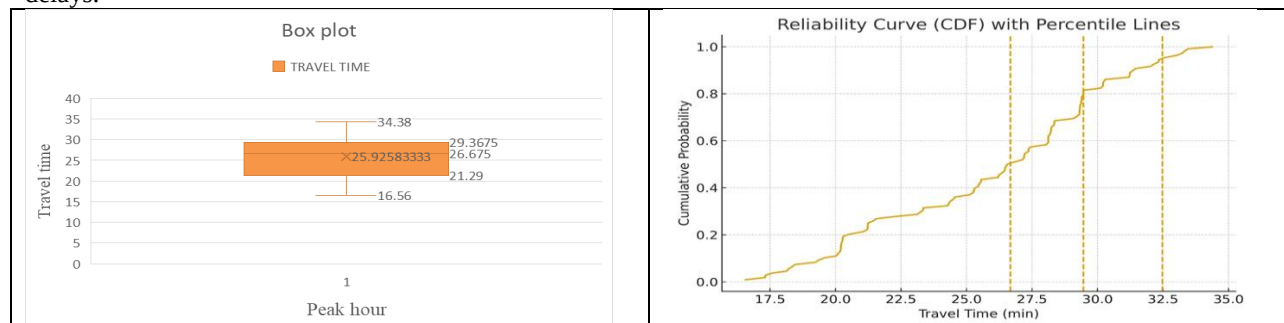


Chart -1: Box plot graph and Cumulative Distribution Function graph of peak hour data

Box plot graph explains that most travel times are between 21 to 29 minutes, which indicates a moderate variation. The median, 26.67, is a bit higher than the mean, 25.93, indicating a slight left skew. Travel time varies by about 18 minutes during peak hour: The extreme outliers are 34.38 and 16.56.

The Cumulative Distribution Function (CDF) shows the probability that a trip will be completed within a given travel time. It provides a direct picture of travel time reliability. The curve rises steadily from 17 min to 35 min, showing the full range of travel time variability on the corridor. The steep parts of the curve show a high concentration of travel times in that range. Flatter sections, near 17 to 20 minutes and 32 to 35 minutes, indicate less frequent travel times. These represent free-flow and highly congested conditions, respectively.

5.4 Travel Time Reliability (TTR) indices for the Off-Peak Hour data

Table -5: TTR indices for Off-Peak Hour data

Metric	Value	Interpretation
Mean Travel Time	24.28 min	Average travel duration for this corridor
Standard Deviation	4.93 min	Indicates moderate variability in travel time
Minimum Travel Time (FFT)	15.54 min	Fastest achievable (free-flow) travel time
Maximum Travel Time	31.23 min	Worst observed travel time
95th Percentile Travel Time	30.34 min	Time within which 95% of trips finish
Free Flow Time (min)	10 min	Fastest achievable time under minimal congestion
Travel Time Index (TTI)	1.56	Travelers need 56% more time than free-flow conditions
Planning Time Index (PTI)	1.95	A traveler should plan nearly 2× the free-flow time PTI = borderline high unreliability
Buffer Index (BI)	24.94%	Additional time needed to arrive “on time” 95% of the time good, 20–40% = moderate
Misery Index (MI)	1.95	Worst-case congestion severity → indicates significant peak-delay events

From table 5, the TTR values concluded that a moderate degree of variability ($SD = 4.93$ minutes), the average travel time is 24.28 minutes. Ten minutes is the free-flow time, but under actual circumstances, 56% more time is needed ($TTI = 1.56$). The average upper bound of delay is shown by the fact that 95% of trips end in 30.34 minutes.. Commuters should budget for nearly twice the free-flow time, according to the Planning Time Index (1.95), which indicates borderline high unreliability. Travel times range between 15.54 min (fastest) and 31.23 min (worst).

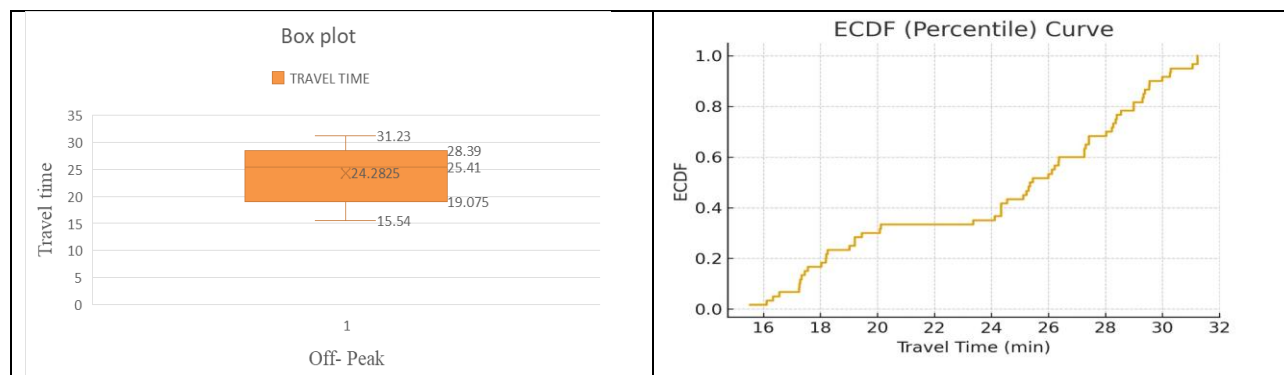


Chart -2: Box plot graph and Cumulative Distribution Function graph for off- peak hour data

Box plot graph explains that the majority of trips during off-peak hours fall between 19.08 minutes (Q1) and 28.39 minutes (Q3), with travel times ranging from 15.54 minutes to 31.23 minutes. The majority of travel times fall between 19 and 28 minutes. There are only sporadic delays of up to 31 minutes. The data is fairly symmetric and does not exhibit extreme skew. The median and mean values are close.

The CDF (Empirical Cumulative Distribution Function) shows that Ten percent of trips last less than seventeen minutes. About 20% of journeys take under 18 to 19 minutes. This indicates that there are a few very quick, unrestricted trips. For most trips, the ECDF rises steadily between 24 and 30 minutes. This displays the predominant travel-time band associated with congestion. The longest recorded travel times are indicated by the curve approaching 1.0 (100%) around 31–32 minutes. A steep curve, which we observe around 26 to 30 minutes, indicates that the majority of values are clustered. Additionally, 95% of all trips finish in about 30 minutes, which supports the reliability metrics you calculated.

6. CONCLUSIONS

This study evaluates the travel time performance of the studied corridor using standard Travel Time Reliability (TTR) metrics. The results indicate significant congestion and notable variability, especially during peak operating periods.

Peak hour data: The study indicates substantial congestion, much higher than typical urban road benchmarks (1.3–2.0). PTI reflects how much time travellers must plan to be 95% confident of arriving on time. A PTI of 3.25 indicates very high unreliability, where commuters must plan for more than three times the free-flow duration. Travelers must budget 25% additional time beyond average conditions to meet on-time arrival expectations. This falls in the moderate unreliability range, signalling that delays occur frequently and unpredictably..

The corridor experiences high congestion, as shown by the elevated TTI. Travel time variability is moderate but significant, with visible peaks during busy periods. High PTI and BI values confirm that the corridor is operationally unreliable, requiring extra planning time for consistent arrival. The Misery Index indicates periodic extreme delays, contributing to user dissatisfaction. Overall, the corridor exhibits poor travel time reliability, and improvements such as congestion management, signal coordination, and demand distribution strategies may be required.

Off - Peak hour data: The study indicate moderate congestion category, commonly seen in urban peak-hour traffic. PTI suggests that users must plan for nearly double the free-flow time to ensure timely arrival. With PTI approaching 2.0, the corridor shows borderline high unreliability, indicating significant day-to-day or hour-to-hour variation. The BI shows that commuters need to budget an additional 25% time as a buffer to be confident of on-time arrival. This falls within the moderate unreliability range (20–40%), meaning the corridor does not provide consistently reliable travel times. This reflects the severity of worst-delay conditions. A value near 2.0 indicates noticeable peak-delay events, though not extreme. Some trips may experience substantial delays, impacting overall user experience.

Overall corridor experiences moderate congestion, reflected in an elevated TTI. Reliability is moderate, with occasional significant peaks in delay. Travellers must add considerable planning time and buffer to account for variability. Some trips experience delay spikes, increasing the Misery Index. Overall performance is acceptable but not optimal, requiring operational improvements for better consistency. The evaluated corridor shows moderate traffic congestion and moderate unreliability, making travel times somewhat unpredictable. While average travel

times are manageable, the presence of delay spikes and a high planning time requirement indicate a need for traffic management interventions such as signal optimization, congestion management, and peak-hour regulation.

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