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ANALYSIS OF IMPACT OF BANGALORE METRO RAIL ON TRAFFIC DELAY FROM YELACHENAHALLI TO SILK INSTITUTE

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Abstract:

This study quantitatively assesses the impact of the Bangalore Metro Rail (BMR) on Travel Time Reliability (TTR) along a heterogeneous urban traffic corridor. In mixed-traffic environments such as Bangalore—characterized by modal diversity, weak lane discipline, and stochastic driver behaviour—TTR serves as a critical performance measure for evaluating network efficiency and operational stability. Metro rail systems, as major public transport interventions, are known to influence roadway performance by modifying traffic demand distribution, reducing vehicular congestion, and improving overall network resilience.

The analysis covers a 6.29 km arterial stretch from Yelchenahalli to Silk Institute on Kanakapura Road, Karnataka, India. Empirical data were collected using the Manual Test Vehicle Technique across one full weekday cycle for both directions, capturing morning peak (07:00–10:00), evening peak (17:00–20:00), and off-peak periods. Statistical evaluation of travel time distributions and reliability indices reveals that the commissioning of the BMR yields a significant improvement in corridor performance. Specifically, the average Travel Time Index (TTI) decreased by 15% relative to the pre-BMR scenario and by 23.8% relative to the BMR-constructionphase.

These findings provide robust empirical evidence that metro operations enhance travel time reliability in dense, mixed-traffic urban contexts, underscoring the role of high-capacity public transport in improving mobility performance on constrained urban corridors.

Keywords: Public Transport, Traffic Congestion, Congestion Indices, Travel Time Reliability

I. INTRODUCTION

Traffic congestion is a major problem in Bangalore city, the capital of Karnataka State and is the IT capital of India. The city is distinct in its nature due to its climate, terrain and peace-loving people. The town attracts a large number of individuals from all around India, making it India's most cosmopolitan metropolis. The massive growth that the city has witnessed in the last two decades has brought the city to fame but also caused severe traffic congestion on most of the existing urban road networks. To alleviate traffic congestion, increasing attention has been given to developing a Mass Rapid Transport System (MRTS), with the aim of best using existing transportation networks through various advanced technologies. Several ITS applications rely on the accurate and reliable estimation of Travel Time (TT) data. The provision of updated time period information enables travellers to form informed path choice decisions to avoid congested sites [6–8]. Moreover, the updated TT information allows for network operators to gauge the network performance and to spot bottlenecks for proactively deploying effective controls so as to improve overall traffic conditions.

Traffic congestion significantly affects the economic performance of the city and the living standards of the people. During peak periods, the majority of urban areas' traffic demand exceeds highway capacity. There is a lot of traffic on the roads because of the increase in the population and motorized vehicles. Increasing population and vehicles,

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the transhumance of rural inhabitants to metropolitan cities looking for superior opportunities are the elemental reason for the traffic jam. Traffic Congestion may be categorized into two types, i.e. recurring type, which is primarily takes place due to capacity and behavioural issues, or non-recurring type, which is because of accidents, construction, or emergencies. The impacts of recurring and non-recurring congestion, which have different sources yet, are identical. A traffic bottleneck adds to the inconvenience, causing passenger uncertainty, resulting in personage tension and potentially dangerous transportation conditions. The valuable working hours of road users getting wasted on the road, this secondarily adversely influenced the general economy. Traffic congestion not only affects human beings, but also elevates pollution. One of the best methods to reduce traffic congestion is the introduction of a mass transportation system in the urban road areas to counteract the congestion activities in the heterogeneous traffic conditions. A Comprehensive Traffic and Transportation Plan for Bengaluru (CTTP) was developed in 2011 regarding Travel Demand and Transport Mode Split Forecast in Bangalore as mentioned in table 1.

The common way to determine the impact of public transport (PT) on traffic congestion is to contrast congestion measures in a scenario ‘with PT’ and ‘without PT’. Hence, it's necessary to know how traffic congestion is defined and the way to live traffic jams, particularly in mixed traffic conditions.

Table 1: Travel Demand and Transport Mode Split Forecast in Bangalore (CTTP)

	Without Metro rail – 2025		**With Metro rail – 2025**	
Mode	**Daily Trips**	**Modal Share (%)**	**Daily Trips**	**Modal Share (%)**
Car	778,159	7	603,081	5.4
Two-Wheeler	3,363,559	30.3	2,916,718	26.3
Auto Rickshaws	1,449,958	13.1	798,040	7.2
Public Transport	5,515,380	49.7	6,789,218	61.1
Total	11,107,056	100	11,107,057	100

Source: Comprehensive Traffic and Transportation Plan for Bengaluru (CTTP),2011

MRTS is an elevated/underground urban railway system which facilitates large commuters to travel any part of the city within short duration. The large capacities of such systems make them potentially more efficient in terms of cost and luxury journey than the other automobile transportation. Furthermore, it aids in the decongestion of congested highway routes and provides more environmentally friendly mass transit options. This research was aimed to analyze the impacts of Bangalore Metro Rail (BMR) in reducing the traffic congestion in the selected urban road network when without and with BMR operation in the city. Congestion indices have been evaluated to examine the operational efficiency of the selected road network. Travel time reliability measures play an important role in helping travelers plan their trips efficiently and choose the best routes.

1.1 Study Area

One of the significant and the first step of the research work is the selection of the study area. The study area's location determines the research activities that must be carried out in light of the existing transportation structure, traffic behaviour, and traveller information. The survey was carried out on one of the traffic corridor of Bangalore city known as ‘kanakapura Road’ during January 2016, September 2018 and March 2021. It is access controlled four line divided road passing through the residential localities, educational area, recreation and shopping areas. The study route located in the south part of Bangalore urban area (Kanakapura Road) Karnataka State, India as well Bangalore south is the height Population Density and second largest Employment Density per sq.km in the Bangalore city (WSA Analysis). The road

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stretch (6.29Km) which exists along with BMR phase 2 alignments, Yelachenahalli (YELC) to Silk Institute (SILK) has been taken as the study route for the evaluation of travel time reliability.

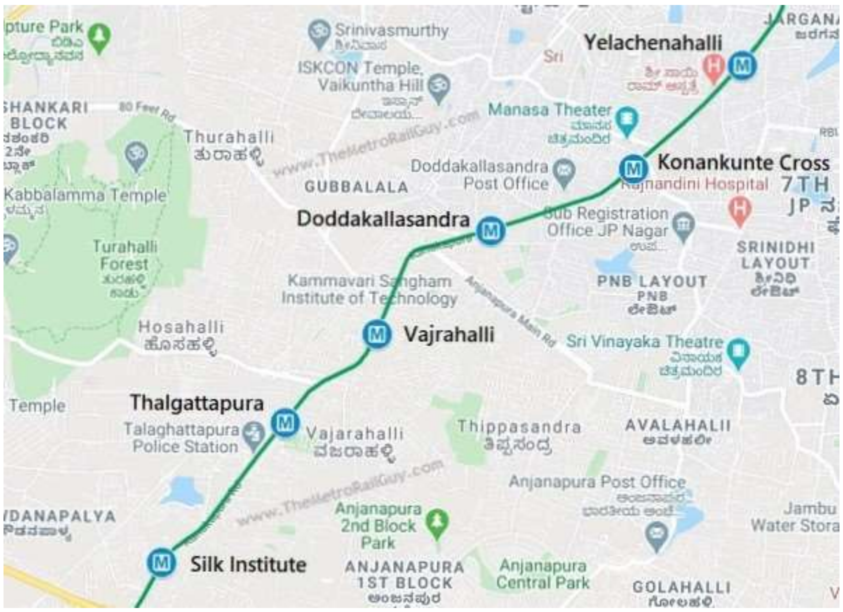

Figure 1: Map Showing Study stretch

II. TRAVEL TIME RELIABILITY

Travel time reliability is important to a variety of transportation users, including drivers, transit riders, freight shippers, and even air travelers. Reliability is important to both personal and business travelers since it helps them to make better use of their own time. Because users of transportation systems placed such a premium on travel time consistency, transportation planners and decision-makers view it as a key performance indicator and a way to improve the current structure's management. The travel time index, 95th percentile value, The Buffer time, Buffer Time Index, and Planning Time Index are all commonly used travel time reliability indicators.

2.1 Measuring Travel Time Reliability

The way traveling time fluctuate over time defines reliability; frequency distributions can be used to evaluate how much variability there is. Calculating the average Travel Time (TT) and the size of the "buffer" – the additional time needed by travelers to ensure a high rate of on-time arrival –After that, it assists us in developing a range of reliability metrics. The Buffer Index, Planning Time, and Planning Time Index are examples of these metrics. They're all supported and have the same underlying distribution of TT, but they describe dependability differently:

• *Travel Time Index (TTI):* It represents the average additional time required during peak times as compared to times of light traffic.

$$TTI = \frac{\text{Mean Travel time}}{\text{Off peak travel time}}$$

Example: Suppose 1.25 would be the TTI. This value indicates that your travel time will take 25% longer than if there is no congestion.

• *Buffer Index (BTI):* It denotes the additional time (or time cushion) that travelers must factor into their average travel time while planning excursions in order to arrive on time.

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$$Buffer\ Time\ Index = \frac{(95th\ percentile\ TT\ -\ Mean\ TT)}{Mean\ TT}$$

• *Planning Time Index (PTI):* It represents the amount of overall time a traveler should allow in order to arrive on time. The buffer index depicts the additional travel time required, whereas the planning time index depicts the total TT required.

$$PTI = \frac{95th\ percentile\ TT}{Off\ peak\ TT}$$

2.2 Manual Test Vehicle Techniques

Data was collected utilizing active test vehicles and a variety of instrumentation, including a manual (clipboard and stopwatch), an electronic distance measuring instrument (DMI), and a global positioning system (GPS) receiver. It entails the use of a data collection vehicle in which an observer collects total travel time at predetermined checkpoints along a route. For each segment along the survey route, this data was transformed to TT, speed, and delay.

III. DATA COLLECTION AND ANALYSIS

Preliminary surveys were conducted to gather essential information on roadway characteristics—including pavement condition, carriageway width, number of lanes, shoulder condition, and geometric features—across three temporal scenarios: before the introduction of the Bangalore Metro Rail (January 2016), during BMR construction (September 2018), and after the BMR became operational (March 2021).

Subsequently, detailed traffic surveys were undertaken to collect travel time reliability data along the selected corridor under typical weekday conditions. Data were obtained for one full week in both directions for each of the three conditions: *without metro rail facilities*, *during metro construction*, and *after metro operations commenced*. Travel time observations were recorded using the Manual Test Vehicle Technique during morning peak hours (07:00–10:00), evening peak hours (17:00–20:00), and off-peak periods to capture a comprehensive range of traffic flow states.

For analytical purposes, all motorized vehicles were categorized into five classes: Bus/Truck, Light Commercial Vehicle (LCV), Car, Two-Wheeler, and Three-Wheeler. The modal share distribution for the study corridor is illustrated in Figure 3.1.

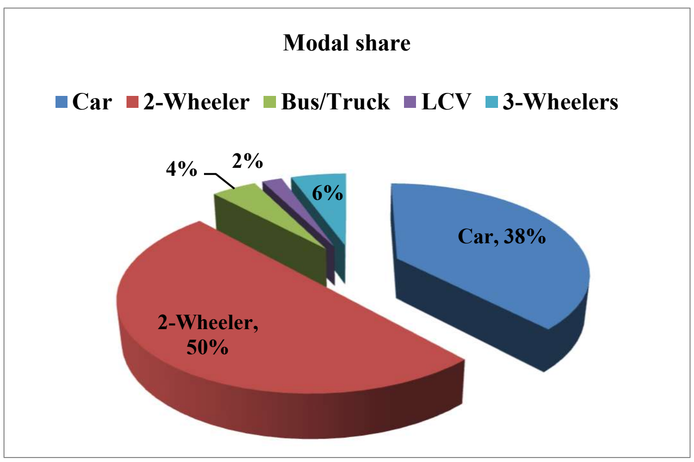
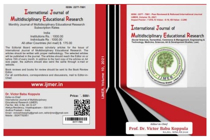


Figure 3.1: Existing model share in study route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Roadway performance is by its very nature consistent and repetitious, as well as very varied and unpredictable. It is consistent and predictable in that peak usage periods occur on a regular basis and can be predicted with a high degree of accuracy. (Most towns are familiar with the scale and timing of “rush hour.”) At the same time, it is highly variable and unpredictable, in that uncommon events such as accidents can drastically alter the performance of the roadway on any given day, affecting both travel speeds and throughput volumes.

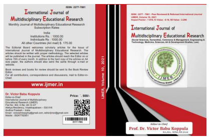
These big performance swings are felt by the traveling public, and their expectation or dread of unstable traffic conditions influences both their perception of roadway performance and the method they prefer to travel. If a road is known to have very fluctuating traffic conditions, for example, a traveller using that road to catch an airplane habitually leaves a lot of “extra” time to get to the airport. In other words, the "reliability" of this traveller's journey is precisely proportional to the route's performance variability.

With this discussion in mind, from a practical standpoint, TTRs are frequently described by how travel times change over time (e.g., hour-to-hour, day-to-day). Table 3.1 typifies this experience with data from study stretch Yelchenahalli(YELC) to Silk Institute(SILK) and Silk Institute(SILK) to Yelchenahalli(YELC) during one week on weekdays from 6:00 a.m. to 9:00 p.m. in various scenarios, such as without metro rail, during metro rail construction, and with metro rail operations (opens to public).

Table 3.1: Travel time index for different conditions

	TRAVEL INDEX FOR YELCH-SILK						TRAVEL INDEX FOR SILK - YELCH					
	WITHOUT BMR		DURING CONSTRUCTION		WITH BMR		WITHOUT BMR		DURING CONSTRUCTION		WITH BMR	
TIME	**TTI**	**PTI**	**TTI**	**PTI**	**TTI**	**PTI**	**TTI**	**PTI**	**TTI**	**PTI**	**TTI**	**PTI**
6-7.	1.285	1.312	1.295	1.362	1.089	1.301	1.231	1.341	1.21	1.401	1.012	1.244
7-8.	1.395	1.441	1.512	1.854	1.192	1.426	1.421	1.674	1.399	1.592	1.201	1.345
8-9.	1.451	1.698	1.551	1.911	1.265	1.4699	1.484	1.744	1.598	1.943	1.224	1.438
9-10.	1.425	1.661	1.52	1.901	1.263	1.429	1.477	1.711	1.412	1.824	1.211	1.411
10-11.	1.403	1.524	1.304	1.545	1.129	1.351	1.362	1.615	1.321	1.678	1.185	1.345
11-12.	1.345	1.498	1.291	1.385	1.062	1.3201	1.3	1.508	1.304	1.497	1.11	1.331
12-13.	1.311	1.44	1.29	1.391	1.059	1.312	1.343	1.425	1.297	1.412	1.08	1.297
13-14.	1.281	1.342	1.289	1.384	1.101	1.3	1.208	1.294	1.27	1.33	1.056	1.261
14-15.	1.282	1.321	1.212	1.395	1.039	1.3099	1.311	1.378	1.284	1.39	1.102	1.26
15-16.	1.301	1.378	1.288	1.375	1.11	1.311	1.387	1.421	1.291	1.408	1.099	1.298
16-17	1.325	1.424	1.314	1.652	1.099	1.324	1.411	1.498	1.395	1.445	1.154	1.356
17-18.	1.367	1.587	1.41	1.899	1.19	1.339	1.432	1.512	1.451	1.61	1.211	1.407
18-19.	1.415	1.674	1.599	1.924	1.221	1.4706	1.448	1.634	1.541	1.91	1.245	1.44
19-20.	1.46	1.724	1.609	1.965	1.249	1.456	1.461	1.645	1.572	1.925	1.207	1.434
20-21.	1.384	1.697	1.345	1.794	1.196	1.321	1.378	1.511	1.41	1.784	1.157	1.398
21-22.	1.312	1.541	1.254	1.455	1.03	1.309	1.301	1.398	1.29	1.41	1.087	1.297

Presently there are enormous changes reflecting after the implementation of Mass Rapid transit system in the Bangalore city when compared to previous conditions (without Metro rail) that has been clearly noticed in the below figures 3.2.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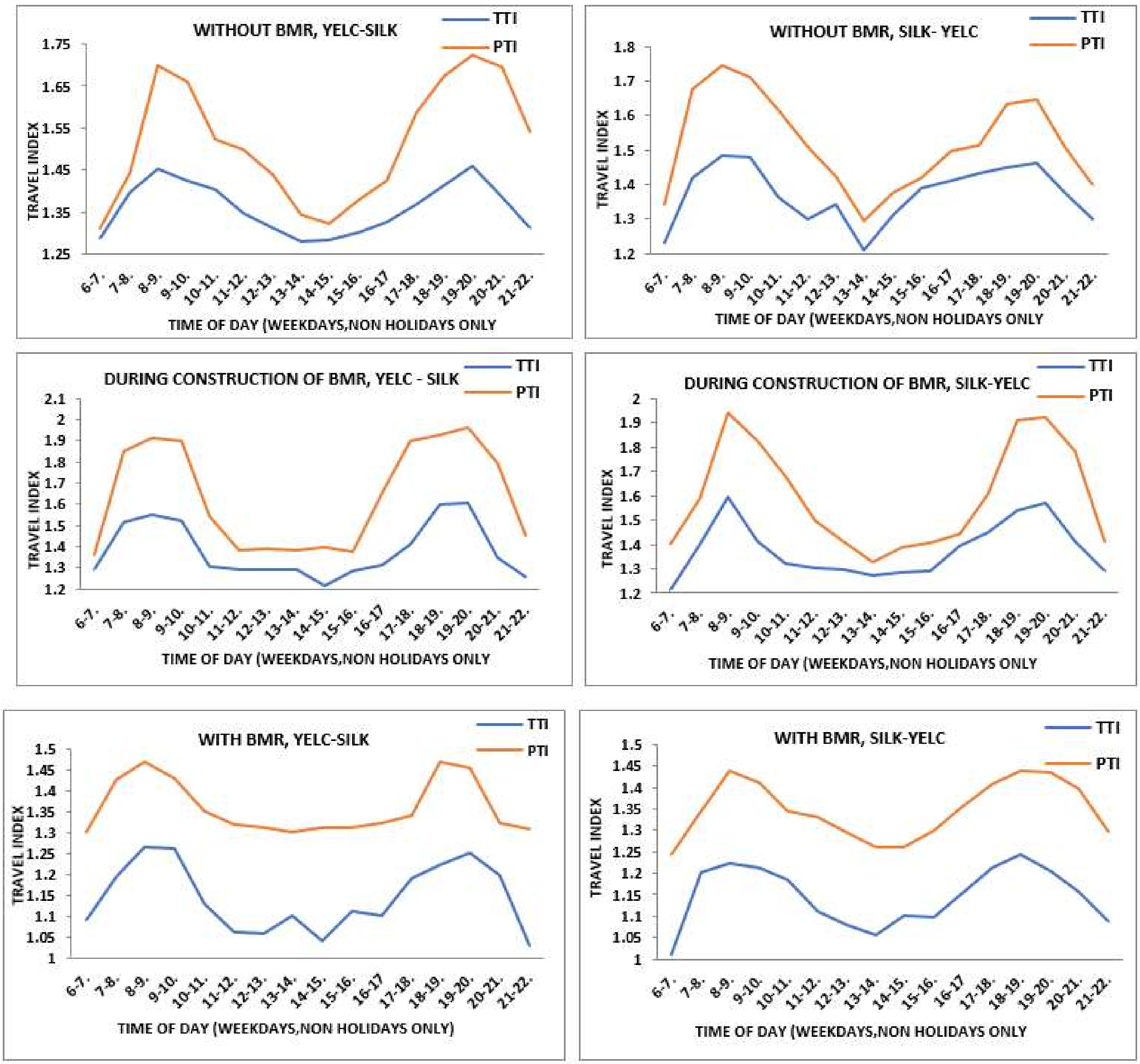
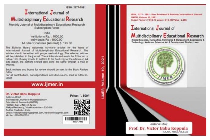


Figure 3.2: Reliability measures are related to average congestion measures

Figure 3.2 shows the variation of travel time index and panning time index with respect to timings variation of a day for different conditions. Earlier when without metro rail operation the maximum TTI and PTI were 1.48 and 1.74 respectively, during the construction of Metro rail it is increased to 1.60 and 1.94 and finally the maximum TTI and PTI are decreased to 1.26 and 1.47 respectively, after the Metro rail opens to public.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The Average Travel Time Index, Buffer Time Index and Planning Time Index for two directions of study route are tabulated in table 3.2 and figure 3.3 in that BTI varies from 15.629 to 22.03 depending on the existence of mass rapid transit system. The buffer index represents the extra buffer time (or time cushion) that the majority travelers add to their average TT when planning trips to make sure on-time arrival. This additional time is included to accommodate for any delays that may occur.

The buffer index is expressed as a percentage, and when reliability declines, its value rises. Buffer index of 40%, for example, suggests that for a 20-minute average TT, a traveler should budget an additional 8 minutes (20 minutes x 40% = 8 minutes) to ensure on-time arrival the majority of the time. The extra 8 minutes is referred to as the buffer time in this scenario.

A 95th percentile travel time is used to reflect a near-worst case TT when calculating the buffer index. It represents the extra time a traveler should allow to be on time for 95% of all trips, whether stated as a percentage or in minutes. A simple illustration is that a commuter or driver who utilizes a 95% dependability indicator would only be late once a month on weekdays.

Table 3.2: Congestion indices for different condition

CONDITIONS	DIRECTION	TTI	BTI	PTI
WITHOUT BMR	**YEL-SILK**	1.464	17.772	1.725
	SILK -YEL	1.484	17.533	1.745
DURING BMR CONSTRUCTION	**YEL-SILK**	1.61	22.034	1.964
	SILK -YEL	1.599	21.534	1.943
WITH BMR	**YEL-SILK**	1.266	16.195	1.471
	SILK -YEL	1.24	15.629	1.434

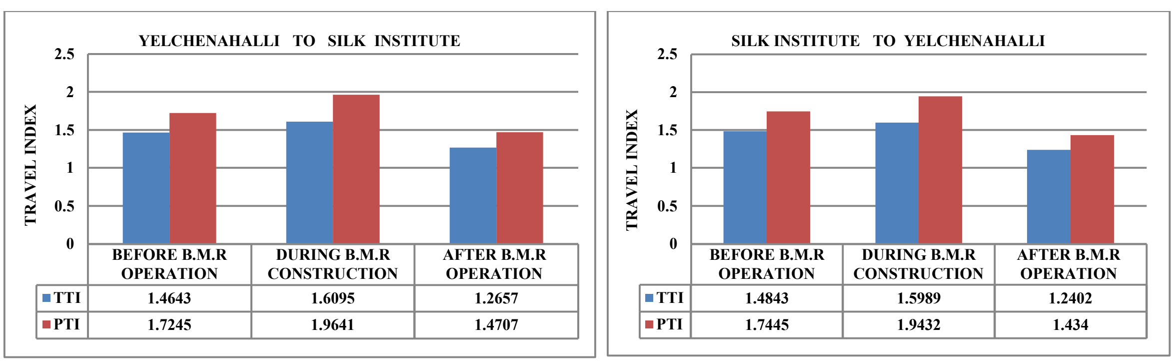

Figure 3.3: Average TTI and PTI for study route

IV. RESULTS AND DISCUSSION

The analysis focused on three key reliability indicators: the Travel Time Index (TTI), Buffer Time Index (BTI), and Planning Time Index (PTI). The results clearly demonstrate that metro operations have significantly improved both average travel times and travel-time variability in both directions of the study corridor.

4.1 Travel Time Index (TTI)

- In the Yelachenahalli to Silk Institute direction, the TTI under *pre-metro* conditions (1.464) increased during *BMR construction* to 1.609 due to recurrent and non-recurrent congestion imposed by construction-related bottlenecks. After the commissioning of the metro, the TTI decreased markedly to 1.265, indicating a substantial reduction in both travel time and the severity of congestion as typified in figure 3.2.

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- A similar trend was observed in the reverse direction. The TTI increased from 1.484 (without metro) to 1.598 (during construction) and then dropped to 1.240 after BMR became operational. These reductions reflect the shift in travel demand from private modes to metro rail and the resulting decongestion of the arterial corridor as typified in figure 3.2.

4.2 Buffer Time Index (BTI)

- BTI values also exhibit notable improvements after the commencement of metro operations. In the Yelachenahalli to Silk Institute direction, BTI increased from 17.77% to 22.03% during metro construction due to unpredictable delays caused by lane closures, diversions, and work zones. With BMR fully operational, BTI declined to 16.19%, indicating lower variability and more predictable travel conditions as shown in table 3.2.
- For the Silk Institute to Yelachenahalli direction, BTI increased from 17.53% (without metro) to 21.53% (construction phase) but subsequently dropped to 15.62% after metro opening. This improvement underscores the enhanced reliability resulting from decreased non-recurring congestion and smoother traffic flow as shown in table 3.2.

4.3 Planning Time Index (PTI)

- The PTI values reinforce the trends observed in TTI and BTI. In the Yelachenahalli to Silk Institute direction, PTI increased from 1.72 (without metro) to 1.96 during construction due to increased uncertainty in travel time. After metro commissioning, PTI fell sharply to 1.47, signifying a smoother and more reliable travel environment and it is symbolized in figure 3.2 & 3.3.
- Similarly, the Silk Institute to Yelachenahalli direction showed an increase in PTI from 1.74 to 1.94 during construction, followed by a significant reduction to 1.43 after the metro became operational. This illustrates the beneficial impact of public transport systems in reducing excessive buffer requirements for trip planning and it is symbolized in figure 3.2 & 3.3.

4.4 Broader Impacts on Congestion and User Experience

- Improved travel-time reliability translates directly into reduced congestion, thereby lowering fuel consumption, travel delays, and vehicular emissions. These improvements carry substantial societal benefits, including enhanced commuter health. The study highlights several congestion-related health symptoms—such as respiratory complications, neuralgia, psychological stress, fatigue, reduced visibility, dehydration, and dust-related allergies—that are mitigated when congestion levels decline.
- Furthermore, in logistics and freight movement, unreliable travel times reduce the efficiency benefits of "just-in-time" operations. Variability in travel time forces operators to allocate higher buffers, increasing operational costs. Hence, the observed improvements in TTR due to BMR have direct implications for freight reliability and supply-chain efficiency along the study corridor.

4.5 Interpretation and Implications

The overall findings demonstrate that metro operations reduce both mean travel times and variability, generating a more stable and predictable traffic environment. In heterogeneous traffic systems such as Bangalore, where lane discipline is weak and modal composition is diverse, these improvements are particularly significant. The results affirm that high-capacity public transport systems play a critical role in enhancing network resilience and improving urban mobility performance.

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V. CONCLUSION

Based on present study, the impact of Bangalore Metro rail in reducing the traffic congestion was studied in terms of the estimation of the travel time reliability in the selected road stretch. Based on the results and analyses of this research, the subsequent conclusions are drawn:

- This study quantified the influence of the Bangalore Metro Rail (BMR) on travel time reliability along a heterogeneous urban corridor, using TTI, BTI and PTI as key performance indicators. The results demonstrate a substantial improvement in reliability after the commissioning of the metro, compared with traffic conditions both before and during its construction. These improvements reflect not only reduced average travel times but also decreased variability arising from non-recurring congestion sources such as incidents, work zones, weather disruptions and other traffic-influencing events. Enhancing reliability therefore delivers a dual benefit—mitigating travel-time fluctuations while simultaneously reducing overall congestion delay.
- The findings further highlight the complexity of mixed-traffic systems in rapidly developing cities like Bangalore, where diverse vehicle classes and weak lane discipline complicate traffic behavior. The operationalization of the metro has altered travel patterns in the corridor, contributing positively to mobility efficiency, environmental quality, public health, and road safety. These broader benefits underscore the importance of high-capacity public transport systems in shaping sustainable urban mobility.
- Although congestion cannot be fully eliminated due to continuous growth in population and vehicle ownership—especially two-wheelers and passenger cars—it can be significantly reduced through integrated strategies. Effective metro operations, improved last-mile connectivity, stringent traffic management, decentralized urban development, regulated roadside activities, and provision of adequate parking infrastructure are essential measures for further enhancing travel time reliability on urban corridors.
- Future research may extend this work using advanced reliability models, microsimulation frameworks, or multi-corridor comparisons to better characterize the long-term system-wide impacts of metro rail expansion in heterogeneous traffic environments.

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