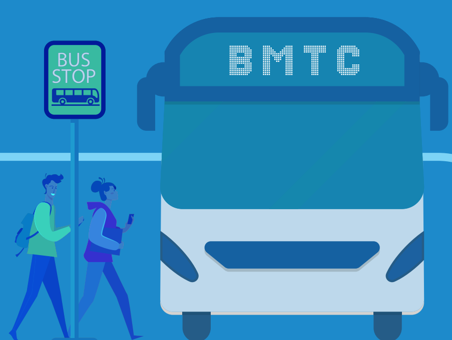
CiSTUP RESEARCH FOR

IMPROVING BMTC PLANNING AND OPERATIONS



INDIAN INSTITUTE OF SCIENCE
भारतीय विज्ञान संस्थान

CiSTUP
Centre for infrastructure, Sustainable Transportation and Urban Planning

A BOOKLET OF ABSTRACTS

FOREWORD

Sathyavathi G.
Managing Director
Bengaluru Metropolitan Transport Corporation (BMTC)

Bengaluru Metropolitan Transport Corporation (BMTC) remains at the forefront of providing efficient and sustainable public transportation solutions to the residents of Bengaluru. Along with Bengaluru Metro Rail Corporation Limited (BMRCL), we are committed to providing reliable mass transport, which is the only viable solution for reducing congestion in the city. To achieve this goal, we recognize the importance of embracing cutting-edge research and innovative solutions that can help us better serve our passengers and the city.

It is with great pleasure that I introduce this research booklet centred on BMTC planning and operations, developed by Centre for infrastructure, Sustainable Transportation and Urban Planning (CiSTUP) at the prestigious Indian Institute of Science (IISc). This report is a testament to BMTC's dedication to fostering academic collaboration and leveraging the knowledge of the IISc experts.

As we continue with our vision and journey of making BMTC sustainable, people-centred and choice mode of travel for everyone, we look forward to having our dedicated BMTC team working hand-in-hand with the researchers and experts at IISc and turning the findings of the research projects in this booklet into implementable solutions. Together, we can make Bengaluru's public transportation system a shining example for cities around the world.

Thank you for your continued support and trust in BMTC.

Warm Regards!

FOREWORD

Abdul Rawoof Pinjari
Professor and Chair, CiSTUP
Indian Institute of Science

Safe, efficient, affordable, and convenient public bus transportation systems are essential for sustainable mobility in cities. Buses are the most common public transportation mode in cities with mass transit systems. Buses can provide mass transit capacity that is cost-effective for operators and affordable for travellers. Buses are also among the most flexible modes of mass transport, for the services can be modified relatively easily to suit emerging needs. Therefore, public bus transit agencies in most cities continuously strive to enhance their services – within the many constraints they face – through a variety of operational and strategic improvements. *Namma* Bengaluru's BMTC is a leading example among such public transit agencies, with a large bus fleet operating over an extensive network.

Due to the above reasons, faculty and researchers at CiSTUP, IISc, have made it a priority to take up research projects relevant to bus transportation systems – with a focus on BMTC's planning and operations. These include optimization of bus routes and schedules, evaluation of bus priority lanes, planning electric bus fleet operations, first- and last-mile service improvements, and safety of bus driving. All projects involve support and collaboration with BMTC, in the form of data, inputs from field experience, etc.

This workshop brings together experts from IISc and officials of BMTC to discuss the findings from CiSTUP's research projects on the above-mentioned topics. In addition, the workshop aims to discuss pathways toward turning the research into implementable solutions and decision-support tools for BMTC.

It gives me a great sense of satisfaction that CiSTUP and BMTC are working together. I thank BMTC's officials for this collaboration. We at CiSTUP look forward to further strengthening the collaborations to bring together the expertise of IISc and the experience of BMTC toward providing sustainable public transportation solutions to Bengaluru.

Warm Regards!

The Bengaluru Metropolitan Transport Corporation (BMTC) is the sole public bus transport provider for Bengaluru, serving urban, sub-urban and rural areas. BMTC is committed to provide quality, safe, reliable, clean and affordable travel. The testimony of its success lies in increasing passenger trips everyday by a wide range of customer base. In an effort to modernize its services for commuter comfort, BMTC strives to strengthen information systems and improve processes through introduction of intelligent technology solution, make capacity enhancement through infrastructure development, user-friendly interchange facilities, fleet upgradation and augmentation, apart from its core activities, which includes fare structuring, route network optimization, planning and monitoring. BMTC reaches far and wide, in every nook and corner of the city, making public transport an attractive travel choice for everyone.

OUR VISION

"Make BMTC sustainable, people-centered and choice mode of travel for everyone"

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OUR MISSION

1. Provide people-centered (quality, efficient, integrated and safe) services
2. Commuter responsive service planning and promotion
3. Optimize resources and build capacity
4. Adopt environment-friendly and sustainable practices
5. Strengthen commuter feedback mechanism
6. Modernize and maintain zero breakdown fleet
7. Evolve effective mechanism to monitor service performance
8. Conduct safety training, performance audits and awareness for stakeholders
9. Increase commercial revenue through monetizing land, buildings & buses
10. Increase efficiency in operations and administration
11. Ensure inter-agency coordination and multi-modal integration
12. Formulate and enforce police measures for sustainability of the service provision
13. Implement Intelligent Transport System to improve the quality of service
14. Extend travel concession to the weaker sections of the society
15. Act as an agent for cultural synthesis and national integration
16. Promote research on urban transport

The Centre for infrastructure, Sustainable Transportation and Urban Planning (CiSTUP) of Indian Institute of Science (IISc) was established in the year 2009 during the centenary celebrations of IISc, with base funding from the Karnataka State Government and inputs from visionary leaders at IISc and the Government.

VISION AND MISSION

Our vision is to become a preeminent centre for impactful and multidisciplinary research, education, and technology transfer in the following areas:

- Multimodal transportation science, systems engineering, and technology;
- Sustainable transportation systems and urban planning; and
- Infrastructure systems, as it relates to transportation.

Our mission is to provide thought leadership for planning, operation, design, management, and policy of transportation systems in India through the following activities:

- Creation of scientific knowledge (through high impact publications), decision-support tools, and technology solutions;
- Education of next generation transportation leaders;
- Training of transportation professionals and capacity building for decision-makers; and
- Collaboration with government, industry, and other academic institutions.

A MIX OF FUNDAMENTAL AND APPLIED RESEARCH

In addition to fundamental research in transportation science that will bear fruit for practice in the long-term, a good part of the Centre's activity is applied research. Several projects of CiSTUP are inspired from current and emerging mobility problems faced by cities; more specifically, to guide public transit agencies, metropolitan planning and urban development organizations; and state- and national-level transportation Departments. Many such organizations of the Government of Karnataka are stakeholders of the Centre. Equally important are CiSTUP's interactions with leading industry and technology companies who are playing an increasing role in the areas of smart mobility and intelligent transport systems for smart cities. The combination of academic strength and interactions with government and industry makes the Centre ideally positioned for translational research in transportation. Notable in this regard is that the faculty and researchers of CiSTUP have memberships and leadership roles in academic, government and professional committees – locally, nationally, and internationally.

CiSTUP WITHIN IISc

Within IISc, CiSTUP is a part of the Interdisciplinary Research Division, which also houses a variety of other interdisciplinary centres focusing on cyber physical systems, management sciences, public policy, economics, energy, water, data science, nanoscale systems, and bio-engineering. CiSTUP serves as a hub for faculty and students from various disciplines across the campus to work together on research problems relevant to mobility and transportation. The Centre also supports students and faculty working on research in areas relevant to CiSTUP. Further, faculty and researchers of CiSTUP have strong academic and/or practical backgrounds from a variety of disciplines. This helps us bring to bear a multitude of perspectives to solving transportation problems.

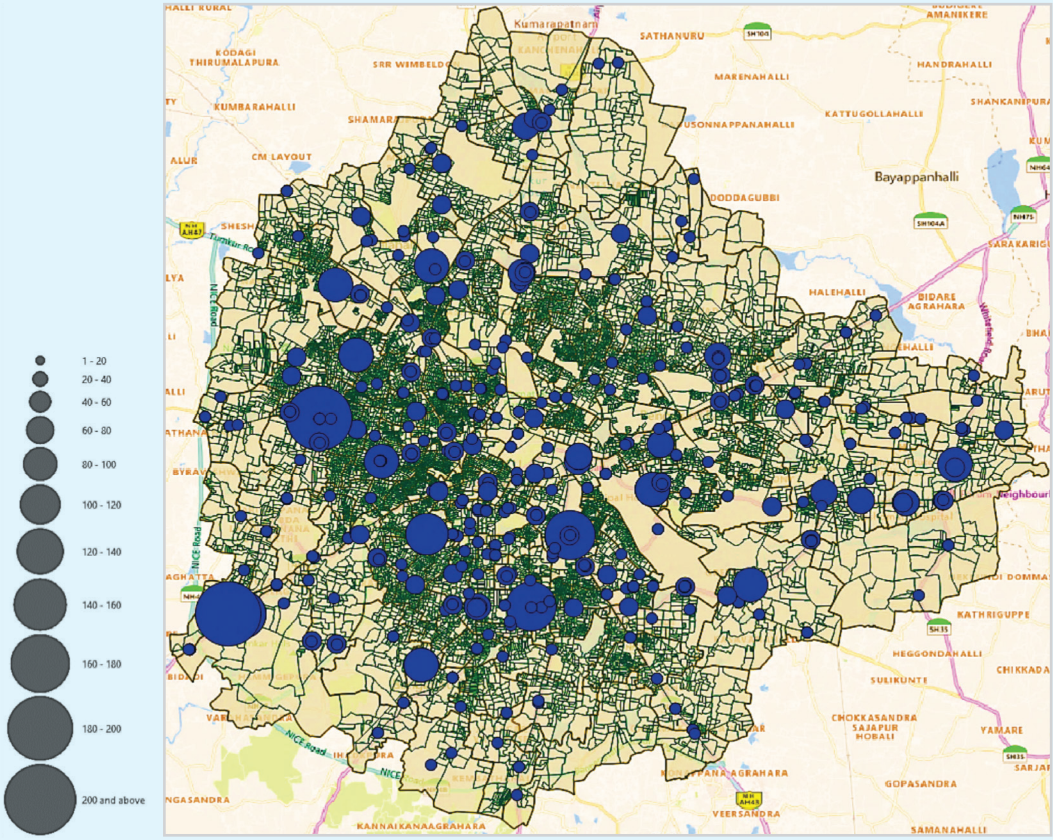
ARTICLE ONE

PROF. ABDUL RAWOOF PINJARI

RIDERSHIP AND REVENUE FORECASTING MODELS FOR BUS TRANSIT AGENCIES: APPLICATION TO BMTC RIDERSHIP

POTENTIAL BENEFITS TO BMTC

BMTC can use the proposed method and models as decision-support tools to forecast changes in ridership and passenger kilometres (and revenue) due to changes in route structure, addition or deletion of routes, changes in service frequency, changes in spatial distribution of land-use, etc.

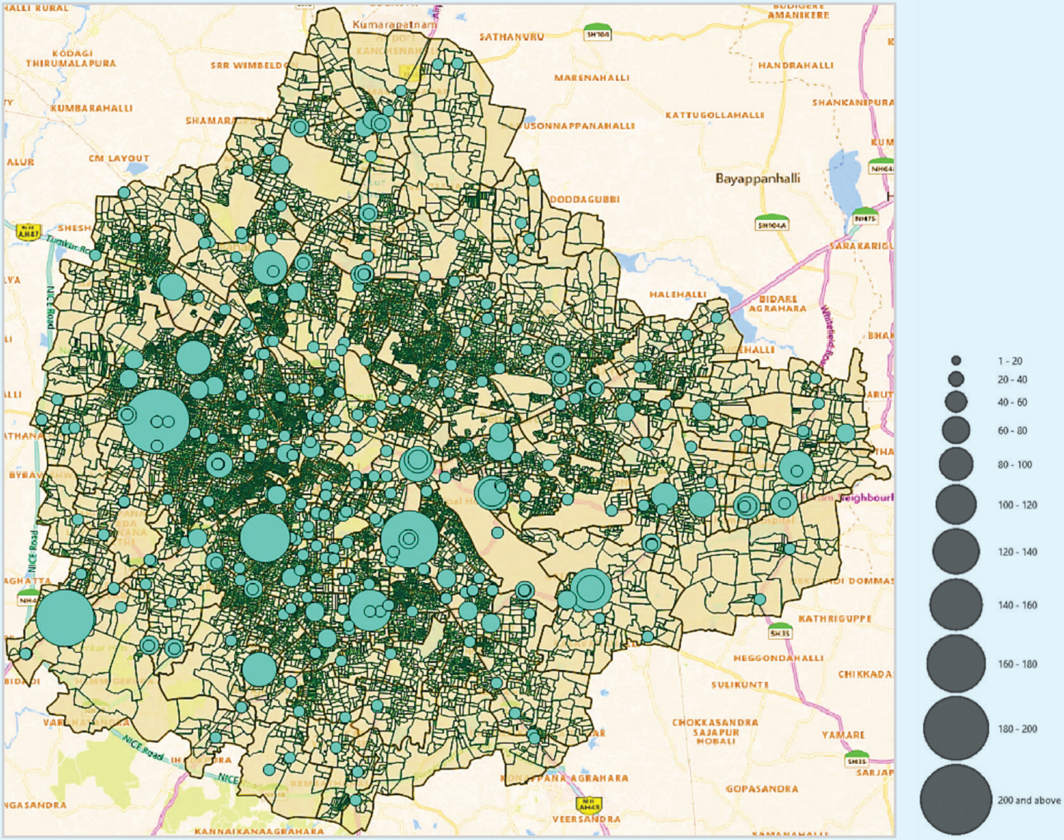


Observed boardings at AM peak at a sample of bus stops in Bengaluru

BRIEF PROJECT SUMMARY

Bus transit agencies strive to improve their services through a variety of strategic and operational improvements – such as changes to their route structure, increase in service frequency, changes to schedules and service network, pricing, and enhancing connectivity to other modes (e.g., metro). External factors – spatial distribution of population and urban activity – also influence ridership. Transit agencies will benefit from forecasting models that can be used to quantify the changes in ridership and revenue due to changes in service characteristics and external factors. In this study, we developed statistical models for forecasting bus ridership (at stop level and route level) and passenger kilometres (at route level) using bus ticket sales data from BMTC. In doing so, the study addresses the following substantive and methodological issues associated with modelling transit demand: (a) relating spatially-aggregate demand data to disaggregate, stop-level catchment area characteristics, (b) the influence of inter-route interactions such as competition and complementarity for transit riders within the bus network and with other transit networks (e.g., Metro), (c) the accessibility provided by the transit network to different locations in the city, and (d) demand-supply interactions.

More information is at the publications, scan the QR code.



Model Predictions

KEY FINDING

- On medium- to high-frequency routes, BMTC will gain more ridership and passenger kilometres by decreasing headway variance (i.e., increase service reliability) than increasing service frequency.
- Bus routes with high overlap with metro lines lose riders to metro. However, feeder services and routes with some overlap with metro lines can help both BMTC and metro. Our models can be used to determine the extent of beneficial overlap for different levels of demand and supply.

FUTURE RESEARCH

- Enhance the method to forecast bus ridership changes due to improvements in last-mile connectivity, changes in pricing, metro expansion, changes in service and pricing of other modes.
- Develop a software tool to forecast route-level ridership and passenger kilometres for BMTC.

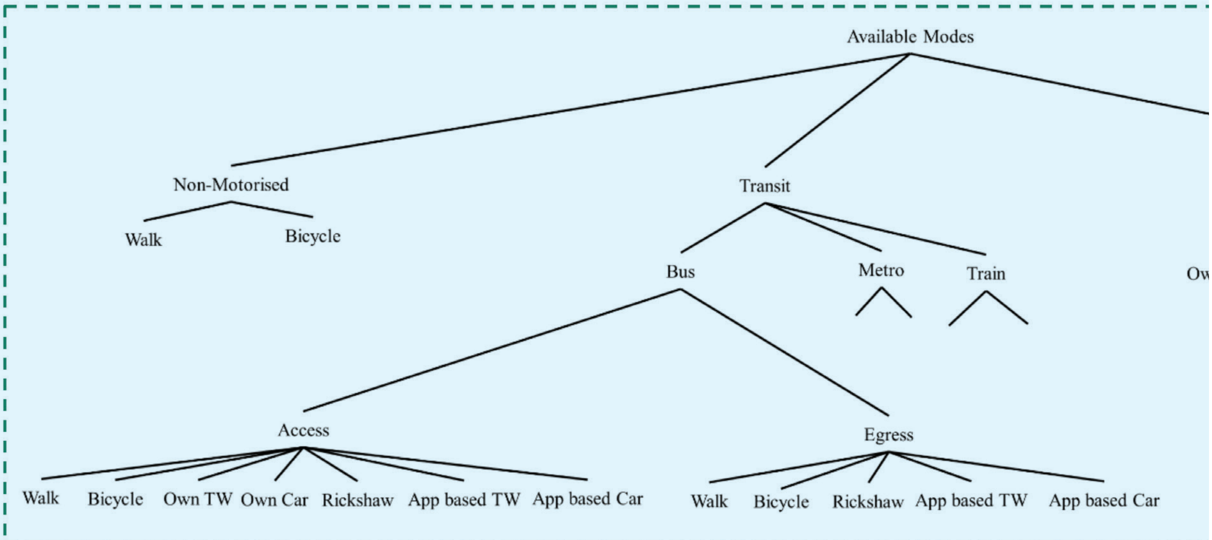
ARTICLE TWO

PROF. ABDUL RAWOOF PINJARI

MULTIMODAL MODE CHOICE BEHAVIOUR DATA, MODELLING AND ANALYSIS TO INCREASE TRANSIT MODE SHARE

POTENTIAL BENEFITS TO BMTC

The proposed models can be used to evaluate the benefits of different first- and last-mile connectivity strategies to enhance transit ridership. The findings can be used to enhance first- and last-mile connectivity in Bengaluru to enable multimodal travel (thereby increase transit ridership).



Econometric Multimodal Mode Choice Model

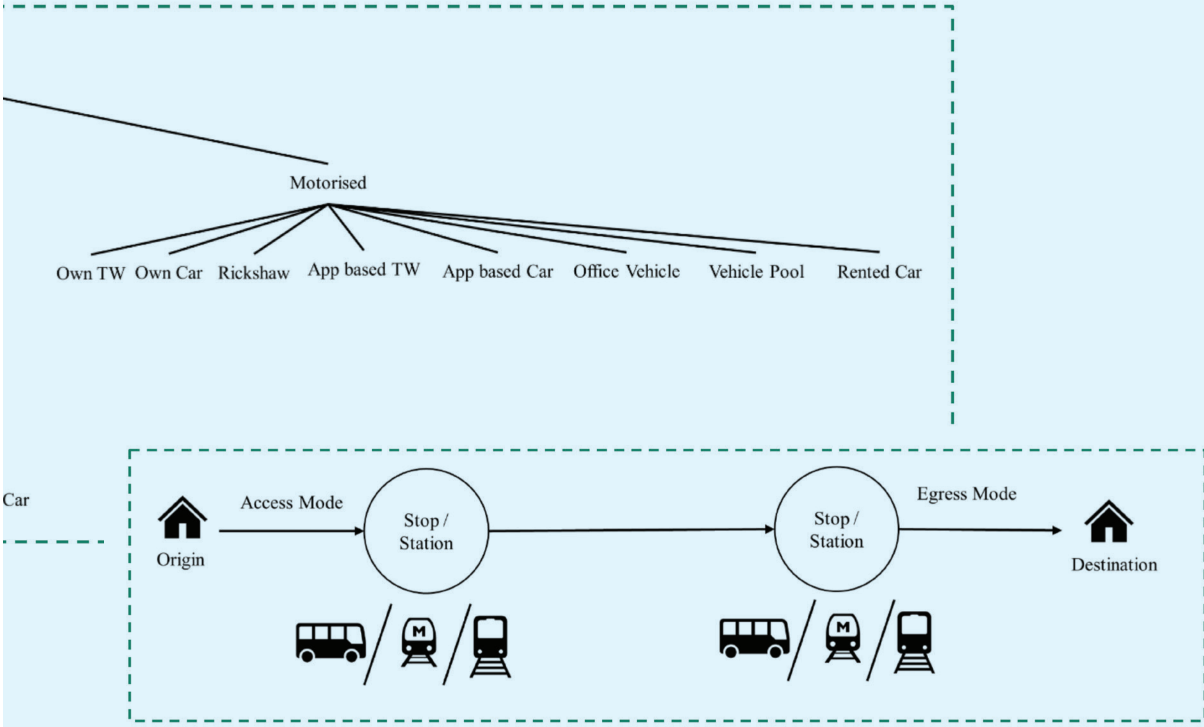
BRIEF PROJECT SUMMARY

Almost all public transit tips are multimodal in nature, with non-negligible first-mile and last-mile legs that involve non-transit modes, such as walk, cycle, auto-rickshaw, personal vehicles, and ride-hailing. Some transit trips may also involve multiple transit modes (e.g., bus+metro) along with non-transit first-/last-mile legs.

This makes it important to understand and quantify the influence of improvements in non-transit connectivity to transit stops/stations on travellers' choice of public transit. Doing so can help us understand the spatial and temporal extent of connectivity to transit stops/stations.

This study involved formulation and application of an econometric multimodal mode choice model to analyse the factors influencing commuters' mode choice in Bengaluru, with a focus on the influence of first- and last-mile connectivity. The model was calibrated using data from travel behaviour surveys in Bengaluru.

The survey data and the model simulations together provided insights on what actions can potentially help increase mode share of bus and metro transit systems in Bengaluru.



An illustration of multimodal transit travel

KEY FINDING

» Our survey data indicates that at least 30% of current metro travellers use bus (in combination w/ metro) on their trips. An additional 15% of metro travellers use other non-walking modes to reach metro stations. On the other hand, the vast majority (95%) of current bus travellers reach bus stops by walk.

» If bus and metro modes are made available to all surveyed individuals within distances of up to 1 km and 4 km, respectively, our simulations indicate that nearly 60% of them would choose transit (bus, bus+metro, or metro). Reducing travel costs by ride-hailing to transit stations would not help attract many transit riders. The key is in making transit stops/stations more accessible to travel origins and destinations.

FUTURE RESEARCH

» Embed the multimodal mode choice model in a city-scale travel demand analysis to forecast changes in transit mode shares of Bengaluru population due to enhanced connectivity to transit.

ARTICLE THREE

PROF. PUNIT RATHORE

EXAMINING THE EFFECTS OF 'ADAS' ON DRIVING BEHAVIOR UNDER INDIAN DRIVING CONDITIONS

POTENTIAL BENEFITS TO BMTC

The usefulness of ADAS or advanced driver warning systems under heterogeneous disordered traffic (HDT) conditions is still not well understood in scientific literature. Too many ADAS warnings can have detrimental effects on drivers' behavior, particularly when driving larger vehicles (like buses) under densely packed HDT conditions, like on Indian roads. This work will allow us to optimize ADAS for Indian drivers and traffic conditions, reducing driver fatigue and making the drivers more aware of their surroundings, thus improving the overall road safety of bus drivers. For BMTC, this will allow them to understand the best ADAS warnings and modalities for their bus drivers.

BRIEF PROJECT SUMMARY

A leading cause of traffic collisions is driver error, accounting for about 84% of all crashes. Apart from erroneous driving, there are other behavioral issues, such as not following lane discipline, suddenly accelerating/decelerating, driving too close to leading vehicles, and more; all of which are frequently encountered on Indian roads. An emerging solution (in the Indian market space) aimed at tackling such driver errors and behavioral issues is the Advanced Driver Assistance System (ADAS). Considering the advantages ADAS can provide in the Indian context, it is vital that at least Level-0 and Level-1 ADAS should be adopted and standardized in India as soon as possible. However, lack of knowledge/familiarity of ADAS among drivers, and other such limitations specific to Indian traffic conditions/drivers have not been fully explored in the literature. When considering ADAS and their usability in the Indian context, one needs to consider densely packed, congested, highly stochastic, and often loud traffic conditions. Therefore, in order to better understand the usability and effectiveness of ADAS on Indian roads and in Indian traffic conditions it is imperative to capture and analyze how drivers on Indian roads respond to different kinds of ADAS alerts.

This will be achieved by conducting and analyzing several driving-behavior-related experiments through realistic-looking simulation environments, using a high-fidelity heavy-vehicle simulator. To this end, multiple simulation environments and scenarios mimicking Indian traffic conditions have already been developed. Real bus drivers will be hired and brought in to drive the simulator. Drivers will be presented with different traffic conditions, such as with varying traffic densities, and lead vehicles; and their driving behavior (like accelerating, braking, gear-shifting, and lane-changing patterns), and physiological data will be captured. Drivers will also be exposed to different types of ADAS alerts, and the effect of these warnings on drivers' behavior will be observed. The experiments are designed to enable a deep understanding of the unique driving behavior of Indian drivers. The findings of this work will allow for the identification of ideal warning types, and optimal warning modalities, best suited for Indian traffic conditions. Thus, further improving road safety, and alleviating the effects of traffic collisions.

Illustration of an ADAS alert inside simulation environment

KEY FINDING

- » We hypothesize that raising multiple warnings simultaneously can overload drivers' senses.
- » We hypothesize that audio warnings are more likely to be detrimental in the Indian use case, because of the disordered nature of traffic. For instance, 'Blind Spot Warning' which are a common occurrence on Indian roads.
- » The design of experiments (DoE) has been finalized. For the first experiment, we will only focus on one ADAS warning type. We will observe drivers' behavior and physiology under different traffic densities and with different lead vehicles.
- » The project is ongoing.

FUTURE RESEARCH

We are planning to conduct the first experiment with over twice the number of drivers used in most scientific studies before. We plan to increase the number of drivers even more in the next experiment. Plus, we plan to conduct similar experiments in the real world, i.e., on Indian roads. The Indian use-case optimized ADAS generated as part of this work will empower organizations like BMTC, to choose the best ADAS systems for their use case. This would also help improve the safety of their drivers, passengers, and their busses, and reduce risk to other vehicles/pedestrians on the streets.

ARTICLE FOUR
PROF. PUNIT RATHORE

DEVELOPMENT OF AN INTEGRATED TRAFFIC AND HEAVY VEHICLE SIMULATOR [ITHVS] FOR DRIVER BEHAVIOR AND SAFETY RESEARCH IN INDIA

POTENTIAL BENEFITS TO BMTC

Simulators are recognized as effective tools for driver training around the globe. The proposed advanced Heavy Vehicle (HV) driving simulator can also be utilized for the same. Notably, features such as the realistic representation of Indian traffic conditions, seamless two-way interaction, and capability to design and test scenarios concerned with intelligent transport systems that most current HV driving simulators lack will offer unprecedented opportunities for realistic training for the BMTC drivers.

BRIEF PROJECT SUMMARY

India is facing an enormous challenge in road safety. Driving errors such as distracted driving, speeding, driving under the influence (for example, alcohol), inexperience, and fatigue are among the major factors contributing to road crashes involving heavy vehicles. The need of the hour is to reduce driver errors and thereby road crashes – a proactive approach. Understanding driver behavior in various scenarios such as low versus high-density traffic, safety-critical traffic situations, infrastructure changes, and in presence/absence of driver assistance systems can enable us to provide driver-specific feedback thereby enhancing traffic safety.

HVs and their drivers are often neglected when it comes to research and development even though they account for about 6% of the total fatalities in India. Therefore, this research aims to enhance the current understanding of HV driver behaviors in Indian traffic conditions using an HV driving simulator. Toward this aim, the specific objective of this project is to develop and integrate a heterogeneous traffic environment simulation tool with the HV simulator and improve trainee driver response in safety-critical scenarios.

A heterogeneous traffic simulation tool capable of mimicking the behavior of different vehicle classes, including cars, buses, motorbikes, and autorickshaws, and their interactions is being developed. This tool serves as the traffic simulation component. The developed heterogeneous traffic simulation tool has been integrated with the HV simulator. The integration process involves establishing the two-way interaction between the HV driven by the participant (character in the simulation hereon subject vehicle) and other vehicles in the simulated traffic environment, optimizing the action, i.e., driver's input through the physical component and reaction, i.e., subject vehicle behavior in the simulation, aiming at realistic visual quality of the simulation, optimizing the scene movement as per the subject vehicle behavior, etc. Simulator experiments have been designed to examine HV driver responses in safety-critical situations such as hard braking of lead vehicles, sudden cut-in of lead vehicles, merging and diverging, negotiating intersections, etc. A trainee assessment tool will be developed to assess the trainee based on his/her actions on the simulator in response to the traffic scene put up to them.

Integrated Traffic and Heavy Vehicle Simulator being driving by a driver

KEY FINDING

- Generating simulation environments is a time-consuming process.
- To ensure the usefulness and time-/cost-effectiveness of simulation systems, faster processes for simulation development need to be developed.
- We have developed (and are evaluating) one such process. The process utilizes available map data and a game engine to generate close-to-real-world static simulation environments.
- Using this method, city-sized environments can be replicated inside a simulator environment within hours.
- The work is ongoing.

FUTURE RESEARCH

We are improving our current method and developing new ones to further reduce the time and effort required to develop close-to-real-world Indian-ized traffic simulation environments. We are also exploring the use of deep learning methods to automate said simulation generation process. In the future, we plan to integrate our India-specific driving scenarios with an assessment system for the driver vis-a-vis the best practice.

ARTICLE FIVE

PROF. RAJESH SUNDARESAN

BUS PRIORITY LANE IN BENGALURU: A STUDY ON ITS EFFECTIVENESS AND DRIVER STRESS

POTENTIAL BENEFITS TO BMTC

The effectiveness of the bus priority lane for BMTC buses was quantified. The directions and segments where the priority lane most effective and least effective were identified. Driver stress during various peak durations were quantified. The outcomes can suggest appropriate corrective measures for the betterment of travel times and driver stress levels.

BRIEF PROJECT SUMMARY

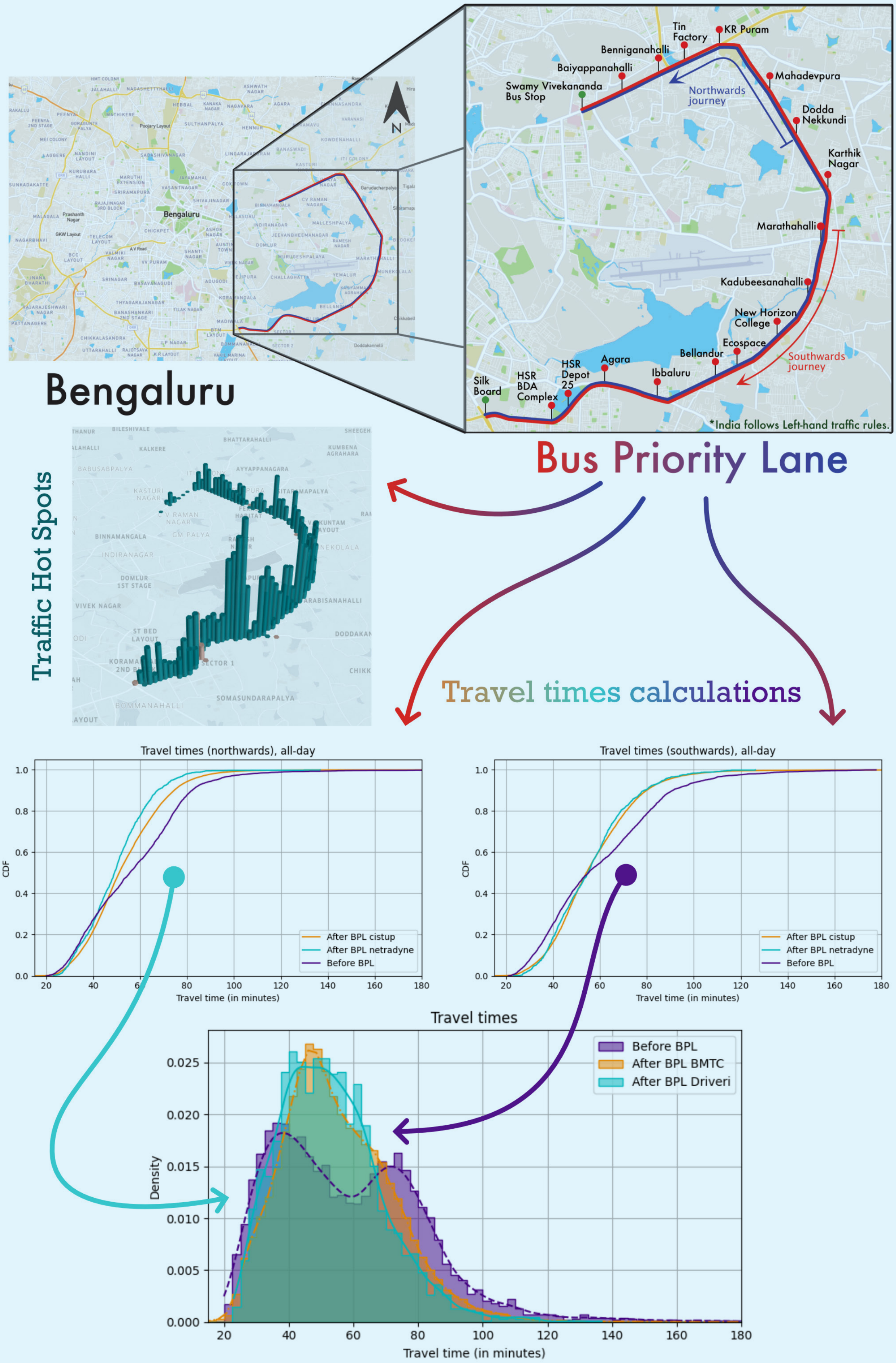
The project, done in partnership with BMTC and Netradyne Technology India Pvt. Ltd., studies the effectiveness of the bus priority lane (BPL) for public transport buses in the city of Bengaluru in India. We use the travel times on the BPL corridor as a measure of the effectiveness of the BPL. We find 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 com- puting 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. Par- titioning 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 correc- tive measures for the betterment of travel times and driv- er 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.

KEY FINDING

We find that there is a significant improvement in the traveltimes after the introduction of the BPL; for the worst 10% of the travel times, we find an improvement between 4% and 28%. Drivers are generally more stressed during the morning peak hours and during the southward trips on the BPL.

FUTURE RESEARCH

Scale up the experiment to study driver stress. Study effectiveness of driver feedback.



Travel Times on the BPL Corridor as a measure of the Effectiveness of the BPL

ARTICLE SIX

PROF. RAJESH SUNDARESAN

UNLOCKING DATA FOR PEOPLE-CENTRIC TRANSPORT-ATION

POTENTIAL BENEFITS TO BMTC

1. *The project provides a solution to the revenue sharing problem between the ride-hailing service providers and the bus agency in the context of first- and last-mile services.*

2. *The solution methodology can increase the effective market share and profit of the bus agency.*

3. *Also, the application of the model can reduce travel times due to the shift of travelers to public transit mode.*

BRIEF PROJECT SUMMARY

Problem statement: Propose a model to facilitate collaboration between the ride-hailing service providers (RSPs) and the bus agency for first- and last-mile services.

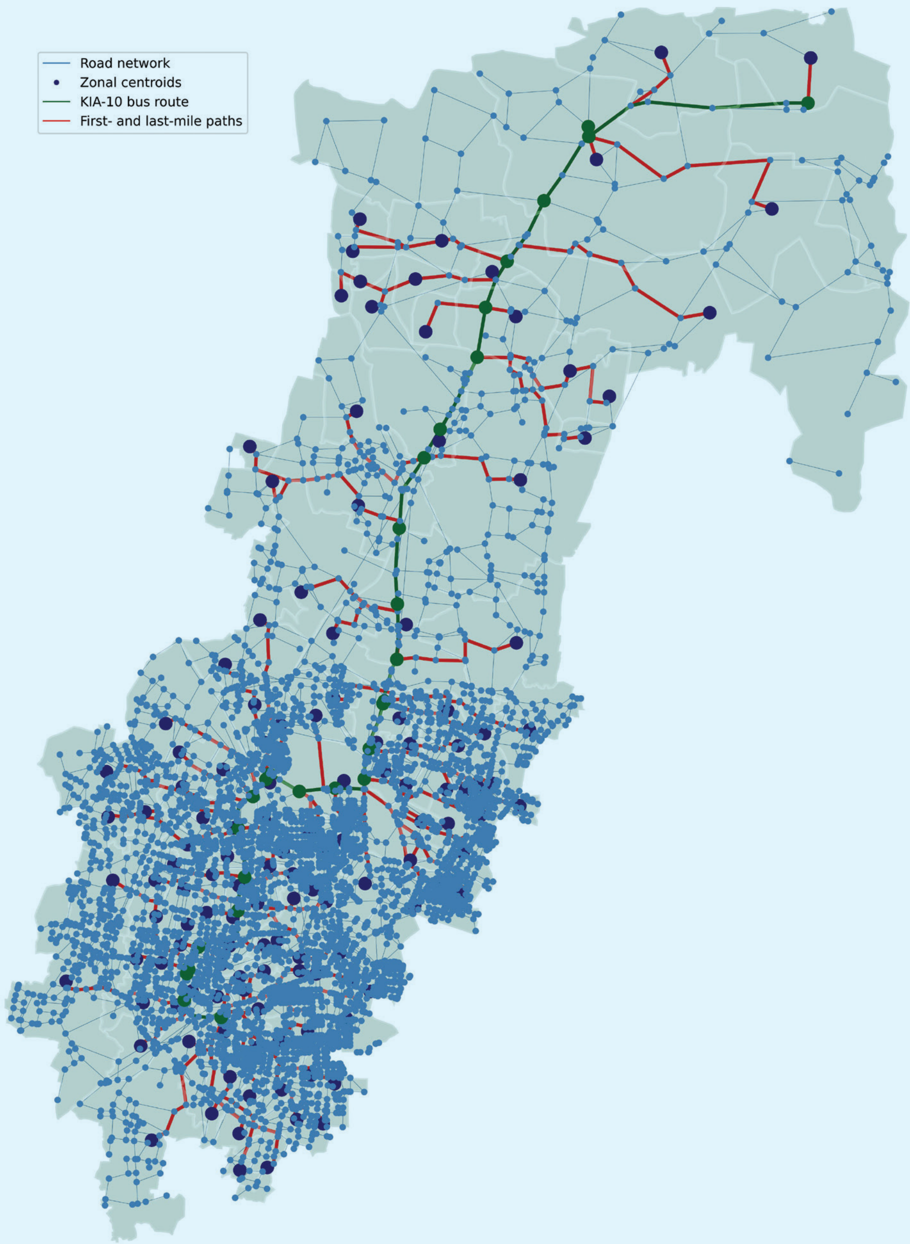
Methodology: We have proposed a tri-level game-theory, discrete choice theory, and traffic network equilibrium theory based model. The model helps the RSPs and the bus agency to set optimal prices for their part in the multi-modal collaborative service. Also, the model can be applied to any city-scale network. The RSPs and the bus agency act as players in a Stackelberg game, with the bus agency as the leader and the RSPs as followers.

The different levels in the model are explained as follows:

1. **Bus agency**: The bus agency is at the top and optimizes its profit as a function of its price corresponding to the collaborative service. While doing so, it has to anticipate the actions (setting of prices) of the RSPs in response to its own actions.

2. **RSPs**: The RSPs are in the middle. We have assumed the presence of two RSPs in the model. However, the model can be easily extended to any number of RSPs. After the bus agency conveys its price, the RSPs optimize their profits as a function of their prices in the collaborative service.

3. **Travelers**: The travelers are at the bottom of the model. Depending on the prices set by the RSPs and the bus agency, they make their mode and route related choices. We have assumed that the travelers consider only the travel prices and travel times associated with the modes to make the choices. The nested logit model is used to determine the shares of modes (the two RSPs are assumed to be present in a nest and the two collaborative modes are present in another nest). Also, we have used the Frank-Wolfe method to determine the route choice of the travelers.



A Tri-level game-theory, discrete choice theory, and traffic network equilibrium theory based model

KEY FINDING

The collaboration model was applied to the KIA-10 bus route and the surrounding travel analysis zones. The simulation results show that the introduction of collaborative service increases the profit and market shares of both the RSPs as well as the bus agency. Also, there is a slight reduction in the travel times and the CO_2 emissions due to vehicles.

FUTURE RESEARCH

The collaboration model can be further enhanced by relaxing the existing assumptions. E.g., multiple bus routes and different vehicle types can be included in the model. Also, the supply side constraints can be introduced.

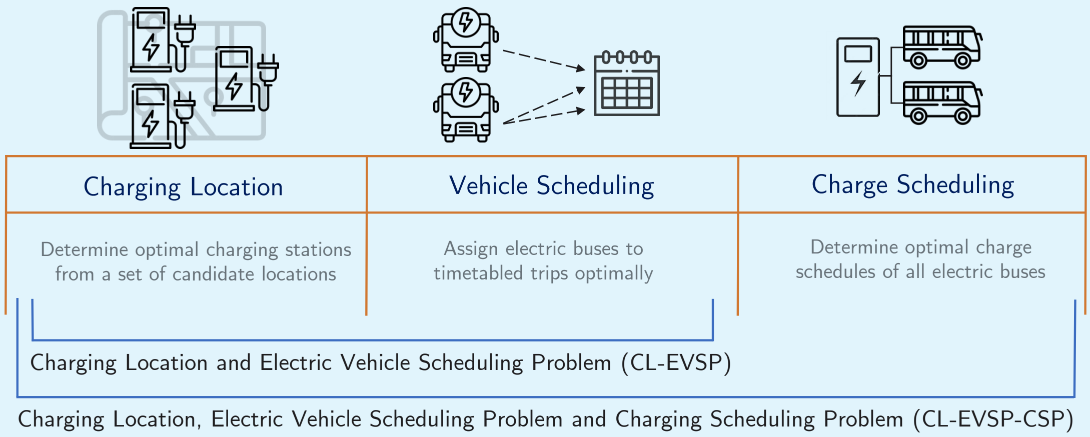
ARTICLE SEVEN

PROF. TARUN RAMBHA

ELECTRIC BUS FLEET PLANNING

POTENTIAL BENEFITS TO BMTC

As we know, BMTC plans to add new buses to its electric fleet under the Fame-II scheme. Deploying charging infrastructure is as essential as procuring new electric buses to ensure battery replenishment of buses during operational hours. However, in many cases, electric bus fleet procurement is not considered in conjunction with the location planning of charging stations or opportunity charging. Our research jointly optimizes the charging locations, electric bus trip schedules, and charging schedules, which will benefit the fleet operator in optimizing costs.



Issues involved in Electric Bus Fleet Planning

BRIEF PROJECT SUMMARY

Given a set of timetabled trips, the goal is to determine the size of the electric bus fleet, assign them to trips, locate charging facilities, and optimize the charging schedule of buses collectively. The following graphic outlines the various issues involved in electric bus fleet planning.

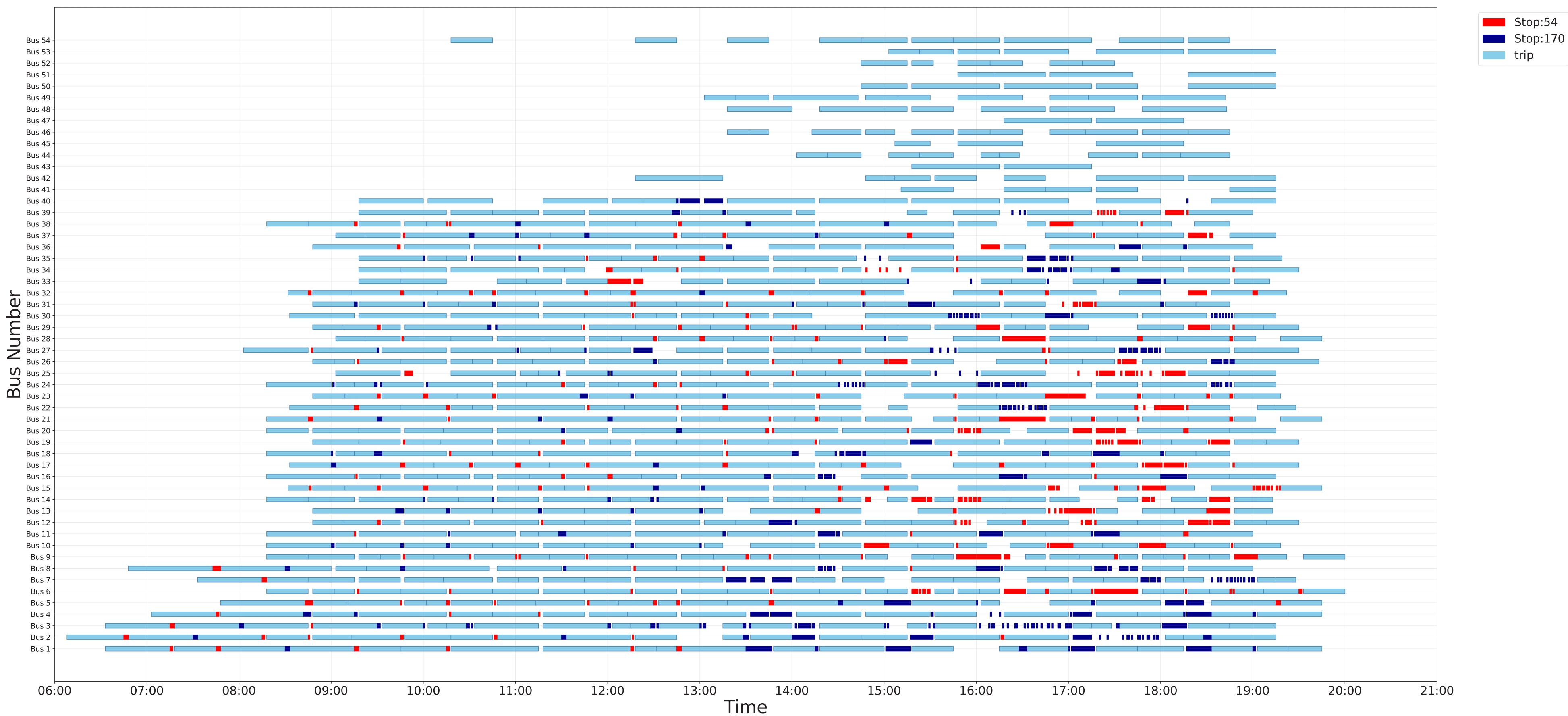
Mixed Integer Linear Programming (MILP) models do not scale well for this joint model. Hence, a local search approach within a Variable Neighbourhood Search (VNS) framework is adopted to solve the problems. The trip and charging schedules of buses from a sample network are presented in the following graphic. Blue bars indicate trips, and the red and purple sections represent charging events at two charging stations.

KEY FINDING

The integrated planning of electric bus scheduling and charging station deployment offers greater fixed and operational cost savings compared to a sequential approach to this problem. Additionally, taking into account the charging schedules of electric buses based on time-of-day electricity prices and grid capacity provides additional cost savings for most transit networks.

FUTURE RESEARCH

The integrated modeling approach demands more computational effort compared to sequential models. Thus far, we have tested our models on small and medium-sized open GTFS datasets from other cities. We would be interested in testing these models to assess the potential savings for larger instances, such as Bengaluru, if we have access to static GTFS data.


Stop:54
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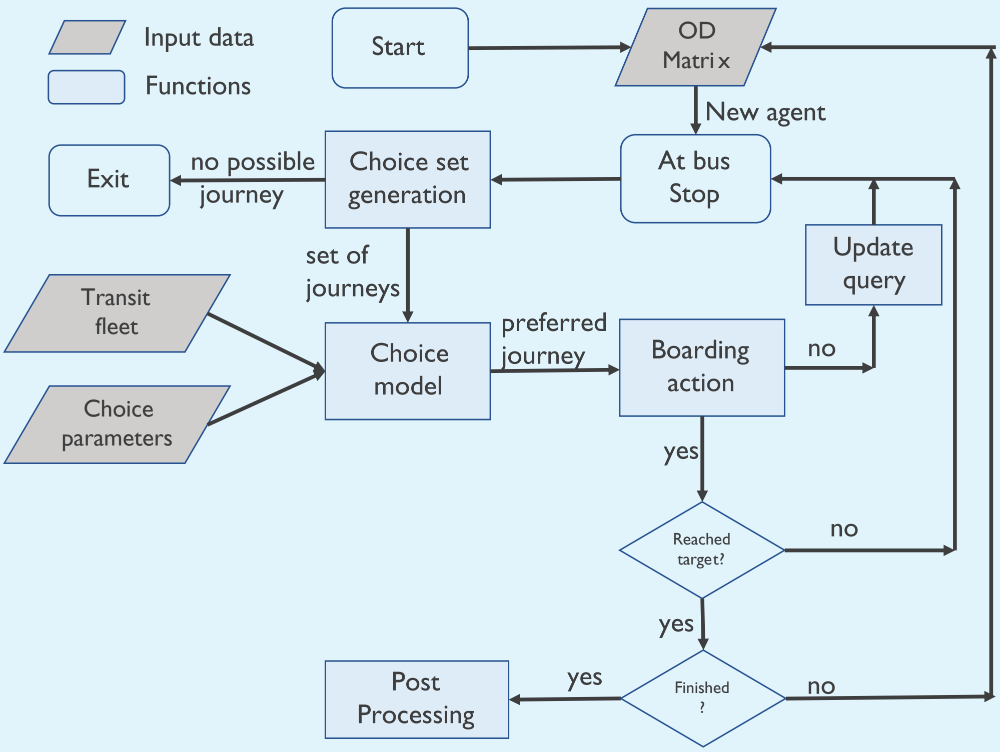
ARTICLE EIGHT

PROF. TARUN RAMBHA

A SCALABLE FRAMEWORK FOR PUBLIC TRANSIT ASSIGNMENT AND BUS-TO-TRIP ASSIGNMENT WITH HETEROGENOUS FLEET

POTENTIAL BENEFITS TO BMTC

We have developed models that take the transit schedule and the demand for public transportation as inputs to predict the journeys chosen by individual passengers. These individual choices are aggregated to determine system-level flows and congestion, considering capacity constraints. These models can be used to predict stop-to-stop occupancies and revenue under new schedules. Additionally, we are working on integrating this with another model that optimizes bus-to-trip assignments for a heterogeneous fleet with varying capacities.



RAPTOR Algorithm

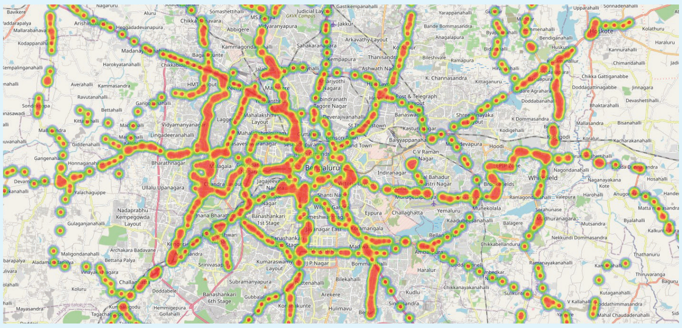
BRIEF PROJECT SUMMARY

The passenger assignment framework generates route choice sets using the RAPTOR algorithm, which provides journeys that optimize time, cost, transfers, waiting times, etc. If no journey is possible, the passenger exits the system. Subsequently, an MNL model is employed to predict the preferred journey. If the passenger cannot board the preferred journey (due to overcrowding), the departure time is updated, and the choice set is regenerated. Otherwise, passengers are assumed to board the bus until the next transfer stop.

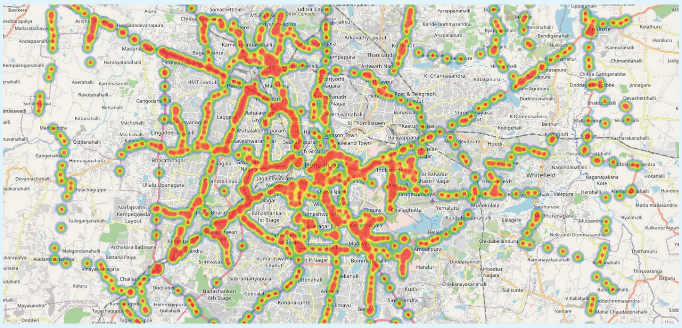
On the supply side, transit operators face critical decisions regarding meeting scheduled timetables with a given fleet. This project aims to provide an efficient tool for solving the vehicle scheduling problem, where we design bus-to-trip assignments allowing a bus to operate on multiple lines. Our approach takes into consideration various objectives, including operational costs, deadhead expenses, and fixed costs. Currently, we are working on integrating these bus-to-trip assignment models with a passenger assignment model to predict the transit performance of heterogeneous fleets. This will help us determine which routes should be serviced by buses with lower capacity and which routes should have high-capacity services.

KEY FINDING

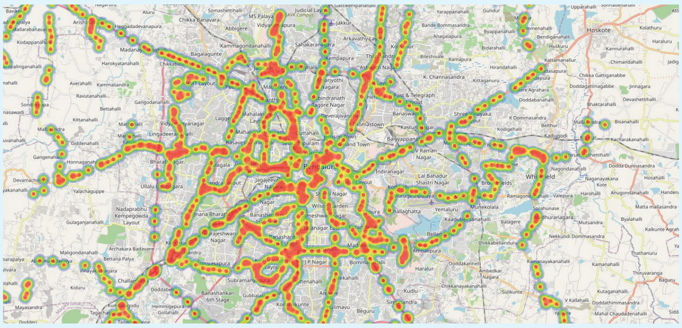
Our proposed transit assignment model can simulate over 10 lakh passengers in less than an hour. The figure below shows a heat map of stops belonging to overcrowded trips at various time intervals. A trip is classified as overcrowded here if the volume-to-capacity ratio of 70% of its link is more than 0.8.



i. 6 - 7pm



ii. 7 - 8pm



iii. 8 - 9pm

FUTURE RESEARCH

Traditional methods for determining passenger preference parameters and origin-destination matrices often require expensive and labour-intensive onboard surveys. We are exploring frameworks in which ETM data can be utilized to refine these models without the need for demand estimation through surveys. Additionally, we have attempted to optimize vehicle-to-trip assignments for 60,000 daily trips reconstructed from older data. Our findings suggest that these trips can be served with 4,922 buses from five depots. However, we aim to expand this study to account for other operational-specific constraints faced by BMTC in determining vehicle schedules.

ARTICLE NINE

PROF. TARUN RAMBHA

EFFICIENT JOURNEY PLANNING APPLICATIONS FOR BMTC

POTENTIAL BENEFITS TO BMTC

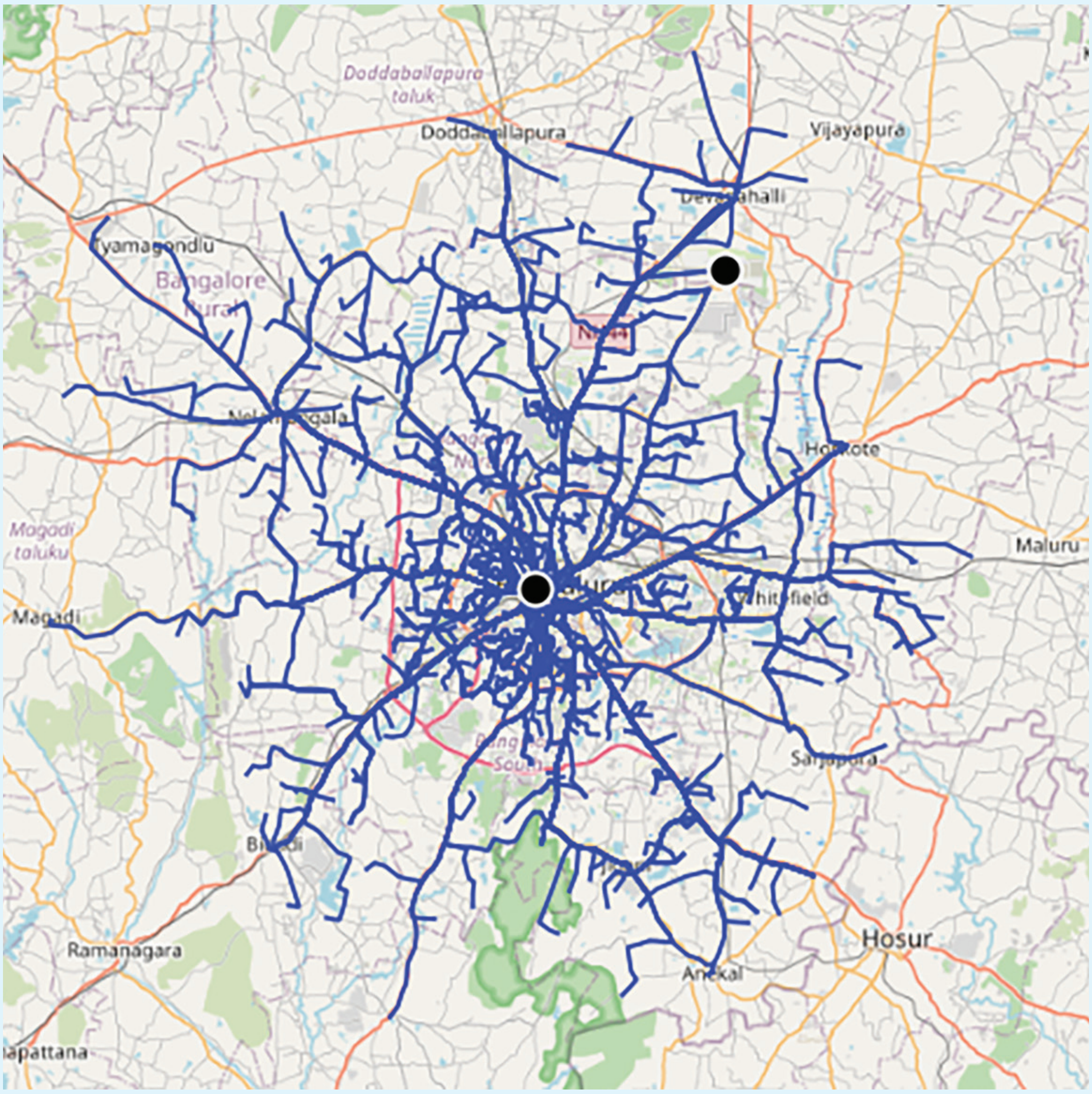
Transit ridership heavily depends on users' ability to plan their journeys effectively. The latest Namma BMTC app's "Journey Planner" feature can be enhanced with state-of-the-art algorithms. Contemporary routing engines like Google Maps prioritize finding Pareto-optimal journeys, which are journeys that cannot be outperformed by other journeys with respect to different objectives, such as (60 minutes, ₹100) or (120 minutes, ₹80). This crucial feature is currently absent in the app.

BRIEF PROJECT SUMMARY

Our research group works with several efficient transit routing algorithms that can address some of the disadvantages of the current application found under the Namma BMTC app's "Journey Planner" tab:

1. **Latency Issues**: The app is slower in generating journey results compared to Google Maps.
2. **Multi-Modal Queries**: The app allows queries only between bus stops, whereas most transit users are willing to walk short distances for better journeys. Furthermore, the app does not consider journeys where walking is involved between transfer stops. Allowing walking in access, egress, and intermediates can significantly enhance the user experience.
3. **Additional Filters**: Besides time and transfers, transit users also prioritize factors such as wait times and cost. However, the app only offers filters based on time and transfers.
4. **Information Overload**: For a given origin-destination pair, the app presents numerous journey options, many of which are impractical (i.e., dominated by other journeys in all aspects). This increases the cognitive load on users, as they must compare various factors to make decisions. Modern routing engines like Google Maps typically post-process and offer a limited set of sensible options.
5. **Query Type**: Studies indicate that users often lack a fixed departure time. For example, passengers may seek optimal journeys departing within a specific time frame, like 0700-0730.

Our project focuses on implementing cutting-edge journey-planning algorithms to address these challenges. One such promising solution for the issues in the Namma BMTC app is Round-based Public Transit Routing (RAPTOR). It can enhance journey quality by incorporating walking between stops while also expediting computations. The algorithm is easily adaptable to additional criteria like cost and crowding. Furthermore, RAPTOR's lack of complex data structures and real-time data adaptability suit dynamic transit systems. Its support for flexible departure times addresses common user preferences, making it a valuable choice. The figure illustrates routes scanned by the RAPTOR algorithm for a query between a single OD pair in the BMTC network.



Implementing Cutting-Edge Journey-Planning Algorithms

KEY FINDING

RAPTOR is easily parallelizable, indicating that it will scale well with the increasing popularity of the app. Preliminary results indicate an average runtime of less than one second on the BMTC network.

FUTURE RESEARCH

While these routing algorithms provide all non-dominated journeys based on fare, time, waiting times, etc., they are still not personalized. Using past queries of users, one can build travel behavioural models to understand their preferences and provide customized journey planning options to each user. Additionally, providing occupancy-specific outputs can help distribute passenger loads and result in a better travel experience.

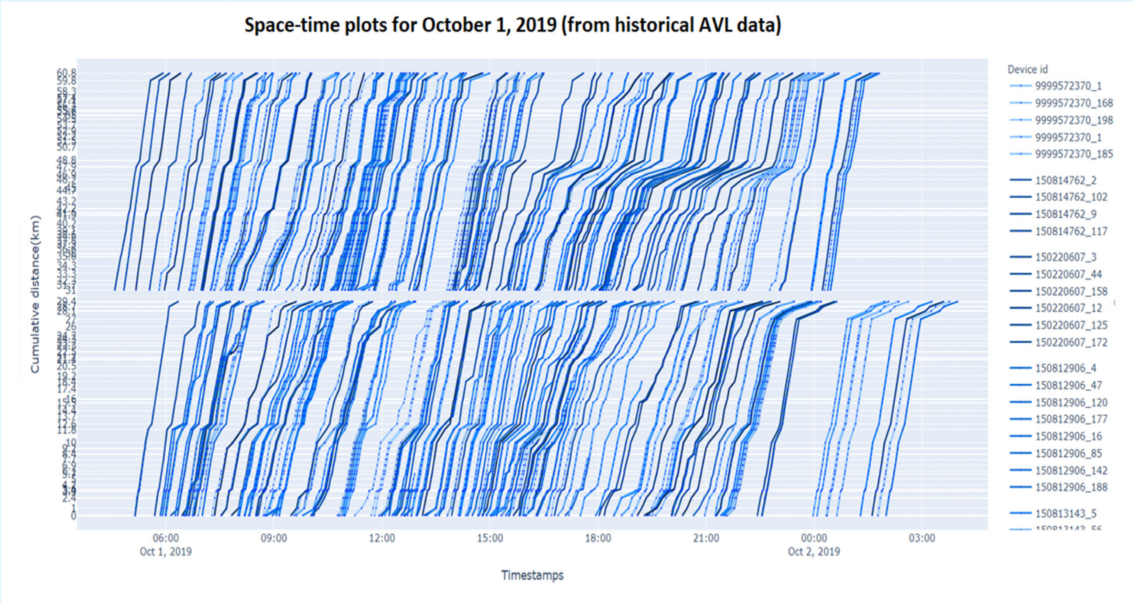
ARTICLE TEN

PROF. TARUN RAMBHA

ADDRESSING BUS-BUNCHING ISSUES USING REAL-TIME HOLDING STRATEGIES

POTENTIAL BENEFITS TO BMTC

Many BMTC routes operate at a high frequency, which can lead to bus bunching, where two or more buses on the same route are next to each other. In this project, we apply dynamic holding strategies to adjust the schedules in real-time at an intermediate control point where there is enough space for buses to park. These strategies can improve the reliability of transit operations and distribute passenger loads evenly.



Space TIme Slots

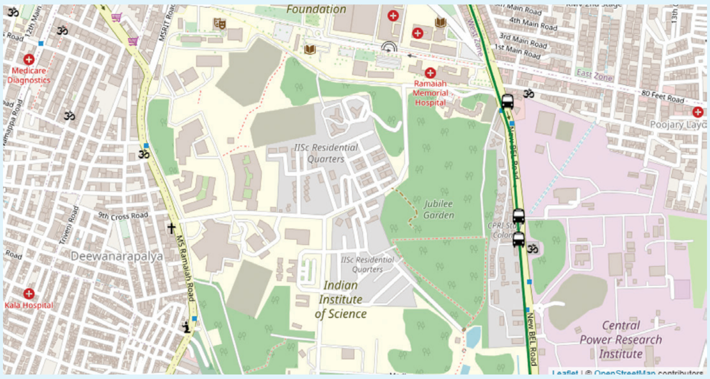
BRIEF PROJECT SUMMARY

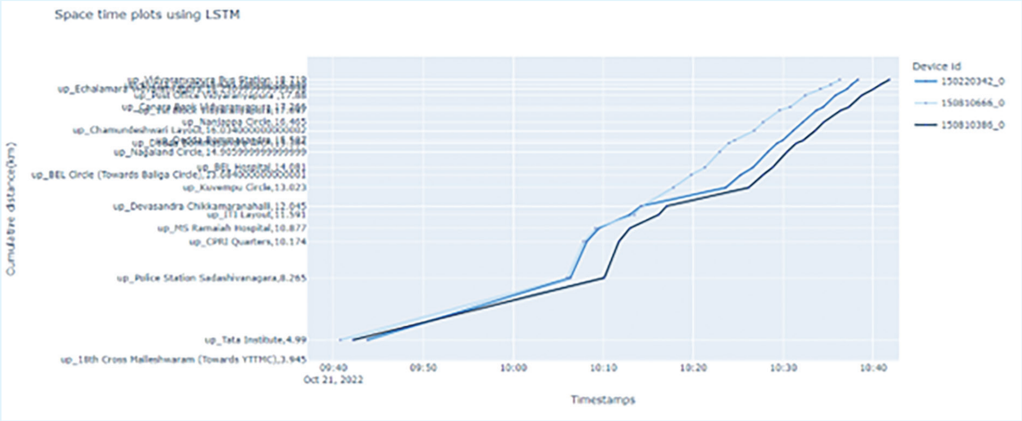
Bus bunching is a common problem affecting the performance, reliability, and service quality of public transport. It occurs when two or more public transit vehicles, originally scheduled with proper headway, end up running on the same route at the same time, typically due to one vehicle being unable to adhere to its schedule. This uncertainty in transit travel times leads to bus bunching, resulting in delayed arrivals at stops, longer passenger wait times, overcrowded buses, and other related issues.

Bus holding is the most commonly adopted methodology to address bus bunching and improve transit service reliability. This method operates by delaying buses that arrive at control points when their headway deviates from the planned schedule, introducing a hold time at these control points. The objective of the control algorithm is to determine the appropriate duration for a bus to wait, considering the positions of other buses and current traffic conditions.

In this work, we utilize recurrent neural networks to enhance the accuracy of estimated time of arrival (ETA) predictions and conducted field tests using scooters following buses as a proxy to assess the impact of holding strategies. These experiments were conducted through a mobile phone application that alerted the driver with both countdowns and voice-assisted commands. Space-time plots of the managed vehicles revealed that implementing holding strategies at select locations with ample parking space can substantially reduce headway variance and mitigate issues associated with bus bunching.

Utilising recurrent neural networks to enhance the accuracy of estimated time of arrival (ETA) predictions and conducting field tests





KEY FINDING

Our experiments on route 276 demonstrate that the application of machine learning (ML) methods enhances ETA predictions, and implementing holding strategies can prove highly effective in reducing headway variances between buses. Additionally, we restrict holding times to minimize inconvenience for passengers already on board.

FUTURE RESEARCH

We are eager to conduct comprehensive pilot programs on a single route for several weeks to quantify the benefits and investigate their impact on ridership. Another avenue for future research involves incorporating occupancy levels into hold time calculations. Additionally, addressing bunching issues among routes that share common segments, like the KIA routes, is another area of interest.

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