Lecture Notes in Intelligent Transportation and Infrastructure
Series Editor: Janusz Kacprzyk

Dipankar Deb
Valentina E. Balas
Rajeeb Dey
Jiten Shah *Editors*

Innovative Research in Transportation Infrastructure

Proceedings of ICIIF 2018

Springer

Lecture Notes in Intelligent Transportation and Infrastructure

Series editor

Janusz Kacprzyk, Systems Research Institute, Polish Academy of Sciences, Warsaw, Poland

The series *Lecture Notes in Intelligent Transportation and Infrastructure* (LNITI) publishes new developments and advances in the various areas of intelligent transportation and infrastructure. The intent is to cover the theory, applications, and perspectives on the state-of-the-art and future developments relevant to topics such as intelligent transportation systems, smart mobility, urban logistics, smart grids, critical infrastructure, smart architecture, smart citizens, intelligent governance, smart architecture and construction design, as well as green and sustainable urban structures. The series contains monographs, conference proceedings, edited volumes, lecture notes and textbooks. Of particular value to both the contributors and the readership are the short publication timeframe and the world-wide distribution, which enable wide and rapid dissemination of high-quality research output.

More information about this series at http://www.springer.com/series/15991

Dipankar Deb · Valentina E. Balas
Rajeeb Dey · Jiten Shah
Editors

Innovative Research in Transportation Infrastructure

Proceedings of ICIIF 2018

Springer

Editors
Dipankar Deb
Department of Electrical Engineering
Institute of Infrastructure Technology Research and Management (IITRAM)
Ahmedabad, Gujarat, India

Valentina E. Balas
Aurel Vlaicu University of Arad
Arad, Romania

Rajeeb Dey
Department of Electrical Engineering
National Institute of Technology
Silchar, Assam, India

Jiten Shah
Institute of Infrastructure Technology Research and Management (IITRAM)
Ahmedabad, Gujarat, India

ISSN 2523-3440 ISSN 2523-3459 (electronic)
Lecture Notes in Intelligent Transportation and Infrastructure
ISBN 978-981-13-2031-6 ISBN 978-981-13-2032-3 (eBook)
https://doi.org/10.1007/978-981-13-2032-3

Library of Congress Control Number: 2018950818

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

This edited book, *Innovative Research in Transportation Infrastructure*, is an outcome of the First International Conference on Innovation in Infrastructure. The chapters aim to present a full picture of the state of the art in modern technology, innovations, and need of the transportation systems, construction, and maintenance methodology and many more, to fulfil the infrastructural gap. Nowadays, inefficient utilization of transportation infrastructure has turned out to be one of the significant issues of road safety for fast-growing urban and rural regions. Numerous initiatives are taken by the government bodies and engineers while keeping in mind the end goal of evolving sustainable transportation by providing smart transportation infrastructure. In order to understand the various issues and probable solutions, the chapters provide in-depth study related to rural and urban infrastructures through various case studies on the deficiency of transportation systems and fundamental problems related to infrastructure.

Some case studies also provide a solution adopting multimodal transportation framework to improve the system in a productive and efficient way. In addition, mobility is a key challenge in sustainable transportation worldwide with a rapid growth of urbanization. As a result, cities experience several traffic-related problems and are major contributors towards greenhouse gas emissions. The chapters in this edited book also contribute to resolving the problem by developing a performance measurement framework using a fuzzy multi-criteria decision-making (MCDM) approach to assess the progress of city performance through service-level benchmarks.

Looking at the current scenario of growing vehicle population, there is a need for the development of new infrastructure for long-distance travels. The chapters also cover modelling techniques and simulation studies which are helpful for evolving fundamental diagrams, determining capacity and level-of-service (LOS) thresholds. Apart from these, evacuation modelling is also covered in order to develop the infrastructure, particularly in disasters.

Another important component is intelligent transportation systems (ITSs) which provides a smart solution to minimize the impact of traffic leading to collision by adopting technological innovations such as Wi-fi, Bluetooth and in-vehicle adaptive control system for safe driving on road or at junctions.

Non-motorized transport is an inevitable component of the holistic development of infrastructure. A chapter in this book also discusses the historical overview of the public bicycle-sharing system that highlights the various PBS systems operated and popularly known for bringing radical changes in transportation systems.

Roads and their maintenance are one of the most important assets for the consequential progress and fetch social benefits of any country. Improper road maintenance can lead to a state of expensive rehabilitation and reconstruction, and the concept of managing roads as assets is not served. The chapters in this book also contribute towards the development of technology to improve road construction methodology and their maintenance and management by introducing a concept like public–private partnership (PPP) to ensure functional efficiency.

Overall, the chapters open new avenues and bring interesting facts to understand the problems and provide unique solutions for sustainable transportation which would help planners to design and implement for the development of efficient infrastructure.

The editors are grateful to Mr. Aninda Bose, Senior Editor, Springer, for publishing these chapters in Lecture Notes in Intelligent Transportation and Infrastructure. We are also grateful to the anonymous reviewers for their comments which led to substantial improvements and reorganizations of these chapters.

Ahmedabad, India Dipankar Deb
Arad, Romania Valentina E. Balas
Silchar, India Rajeeb Dey
Ahmedabad, India Jiten Shah

Contents

Methodological Framework for Modeling Following Behavior of Vehicles Under Indian Traffic Scenario 1
Narayana Raju, Shriniwas Arkatkar and Gaurang Joshi

Exploring Performance of Intercity Expressway Using ITS-Based Technology 13
Chintan Advani, Smit Thakkar, Sachin Shah, Shriniwas Arkatkar and Ashish Bhaskar

Influence of Driving Environment on Safety at Un-signalized T-intersection Under Mixed Traffic Conditions 23
Nishant Pawar, Ninad Gore and Shriniwas Arkatkar

Human Evacuation Simulation During Disaster: A Web Tool 33
Guru Prakash Ramaguru and Venkata Dilip Kumar Pasupuleti

Efficient Road Asset Management with Output and Performance-Based Road Contract 45
Jaykumar Soni, Rajesh Gujar, Tejaskumar Thaker, Sagar Deshmukh and P. R. Patelia

An Innovative Approach to Assess Sustainability of Urban Mobility—Using Fuzzy MCDM Method 55
Partha Tripathy, Anjali K. Khambete and Krupesh A. Chauhan

Determinants of Public–Private Partnership in Infrastructure: Empirical Evidences from India 65
Pravin Jadhav and Rahul Nath Choudhury

In-vehicle Adaptive Traffic Collision Impact System for Next-Generation Traffic 77
Jashvi Mehta, Yashwant Dadi, Deep Patel, Jiten Shah and Dipankar Deb

Analysis of Truck Trips Generated from Port Infrastructure Based on Trip Length Distribution 89
S. C. Rathod and H. R. Varia

Multimodal of Lateral Transport System: A Case Study of Successful Cities Worldwide 101
Nandan Dawda, Gaurang Joshi, Shriniwas Arkatkar and N. Vasudevan

An Infrastructure Review of Public Bicycle Sharing System (PBSS): Global and Indian Scenario 111
Samir J. Patel and Chetan R. Patel

Use of Fibre Reinforcement in Soil for Sustainable Solution of Infrastructure 121
Maharshi Shukla, Jiten Shah and Trudeep Dave

Effects of Material Characteristics on Flexible Pavement Rutting Phenomena in Gujarat 133
Jyoti Trivedi and Rakesh Kumar

Author Index 145

About the Editors

Dipankar Deb completed his Ph.D. at the University of Virginia, Charlottesville, with Prof. Gang Tao, IEEE Fellow and Professor of the ECE Department, in 2007. In 2017, he was elected to be IEEE Senior Member. He has served as Lead Engineer at GE Global Research, Bengaluru (2012–2015), and as Assistant Professor of EE at the IIT Guwahati (2010–2012). He is currently Associate Professor in the Department of Electrical Engineering, Institute of Infrastructure Technology Research and Management. He is also Student Startup and Innovation Project Coordinator at IITRAM, where he mentors students on intellectual property rights (patents).

Valentina E. Balas is currently Full Professor in the Department of Automatics and Applied Software, "Aurel Vlaicu" University of Arad, Romania. She holds a Ph.D. in applied electronics and telecommunications from the Polytechnic University of Timisoara. She is the author of more than 250 research papers in refereed journals and international conference proceedings. Her research interests are in intelligent systems, fuzzy control, soft computing, smart sensors, information fusion, modelling and simulation. She is Editor-in-Chief of the *International Journal of Advanced Intelligence Paradigms* (IJAIP) and the *International Journal of Computational Systems Engineering* (IJCSysE), Member of the Editorial Board for several national and international journals, and Director of the Intelligent Systems Research Centre at Aurel Vlaicu University of Arad. She is Member of EUSFLAT, SIAM, and Senior Member of IEEE, as well as Member of TC—Fuzzy Systems (IEEE CIS), TC—Emergent Technologies (IEEE CIS) and TC—Soft Computing (IEEE SMCS).

Rajeeb Dey is presently working with the National Institute of Technology, Silchar, Assam, India, as Assistant Professor in the Department of Electrical Engineering. Before joining the NIT Silchar, he served at Sikkim Manipal University, Sikkim, for 12 years in various positions (Lecturer, Reader and Associate Professor). His research interests are in time-delay systems and control, robust control, control of biomedical systems and applications of wireless communication in control. He is presently a reviewer for many SCI(E) journals related to control engineering and applied mathematics. He is Senior Member of IEEE, CSS, Life Member of the System Society of India and Member of the Institution of Engineers, India.

Jiten Shah Ph.D., is Assistant Professor in the Department of Civil Engineering, IITRAM, Ahmedabad. His areas of specialization include vehicular and human behavior, transportation planning, traffic facility design, modelling in transportation, traffic flow modelling including non-motorized traffic. He is guiding a Ph.D. student on pedestrian flow behavior and has guided four M.Tech. theses. He was involved in the project "Supra Institutional Network Project for Development of Indian Highway Capacity Manual (Indo-HCM)" funded by Planning Commission of India under 12th Five-Year Plan as a part of his research work. He has several publications to his credit in reputed international and national journals. He is a recipient of the gold medal from The Gujarat Institute of Civil Engineers and Architects (GICEA). He is a reviewer for the journals such as Transportation Letters, Taylor & Francis, Journal of Traffic and Transportation Engineering, Transportation Research Record, TRB, World Review of Intermodal Transportation Research. He is also a member of renowned society/institute including Transportation Research Group of India, Institute of Urban Transportation (India), and The Institute of Engineers (India).

Methodological Framework for Modeling Following Behavior of Vehicles Under Indian Traffic Scenario

Narayana Raju, Shriniwas Arkatkar and Gaurang Joshi

Abstract The present research work is originated with an intent of studying traffic flow characteristics on intercity. For this purpose, two expressway sections: (i) Pune-Mumbai Expressway and (ii) Ahmedabad-Vadodara Expressway were selected, as these are the best available roads in category of intercity expressways, in India. During the course of work, it was found that data may not be fully adequate to develop Measure of Effectiveness (MOEs) thresholds. Consequently, simulation-based approach is to model the traffic flow on selected study sections. With this motivation, simulation model, namely, VISSIM-9.0 was calibrated using newly developed methodology for mixed traffic conditions. In particular, driving behavior parameters were calibrated using high-quality vehicular trajectories. A well-calibrated simulation model was then applied for developing speed-flow-density fundamental diagrams, and thereby determining capacity and Level-of-Service (LoS) thresholds using density and V/C ratio. It was found that the capacity value for six-lane divided expressway (three lanes in each direction) is determined as about 7500 PCU/h/direction, which reasonably matches with the US-HCM (2010) guidelines. It is anticipated that the proposed method of calibrating vehicle-following driving behavior using high-quality trajectory data is transferable to other mixed traffic conditions.

Keywords Expressways · Simulation · Following behavior · Level of service Indian traffic

N. Raju · S. Arkatkar (✉) · G. Joshi
Sardar Vallabhbhai National Institute of Technology, Surat, Surat 395007, India
e-mail: sarkatkar@gmail.com

N. Raju
e-mail: s.narayanaraju.10@gmail.com

G. Joshi
e-mail: gjsvnit92@gmail.com

D. Deb et al. (eds.), *Innovative Research in Transportation Infrastructure*,
Lecture Notes in Intelligent Transportation and Infrastructure,
https://doi.org/10.1007/978-981-13-2032-3_1

1 Background

Expressways are the highest class of roads in the Indian road network and it makes up around 1,455 km in road network, which is operational in India. These road sections are like freeways in the United States, Autobahns in Germany and expressways in China. This topic is very well researched in developed countries. Many researchers have brought out interesting observations on traffic flow characteristics for these kinds of roads. Daganzo et al. [1] analyzed the freeway sections using numerical simulation of traffic flow characteristics on freeways to study the usage of lanes by the vehicles. The study added a good understanding about lane-based behavior, prevailing in developed countries like USA. Geistefeldt and Hohmann [2], in their work, developed LoS thresholds for freeways, using simulation and compared with the available guidelines. From the literature available for developed countries, it can be inferred that for developing expressway capacity and LoS-related estimates, use of simulation model can be one of the approaches in absence of huge amount of loop detector data over wider range of traffic flow conditions. Simulation models can be calibrated and validated for the observed conditions reasonably well, which then may be deployed to develop macroscopic speed-density-flow relationships to get accurate capacity estimates. This approach is adopted in the present study, as there is neither loop detector nor any other automated traffic surveillance data source available to researchers in India. This can be also true for other developing countries, where there may be limited or no automated or sensor-based data source available for modeling. Under prevailing mixed traffic conditions in India, the general practice is to collect traffic data using video graphic survey and traffic data is extracted manually or using semiautomated tool. This necessitates analyzing the traffic flow using approaches like (i) theory-based modeling, (ii) empirical data modeling, and (iii) semiempirical hybrid approach, and using empirical as well as simulated data. Use of simulation models warrants high-quality trajectory database development for the roadway and traffic conditions under consideration. Out of these, the authors have adopted semiempirical approach of calibrating simulation model using field observed data in this research work. In connection to this, very few studies are reported in explaining the performance of expressways in India. Likewise few more studies, Arkatkar and Arasan [3] and Mathew and Radhakrishnan [4], are reported on the use of simulation models for estimating PCU, capacity, and effect of variation in traffic conditions, such as traffic flow and composition through sensitivity analysis. From the literature, it can be inferred that in case of mixed traffic conditions in India, few studies are reported regarding usage of simulation models in modeling traffic flow on different roadway sections, although there are very few for expressways. After review of literature available on simulation studies on expressways in India, it can be inferred that there are following research gaps: (i) researchers have used mostly traffic data in calibrating simulation models, mainly 1 min or 5 min interval data on traffic flow variables, (ii) parameter calibration procedures are not clearly stipulated, (iii) there is no use of high-quality vehicle trajectory data in calibrating car-following parameters, (iv) models are validated using mostly macroscopic parameters such as flow, speed, and density, but not based on microscopic parameters such as vehicle-based driving patterns, (v) there is no comparison of using lane-based and non-lane-based approaches within simulation framework, although real traffic flow pattern is likely to follow reasonable lane discipline on expressways. Keeping in view these research gaps, the objective of this research work was framed to develop a methodology for calibrating vehicle-following models using high-quality trajectory data and validating simulation model VISSIM 9.0 using microlevel driving patterns observed on expressways. The well-calibrated model was then used to estimate capacity and LoS thresholds. Further, the simulation modeling was also evaluated using two schemes: non-lane-based and lane-based approaches, in VISSIM.

2 Study Section

For the present study, midblock road sections on two intercity Expressways, namely Ahmedabad-Vadodara Expressway (AVE) and Pune-Mumbai Expressway (PME) (situated in the western part of India) were selected with sections of trap length 100 and 120 m, respectively. Ahmedabad-Vadodara Expressway is a 4-lane divided roadway section with 2 lanes on each side including hard paved shoulder of 2.6 m width (width 11.0 m), on either side, as depicted in Fig. 1a. As indicated in one of the research gaps, to sense the real vehicle type driving behavior on selected study sections, a time duration of 20 min of the video data was used. This duration was selected in such a way that maximum variation in traffic flow could be captured, as vehicular trajectory data was developed using Traffic Data Extractor developed by IIT Bombay, India in which the longitudinal and lateral position of vehicles were tracked for a time interval of 0.5 s manually. This procedure was followed for tracking 407 vehicles on Ahmedabad-Vadodara Expressway. The second study section, Mumbai-Pune Expressway, with a trap length of 120 m and width 12.5 m, was selected for the present work and is shown in Fig. 1b. It is a 6-lane divided carriageway with a paved shoulder of 1.5 m on either side. In this case also, a traffic video was captured for a duration of 8 h. As previously followed, 20 min of vehicular trajectory data was developed from about 813 vehicles, by tracking them over the study section using same tool. Four different vehicle categories were observed on two study sections, namely Car, Bus, Truck and Light Commercial Vehicle (LCV). Based on the video graphic surveyed data, by means of manual extraction, the fundamental traffic characteristics in terms of PCU [5] were evaluated for the road sections and speed-flow plots. From the analysis, it can be observed that in most of the times, both the road sections are serving at a moderate traffic flow, ranging from 1000 to 4000 PCU/h on Ahmedabad-Vadodara section and 1500 to 7500 PCU/h in the case of Pune-Mumbai section.

It was inferred that these data sets are not having enough variation in flow, which otherwise may require estimating capacity and LoS thresholds. Even it was expected that capturing varied traffic flow on the study sections is dubious throughout all traffic states and congested regime in present situation. Hence, simulation-based semiem-

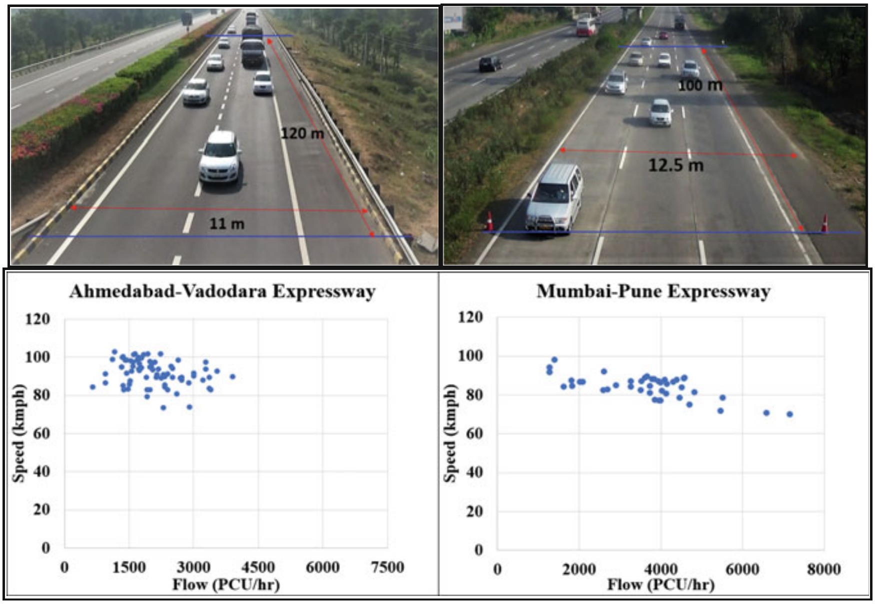


Fig. 1 Snapshot of study sections and their respective speed-flow plots **a** AVE **b** PME

pirical approach was adopted to study the traffic characteristics on expressways. But, to have the confidence on the output robust simulation models is to be developed and also model is to be validated from an aggregated macroscopic level to microlevel, as explained in identified research gaps. On this basis, the study had been carried forward.

3 Simulation Modeling

From the literature, it was inferred that many studies in past had applied traffic simulation tools in solving the critical problems and assessed the optimal solutions. Considering this in the present study, simulation approach had been attempted in studying the traffic characteristics on the expressway sections, but the application of simulation tools in Indian traffic context is less due to the complexity involved in modeling driving behavior. Similarly, very few studies had been carried in this direction in quantifying the driving behavior due to unavailability of trajectory data. Considering this in the present study, microsimulation tool VISSIM 9.0 is used in simulating the road sections. But, in order to have confidence on the outputs from simulation, requires robust simulation models and should show a good correlation with field behavior. It was inferred that driving behavior plays a major role in this direction. In the present study to develop the robust simulation models driving behav-

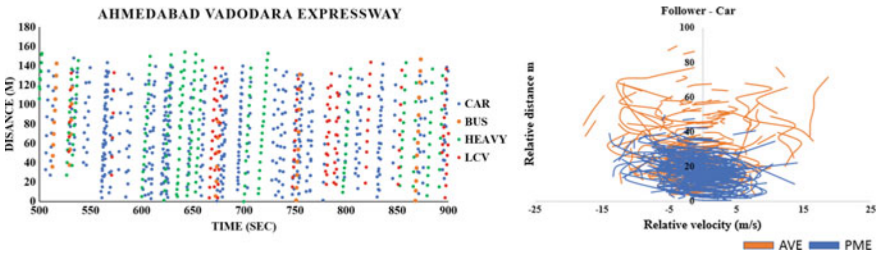


Fig. 2 Time space plots of vehicles and hysteresis plots from following pairs

ior had tweaked, on this lines under Indian traffic [4] had calibrated driving behavior in behavior in VISSIM by means of Genetic Algorithm. Raju et al. [6] had given a vehicular trajectory level framework in calibrating the driving behavior for the mixed traffic conditions. In the present case, the trajectory level framework had applied in modeling the driving behavior for the two study sections for modeling robust simulation models. The key element in studying the driver behavior is the identification of leader–follower pairs in different traffic conditions. In homogeneous traffic condition, it is easy to spot leader–follower vehicle pairs because of the lane-based traffic movement. But under mixed traffic conditions, the driving interactions among the vehicles are much more complex. In the present study to capture the following behavior initially, time space plots of vehicles were plotted on a given lane as shown in Fig. 2a, through visual inspection, the trajectories in following are assumed as leader–follower pairs. But under Indian context, there exists an influence of the vehicles from adjacent lanes, to study the influence of such vehicles, relative distance versus relative velocity (subject follower minus leader) is plotted for 3 combinations: (i) Assumed leader versus vehicle in other lane, (ii) Vehicle in other lane versus assumed follower and (iii) Assumed leader versus assumed follower. From these combinations, the pairs which are showing hysteresis phenomenon (representation of following behavior) are considered as true leader–follower pair. All such pairs are aggregated based on vehicle category wise for both the study sections for calibrating following behavior as shown in Fig. 2b.

3.1 Modeling Following Behavior of Vehicles

From the literature, it was inferred that in case of high-speed roads sections, lanewise movement of vehicles is predominant, and to model the following behavior of vehicles on these roads section in the present Wiedemann 99 model and Gipps model had been taken for analysis. Out of which, Wiedemann 99 model is an inbuilt model in VISSIM and by means of external driving behavior Gipps model is coded in modeling the driving behavior. Wiedemann 99 model is the second implication of car-following model, in which following behavior had expressed by means of ten

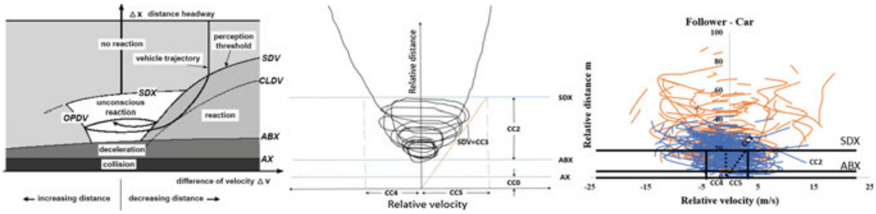


Fig. 3 Pictorial representation of relative distance versus relative velocity among following pairs

parameters, in which each parameter has its significance in explaining the following behavior as given in Table 1. In the present study, the methodology adopted by Raju et al. [6] was used in calibrating the Wiedemann 99 models. On this basis, the parameters were calibrated in Table 1 and as shown in Fig. 3b. Based on the calibration of Wiedemann 99 models, the following behavior of the vehicles had been captured, similarly, the lateral behavior of the vehicles was also taken into account. On this basis, the driving behavior of the vehicles was modelled, and the study had been carried forward in modeling the road section.

Based on the safety reaction time, Gipps [7] if the subject follower vehicle is under the influence of the leading vehicle, in that case, the follower vehicle tends to maintain a safe distance from the leading vehicle by means of acceleration and deceleration. The desired velocity constraint fitted from field data is presented in Eq. (1). Where, $a_n(t)$ is the maximum acceleration that the driver in vehicle n wishes to apply and V_n is desired velocity.

$$v_n^a(t+T) \leq v_n(t) + 2.5Ta_n\left(1 + \frac{v_{n(t)}}{V_n}\right)\sqrt{0.025 + \frac{v_n(t)}{V_n}} \tag{1}$$

$$v_n^d(t+T) \leq b_nT + \sqrt{b_n^2T^2 - b_n\left[2(x_{n-1}(t) - s_{n-1} - x_n(t)) - v_n(t)T - \frac{v_{n-1}^2(t)}{\hat{b}}\right]} \tag{2}$$

$$v_n(t+T) = \min\left\{v_n^a(t+T), v_n^d(t+T)\right\} \tag{3}$$

The velocity limitation that can avoid collision, when the leading vehicle brakes to slow down was derived from the equation of motion, written in Eq. (2). Where b_n is the most severe braking that the driver of vehicle follower wishes to undertake ($b_n < 0$), s_{n-1} is the effective size of leader and b^ is the estimation of b_{n-1}. Combining the limitation, the velocity of vehicle n at time t+T is set as Eq. (3). On this basis, with the help of a genetic algorithm for the leader–follower pairs, the parameters (T, a_n, V_n, b_n and $\hat{b}$) of Gipps model were calibrated for all following vehicles on a aggregated basis as shown in Table 2 within the range [8] and given as inputs to the simulation models.

Table 1 Calibrated parameters of Wiedemann 99 car-following model along with their significance

Parameters	Implication in following behavior	Default	Car	Truck	Bus	LCV
CC0	Desired rear bumper-to-front bumper distance between vehicles in standstill conditions. $AX = CC0$	1.5	1.05	1.70	1.70	1.05
CC1	Defines the time (in seconds) the following driver wishes to keep. The VISSIM manual [11] reports this as headway time, $ABX = Lead\ vehicle\ length + CC0 + CC1 * v_{slower}$	0.9	0.49	1.16	1.16	0.49
CC2	Defines, rather restricts the longitudinal oscillation during following condition $SDX = ABX + CC2$	4	4.93	6.79	6.79	4.93
CC3	Defines the perception of subject vehicle (in seconds) to leader	−8	−8.4	−13.6	−13.6	−8.43
CC4	The maximum negative relative velocity during the following process	−0.35	−0.34	−1.0	−1.0	−0.34
CC5	The maximum positive relative velocity during the following process	0.35	0.28	0.22	0.22	0.28
CC6	Defines the influence of distance on speed oscillation during following condition	11.44	11.44	11.44	11.44	11.44
CC7	Defines actual acceleration during oscillation in a following process	0.25	0.26	0.25	0.25	0.26
CC8	Defines the desired acceleration when starting from a standstill	3.5	2.20	3.50	3.50	2.20
CC9	Defines the desired acceleration when at 80 km/h	1.5	1.33	1.46	1.46	1.33

Table 2 Optimized parameters of Gipps model for AVE and PME

Parameter	Range		Study section	
	Min	Max	AVE	PME
T	0	1	0.05	0.08
an	2	6	5.35	2.17
V_n	5	50	45.2	48.8
bn	−10	−4	−2.15	−0.95
ƀ	−10	−4	−1.38	−1.95

4 Development of Macroscopic Plots

From the earlier reported studies on freeways in the developed countries [9, 10], it was observed that most of the times Wiedemann 99 model is used in expressing the following behavior. The main implication beyond this is that Wiedemann 99 is an upgraded model and able to express the closing up and giving up behavior of vehicles in the following conditions. Along with that Gipps model which is good in replicating lanewise behavior of traffic is used as following behavior in the simulation models. In the present study to develop the macroscopic plots for the midblock road section, a 1km long section is created with a buffer sections of 100 m at the start and at the end. On this basis, simulation runs were carried out for a varying volume levels ranging from 500 vehicles/h to 10,000 vehicles/h with an interval of 500 vehicles/h for 1 h each at 10 different random seeds and average of the ten seeds were taken for the analysis. This is very important to develop the complete macroscopic plots of the road section. Based on this methodology, the simulation runs were carried out by inputting the calibrated Wiedemann 99 parameters and coded Gipps model in the simulation models. On this basis speed, density and flow were evaluated in terms PCU [11] for each 5 min interval from the study section. Macroscopic plots were developed for the study sections and speed-flow plots are shown in Fig. 4. From the analysis, it was found that simulation models with Wiedemann 99 following behavior are having a good correction with the field and were able to produce a resemble flow at varying traffic. Whereas with Gipps model, as the model is oriented in much about safety distance, due to this the simulation model were unable to replicate the varying traffic flow conditions. From the speed-flow plots, it was observed that the simulated macroscopic plots were able to match the field data in the given range and the capacity of the sections was found to be around 7500–7750 PCU/h for AVE and 7700–8000 PCU/h for PME. Similarly, the characteristics such as capacity and free speeds were reported in Table 3. Further in the research work Wiedemann 99 model is used in the simulation models.

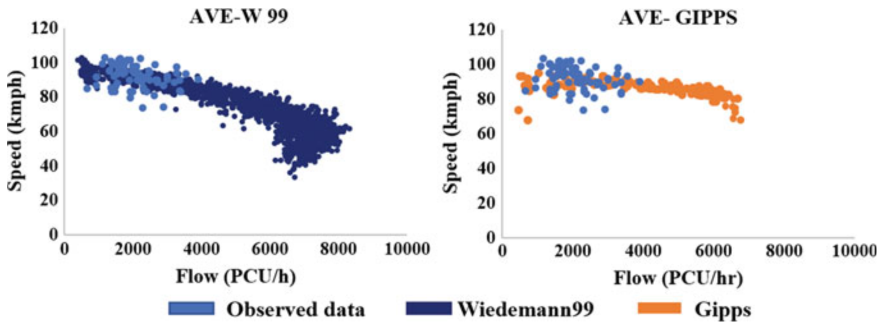


Fig. 4 Speed versus flow over the AVE with different following behavior

Table 3 Macroscopic characteristics

Study area	Characteristics	Wiedemann 99	Gipps
Ahmedabad-Vadodara Expressway	Capacity (PCU/h)	7477	7109
	Free flow speed (kmph)	105	100
Mumbai-Pune Expressway	Capacity (PCU/h)	7805	7603
	Free flow speed (kmph)	103	95

5 Simulation Model Application

Level of Service (LoS) is a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, comfort, convenience, and safety. As expressways are new in Indian context, the level-of-service guidelines were not available in the present context and it was inferred that with the observed traffic data range from the macroscopic plots it was difficult to define the level-of-service thresholds for the road sections. Considering this in the present study, it was attempted to define the level-of-service guidelines for the road section, for that lane-based simulation model with Wiedemann 99 model which is having good correlation with field conditions is taken up, for this the macroscopic plots developed in the intial phase were used. On this basis, the study had been carried forward. The methodology adopted, as per HCM [12], for developing level-of-service criteria for multilane highways, involves the development of speed-flow relationship and delineation of various level-of-service boundaries on the speed-flow curves, based on density. Hence with the help of simulation, speed-flow curve was used developing the level-of-service criteria for Expressways. Based on the relationships between speed, flow and density with the help of K-mean clustering method [13] had employed in defining the

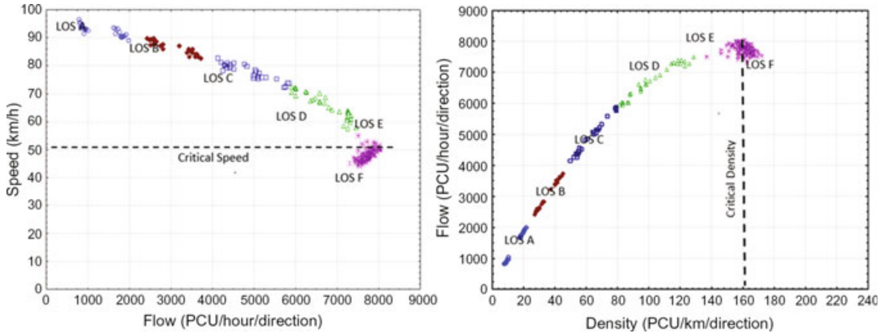


Fig. 5 Level-of-service thresholds on PME

Table 4 LOS thresholds for the study sections

Study section	LOS	Speed (kmph)	Flow (PCU/hr/direction)	Density (PCU/km/direction)	V/C ratio (clustering)	V/C ratio (HCM 2010)
Ahmedabad-Vadodara Expressway	A	>90	<1947	<23	0.26	0.3
	B	90–83	1948–3640	24–42	0.47	0.5
	C	82–71	3641–5565	43–75	0.73	0.71
	D	70–59	5566–6829	76–117	0.9	0.89
	E	58–52	6830–7613	118–147	1	1
Mumbai-Pune Expressway	A	>89	<1993	<22	0.25	0.3
	B	89–83	1994–3734	23–45	0.46	0.5
	C	82–74	3735–5858	46–80	0.73	0.71
	D	73–58	5859–7265	81–126	0.9	0.89
	E	57–50	7266–8045	127–161	1	1

level-of-service thresholds. To develop the LOS guidelines, speed, flow, and density data for 5 min interval were used and these data sets are ranged from free flow condition to capacity condition and some few points lie even in congested state. For clustering, K-mean technique was adopted by using STATISTICA.10 software. From the data sets, clusters were defined based on speed, flow, and density which represent LOS A to LOS F as shown in Fig. 5. To get the better results for boundary delineation, 250 iterations were done with the help of software. After defining clusters, data points were plotted for speed-flow and flow density curves to define thresholds of LoS. On this basis, LoS analysis had been carried for both the road sections as reported in Table 4 along with V/C ratios for different LOS from HCM [17] are compared with clustered data.

6 Conclusions

Based on the research framework adopted in the present study, with the help of through validated simulation models, level-of-service thresholds were defined for the study sections. During this course, the following inferences were observed from this research work and are as following. From the observed data on the study locations, it is inferred that characteristics of the high-speed roads should not be studied with empirical observations alone, as variation in traffic volume will be less on these road sections, unlike the urban roads. It is also observed that vehicular trajectory data is indispensable source for simulating the road sections effectively in robust way, but at present, very few vehicular trajectory data sets are available under Indian conditions, as NGSIM data, which is hugely available and accessible in the US. Under Indian traffic conditions, only a few studies had reported the usage of trajectory data, but this is the first study on Indian expressways.

References

1. Daganzo CF, Lin W-H, Del Castillo JM (1997) A simple physical principle for the simulation of freeways with special lanes and priority vehicles. Transp Res Part B Methodol 31(2):103–125
2. Geistefeldt J, Hohmann S (2013) Assessment of different design hours for freeways. In: Transportation Research Board 92th annual meeting
3. Arkatkar SS, Arasan VT (2010) Effect of gradient and its length on performance of vehicles under heterogeneous traffic conditions. J Transp Eng 136(December):1120–1136
4. Mathew TV, Radhakrishnan P (2010) Calibration of microsimulation models for nonlane-based heterogeneous traffic at signalized intersections. J Urban Plan Dev 136(1):59–66
5. Kumar P, Arkatkar SS, Joshi G, Ashish D (2017) New methodology for estimating PCU on multi lane urban roads under mixed traffic scenario based on area occupancy. In: Transportation Research Board 96th annual meeting [Internet], Washington DC, p 17-03248. http://docs.trb.org/prp/17-03248.pdf
6. Raju N, Kumar P, Chepuri A, Arkatkar SS, Joshi G (2017) Calibration of vehicle following models using trajectory data under heterogeneous traffic conditions. In: 96th annual Transportation Research Board, Washington DC
7. Gipps PG (1981) A behavioral car-following model for computer simulation. Transp Res Part B 15(2):105–111
8. Zheng J, Suzuki K, Fujita M (2012) Evaluation of car-following models using trajectory data from real traffic. Procedia Soc Behav Sci [Internet] 43:356–366. http://linkinghub.elsevier.com/retrieve/pii/S1877042812009901
9. Gomes G, May A, Horowitz R (2004) Calibration of VISSIM for a congested freeway. Calif Partners Adv Transit Highw 36
10. Woody T (2006) Calibrating freeway simulation models in VISSIM. Univ Washingt Seattle CEE 416:580
11. PTV (2016) PTV VISSIM 9 user manual; 1055
12. Brilon W, Lohoff J (2011) Speed-flow models for freeways. Procedia Soc Behav Sci 26–36
13. Sangalli LM, Secchi P, Vantini S, Vitelli V (2010) k-mean alignment for curve clustering. Comput Stat Data Anal 54(5):1219–1233

Exploring Performance of Intercity Expressway Using ITS-Based Technology

Chintan Advani, Smit Thakkar, Sachin Shah, Shriniwas Arkatkar and Ashish Bhaskar

Abstract Traffic data collection under mixed traffic conditions is one of the major problems faced by researchers as well as traffic regulatory authorities. For mixed traffic observed in developing countries, no suitable tool is available for this purpose. Keeping in view the necessities of acquiring an extensive database and the difficulties associated with its collection, ITS techniques can be implemented as an accurate and efficient methods of data collection. Among the emerging methods, Bluetooth-based sensors are gaining popularity, but the number of active Bluetooth devices in the traffic stream in India is generally very low and is hindrance to the effectiveness of data collection. Thus, the main aim of this research is to test the reliability of such Wi-Fi/Bluetooth-based sensor which is one of the most reliable and easy-to-use instruments that can aid us in solving above parameters efficiently. Exploration for the performance of such ITS-based technology is carried out in the determination of traffic flow parameters on NE-1 expressway of India and thereby validating the results with the help of videography survey data.

Keywords Wi-Fi/Bluetooth sensors · Travel time · Penetration rate · Expressway

C. Advani · S. Thakkar · S. Shah · S. Arkatkar (✉)
Civil Engineering Department, Sardar Vallabhbhai National Institute of Technology, Surat, Surat 395007, India
e-mail: sarkatkar@gmail.com

C. Advani
e-mail: chintanadvani@gmail.com

S. Thakkar
e-mail: thakkarsmit11@gmail.com

S. Shah
e-mail: sss342714@gmail.com

A. Bhaskar
Department of Civil Engineering, Queensland University of Technology, Brisbane, Australia
e-mail: ashish.bhaskar@gmail.com

D. Deb et al. (eds.), *Innovative Research in Transportation Infrastructure*,
Lecture Notes in Intelligent Transportation and Infrastructure,
https://doi.org/10.1007/978-981-13-2032-3_2

1 Introduction to ITS and Wi-Fi/Bluetooth Sensors

Intelligent Transport Systems (ITS) have globally proven to optimize the utilization of existing transport infrastructure and improve transportation systems in terms of efficiency, quality, comfort, and safety. Having realized these potentials, the government bodies and other organizations in India are presently working towards implementing various ITS services across the country. One such ITS application is Wi-Fi/Bluetooth-based sensors, which is gaining distinction lately. Since the late 2000s, Wi-Fi/Bluetooth-based travel time estimation system has received wide attention due to its noninvasiveness, cost-effectiveness, and ease of installation. The Wi-Fi/Bluetooth technology gives an outstanding level of precision compared to the other methods, i.e., inductive loops, radar detectors, and image processors commonly used to infer travel time. This paper seeks to incorporate the findings of the studies on the experiences and practices regarding the system design and installation. It also clarifies the general performance of the technology and factors affecting the performance.

The system is based on the concept of reidentifying vehicles at distinct sites and calculating the time it took for the vehicle to travel the distance between them. The sensor integrates a mix of technologies that enable it to audit the Bluetooth and Wi-Fi spectra of devices within its coverage radius. It captures the public parts of the Bluetooth or Wi-Fi signals. The MAC addresses are 48-bit electronic identifiers for each device in the form of "12:34:56: 78:90: ab". The uniqueness of the MAC address makes it possible to use a matching algorithm to log the device when becomes visible for the sensor. The logged device is time stamped and when it is logged again by another sensor at a different location, the difference in time stamps can be used to estimate the travel time between both locations. Raw measured data cannot be used without a preprocessing aimed at filtering out outliers that could bias the sample. However, working with the MAC address of Bluetooth device ensures privacy, since the MAC address is not associated with any other personal data; the audited data cannot be related to individuals.

2 Literature Review

A comparative study to calculate travel time reliability in Calgary, Alberta, Canada [1] focuses on examining the accuracy and applicability of traffic data from crowdsourcing techniques for travel time and reliability studies. The study results showed that the Bluetooth technology as the benchmark was able to provide reliable traffic data for the selected study corridors for short study periods. Furthermore, it is addressed whether a lower detection rate, compared to the 3% minimum penetration rate recommended by several sources for using the Bluetooth technology, will provide reliable estimates with a reasonable accuracy for travel time studies on Canadian roads. It is in the light of the abovementioned scenarios that we decided to explore the possibilities of using Bluetooth/Wi-Fi sensors on Expressway, which, as per literature, could provide robust detection of vehicles [2, 3], for this purpose. A framework to model the Traffic and Communication Simulation was proposed in a study [2], which investigated the modeled temporal errors from the Bluetooth Media Access Control Scanner (BMS) data and thereafter, the accuracy and reliability of travel time estimations from BMS data, which was a sign of promise of the abilities of Bluetooth Scanners as a means of traffic analysis. The effect of antenna characteristics on MAC address data in terms of travel time estimation for pedestrians and cyclists was studied in another work [4], which also compared the effects of small and big antenna gains in order to suggest optimal set up for increasing the accuracy. A study pertaining to Indian conditions [5] reported on the use of a Bluetooth-based sensor to capture the travel time data and evaluated the reliability along two alternate routes in Chennai, India. Based on the data collected over a one month span, the authors observed that Bluetooth technology has the potential to provide fairly accurate travel time estimations across urban arterials in India. The general observations based on literature was that Bluetooth could perform consistently in measuring travel time reliability. On the other hand, the usage of Wi-Fi, which can help obtain a similar database, was observed to be one of the less explored technologies in this domain. It is also worth noting that, even though Bluetooth is gaining popularity in India as a data collection method because of its cost-effectiveness and ease of installation, studies pertaining to this area were not widely observed in Indian conditions. Another study [6] heralded Bluetooth as a not-fully-explored technology in the management of urban transport networks, and encouraged researchers and practitioners to take a more cautious look at what is currently understood as a mature technology for monitoring travelers in urban environments. It was on the backdrop of these findings that the motivation to pursue this topic and carry out this case study on an intercity expressway.

3 Field Implementation and Data Collection

A roadside unit is a piece of equipment that detects passing Wi-Fi/ Bluetooth devices and sends the information along or stores it. Wi-Fi and Bluetooth scanner with 5 dBi antenna gain were placed in two different locations as shown in Fig. 1.

Penetration rate, estimation of travel time, and travel speed were carried out on the stretch of 5.36 km between two road over bridge (ROB) on an intercity expressway between two prominent cities of Gujarat state, i.e., Ahmedabad and Vadodara. Two data collection units were installed at two different locations denoted by ROB 5 and ROB 8 as shown in Fig. 1. The units were installed in the median such that traffic from both the directions was effectively detected at both the locations. The study segment was devoid of any escapes between the two chosen locations adding an advantage to penetration rate analysis. The study segment of expressway was four lanes divided having carriageway width of 22 m including 2.5 m paved shoulders at each side and 2 m wide median. Continuous power source was provided to the sensors using 12 V DC batteries and was placed as shown in Fig. 2 for both the locations.

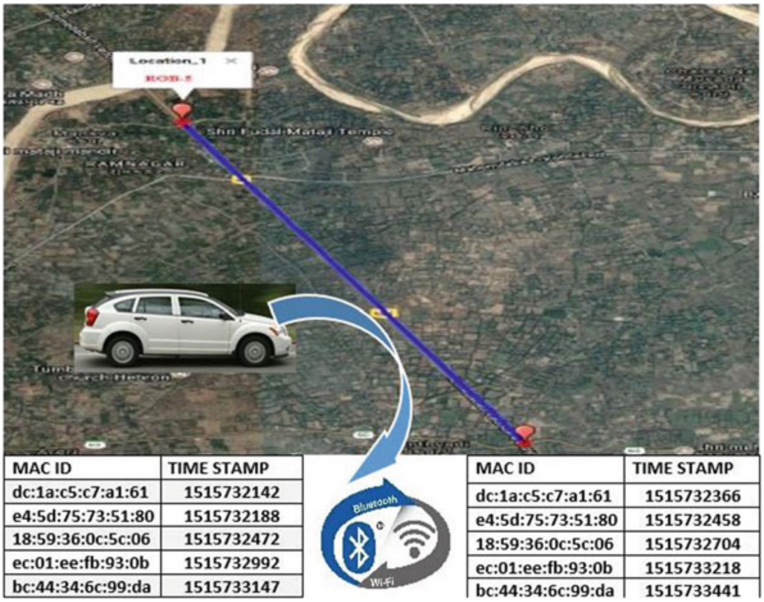


Fig. 1 Wi-Fi probing strategy

Fig. 2 Deployment of sensor on site

The radius of detection for Wi-Fi device for 5 dBi antenna was 70–80 m whereas for Bluetooth devices it was 40–50 m on open ground without any obstructions. Two video cameras were also installed at ROB 5 at a height of 6.5 m in such a way that traffic from both the direction. In the abovementioned method, the data was collected for 8 h on 12 January, 2017 from 10:00 AM to 6:00 PM. Classified vehicle count was further carried out manually for the study duration and the data collected by the sensors for the same duration was further filtered on hourly basis as shown in Table 1.

Table 1 Vehicle count at ROB 5 and Wi-Fi/Bluetooth detection at ROB 5 and 8

Hour of the day	Videographic volume		Wi-Fi detections		Bluetooth detections	
	Cars	Total volume	ROB 5	ROB 8	ROB 5	ROB 8
10:00:00	1228	1958	356	267	35	21
11:00:00	1198	1818	276	255	31	32
12:00:00	1056	1589	252	207	29	35
13:00:00	1073	1635	251	153	16	22
14:00:00	1298	1839	300	211	27	26
15:00:00	1345	2118	385	244	41	27
16:00:00	1595	2542	436	283	42	35
17:00:00	1460	2228	395	342	58	48

Table 1 indicates the number of detections at the both the ROBs where the sensors were placed as stated above. The unique detections at Rob 5 are comparatively more to that of ROB 8. This is owing to the higher no. of vehicles passing through ROB 5 and hence more unique detection at that location.

Moreover, at both the stations, the total number of Bluetooth detections is very less when compared with that of Wi-Fi detections for the same hourly durations indicating the significance for the use of Wi-Fi data as a better solution to determine traffic characteristics.

4 Data Analysis

4.1 Penetration Rate

The ratio of unique Wi-Fi/Bluetooth detections to that of volume count at same location and time is termed as penetration rate. Thus, as a performance measurement indicator of the sensors, a penetration rate analysis was carried out to find the percentage of vehicles detected using sensor. As per literature review, it was observed that major studies in the field of transportation regarding travel time analysis have been made on reliability test for Bluetooth sensor, but the data in Table 1 and Fig. 3 indicates that Wi-Fi data is much more reliable compared to Bluetooth data.

The reliability is measured by determining the percentage detection of unique Bluetooth and Wi-Fi Mac IDs obtained from the sensor with the manual video extraction for the same hour on the route. Analyses indicate that the Bluetooth detection was 1.74% of the total vehicles, whereas Wi-Fi detected 16.74% of the total vehicles. This is due to less number of the active Bluetooth device compared to Wi-Fi enabled devices. The variation of unique MAC Id detections and variation in vehicle counts for the same duration during the study period for every one-hour interval can be seen

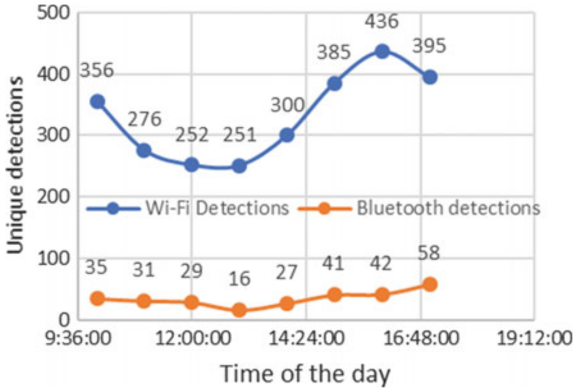


Fig. 3 Comparison of Wi-Fi and Bluetooth detections

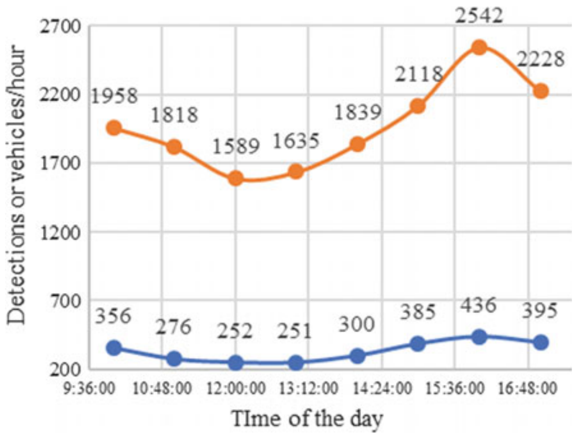


Fig. 4 Comparison plot between vehicle counts and Wi-Fi detections

in Fig. 4. The trend of video graphic volume count and unique Wi-Fi detection is nearly same indicating high reliability of the data set as well as application of sensor.

Thus, to determine the reliability of the penetration rate of the data set for the study period, a graph of Vehicle count versus Mac Id detection was plotted for every one-hour interval and can be seen in Fig. 5. The results indicate an R^2 value of 0.93 which is significantly high to justify the results. Thus, the use of Wi-Fi data can be an effective solution for evaluation of the expressway performance.

4.2 Travel Time Determination

Travel time was obtained by tracing a unique id at both the stations along with their corresponding time stamp. Thereafter, the difference in first time stamp between two stations was computed as travel time for any vehicle's Mac id. Here, the samples of travel time are obtained for both the direction on the expressway which helps to

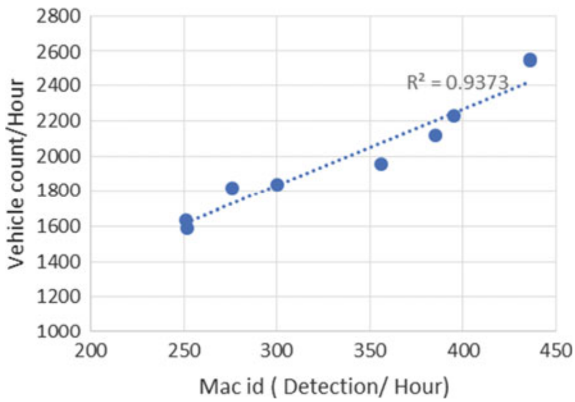


Fig. 5 Vehicle count versus Wi-Fi detections at ROB 5

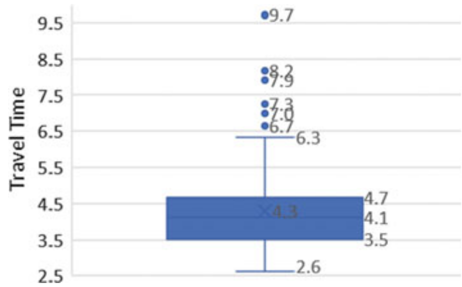


Fig. 6 Whisker box plot of travel speed in both directions

determine the homogeneity of travel time along both the directions and evaluate the performance of sensors.

Thus, whisker box plot is one such effective statistical measure which was used to separate the commercial vehicles from cars on expressway. Figure 6 represents the whisker box plot which represents the variation within the dataset of travel time of both the direction for the same mid-block section with upper and lower limit representing 75th (3rd Quartile) and 25th (1st Quartile) percentile value, respectively.

4.3 Travel Speed Determination and Model Development

For determination of better picture in variation of travel time for various categories of vehicle and their bifurcation based on their composition, the above travel time plots are presented in terms of travel speed based on their frequency for specified class interval as shown in Fig. 7.

Figure 7 represents that the travel speed variation is normally distributed for the detections in study period. The whisker box plot indicates the upper limiting value of 4.7 min which corresponds to speed limit of 60 km/h in Fig. 6. Also, literature review states that for a use of 5 dbi antenna the coverage area is considerably large

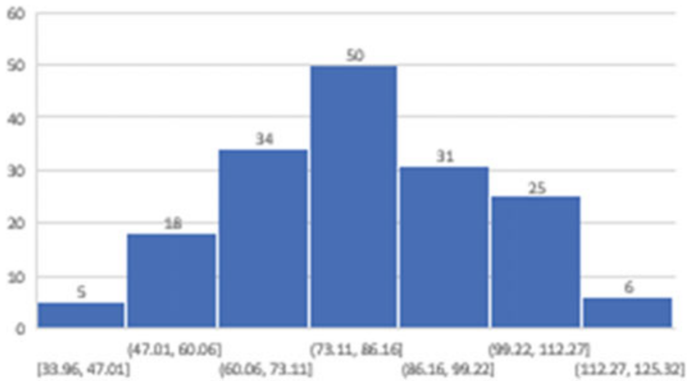


Fig. 7 Speed histogram for both directions (km/h)

and based on the inquiry cycle of the sensor, for the speed corresponding to less than or equal to 60, there is high probability of the id getting detected. This suggests that commercial vehicle should be being detected if it possesses the Wi-Fi active device in the vehicle as the average travel speed on the expressway is comparatively low. But the Fig. 7 indicates that only 15% of the total Mac ids which are detected at both locations are within the above-specified limit.

Thus, this indicates that a major proportion of commercial vehicles traveling on expressway does not possess the Wi-Fi enabled devices in the vehicle. Owing to this, it becomes necessary to determine the modified penetration rate considering the detections obtained from the sensor as that of only non-commercial vehicles.

Figure 8 shows that the normal distribution is the best possible distribution for the speed data obtained from the Wi-Fi Sensors placed at both the locations. The distribution results into a mean value of 80 km/h and standard deviation of 18.06 which is in coherence with the result obtained from the speed histogram as shown in Fig. 7. The modified penetration rate is shown in Fig. 9 which states that the penetration rate increase from an average of 16.74–25.67% and which seems to be more feasible as seen in the literature review.

The cumulative frequency diagram (CFD) in Fig. 10 is a plot of speed versus probability. The 50th percentile in CFD corresponds to 80 km/h speed whereas 60 km/h corresponds to probability of 12.5%. Also, based on Fig. 4, the speed less than 60 km/h corresponds to 15% of the commercial vehicle. Thus, the above results indicate that the assumed hypothesis that the vehicle speed less than 60 km/h is a commercial vehicle holds true and the modified penetration is much more reliable than the previously considered.

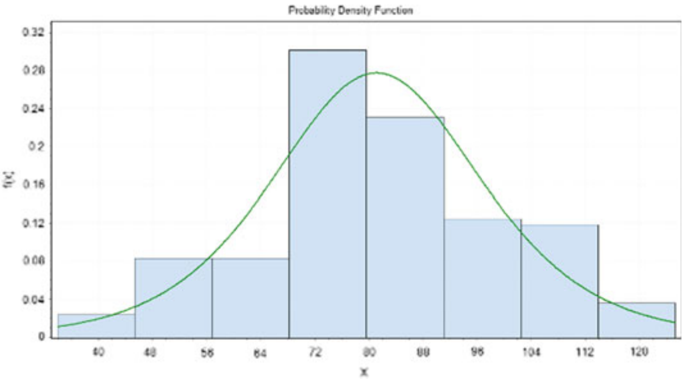
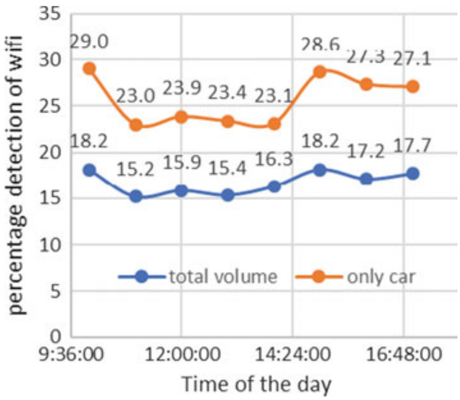


Fig. 8 Distribution of travel speed in easy fit software

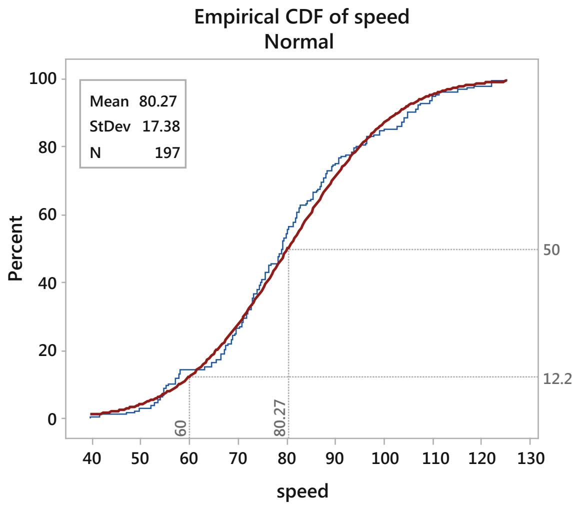
Fig. 9 Change in penetration rate for just cars



5 Conclusion

This study demonstrated the collection of time-stamped MAC address data for a stretch of 5.36 km between two locations, i.e., ROB 5 and ROB 8. The MAC address data was filtered utilizing upstream and downstream Wi-Fi/Bluetooth DCUs, so that the performance of the expressway could be analyzed. The data collected from the sensors resulted in the successful determination of 16.74% penetration rate for Wi-Fi devices, compared to only 1.74% penetration rate for Bluetooth devices. This is due to less number of active Bluetooth device compared to Wi-Fi enabled devices. The sensors were able to detect the variation in directional split of traffic in terms of variation in number of detections. The study shows that out of total volume, only 15% of the volume detected by sensors is found to be commercial vehicles and thus considering them in penetration rate analysis would lead to incorrect results. Thus, after considering only cars out of total volume, the modified penetration rate increase from an average of 16.74–25.67% and which seems to be more feasible

Fig. 10 CFD of travel speed in both directions



as seen in the literature review. Thus, the technology can also be indirectly used to differentiate the commercial and non-commercial vehicles on expressway. The cumulative frequency diagram (CFD) plotted clearly shows that the proportion of commercial vehicles carrying a Wi-Fi enabled device is very less, i.e., only 15% based on the speed less than 60 km/h corresponding to commercial vehicles.

During the study, the limitations encountered were inefficiency of the DCU to obtain classified vehicle count, range of the DCU is highly influenced by the presence of type of obstructions, speed or the vehicle to be detected and consideration of each MAC ID detection as a single vehicle unit may not represent the true scenario. Thus, to increase the penetration rate and to effectively capture the vehicles moving at a higher speed, antenna of higher strength with more coverage area can be used unlike the weaker antennas which are preferable for urban roads.

References

1. Tahmasseby S (2015) Traffic data: Bluetooth sensors vs. crowdsourcing—a comparative study to calculate travel time reliability in Calgary, Alberta, Canada. J Traffic Transp Eng 3:63–79
2. Bhaskar A, Chung E (2013) Fundamental understanding on the use of Bluetooth scanner as a complementary transport data. Transp Res Part C: Emerg Technol 37:42–72
3. Abbott-Jard M, Shah H, Bhaskar A (2013) Empirical evaluation of Bluetooth and Wi-Fi scanning for road transport. In: O'Keeffe B (ed) Australasian transport research forum 2013 proceedings, 2–4 October 2013, Australia
4. Abedi N, Bhaskar A, Chung E, Miska M (2015) Assessment of antenna characteristic effects on pedestrian and cyclist's travel-time estimation based on Bluetooth and Wi-Fi MAC addresses. Transp Res Part C: Emerg Technol 60:124–141
5. Abedi N (2014) Monitoring spatiotemporal dynamics of human movement based on MAC address data. Masters dissertation, Queensland University of Technology
6. Nantes A, Miska MP, Bhaskar A, Chung E (2014) Noisy Bluetooth traffic data. Road Transp Res J Aust N Z Res Pract 23(1):33

Influence of Driving Environment on Safety at Un-signalized T-intersection Under Mixed Traffic Conditions

Nishant Pawar, Ninad Gore and Shriniwas Arkatkar

Abstract Road traffic safety is an important issue and should be given utmost priority by traffic engineers. This research aims to proactively evaluate safety for two un-signalized T-intersections along the western frontier of India with varying driving environment under mixed traffic condition using surrogate safety measure, Post Encroachment Time (PET). PET for different vehicle category as per approach leg was extracted. The Generalized Extreme Value (GEV) was found to be the best fitted distribution for explaining the temporal variations observed in PET values and was further extended to estimate crash probability. It was observed that driving environment has a prominent effect on crash probability. Improved driving environment reduced crash probability at the intersection. Results indicated minor approach road users comparatively have more crash probability to major approach road users. Median to be introduced at undivided intersection to enhance the driving environment and speed breakers, sign board installation is suggested at both the intersections.

Keywords Driving environment · Post encroachment time · Generalized extreme value · Probability of crash

1 Introduction and Background

India has world's largest youth population and is likely to have the world's largest workforce by 2027. Naturally, in the forthcoming years, there will be rapid growth in travel demand. At present due to rise in income levels and due to inadequate,

N. Pawar · N. Gore · S. Arkatkar (✉)
Civil Engineering Department, Sardar Vallabhbhai National Institute of Technology, Surat, Surat 395007, India
e-mail: sarkatkar@gmail.com

N. Pawar
e-mail: pawarnishant2@gmail.com

N. Gore
e-mail: ninadgore24@gmail.com

D. Deb et al. (eds.), *Innovative Research in Transportation Infrastructure*, Lecture Notes in Intelligent Transportation and Infrastructure,
https://doi.org/10.1007/978-981-13-2032-3_3

inefficient public transportation services lead to affordability of motorcycle and car ownership which resulted in shift of people from public to private transport. According to a report of Road Accident in India 2016, youth of age group 18–34 years and working age group of 18–60 years accounted 46 and 83% in the total road accident fatalities. Also, 45% of the total accidents occurred on other district roads where 37% accidents occurred on junctions and 72% accidents befallen at uncontrolled junctions. Henceforth, safety of road user at un-signalized intersection must be given utmost priority and research must be carried out considering various aspects of roadway geometric conditions, traffic characteristics and road user behaviour along with vehicular stream characteristics to improve overall infrastructure for all kind of road users to minimize various factors responsible for road accidents.

Research has been carried out in the past to evaluate the safety of the intersection by studying past accident data available from the local and state transportation authorities. Crash models were developed to predict the crash occurrence at a particular intersection. Major drawback of traditional approach is to rely on the past accident data. In developing countries like India, where accidents are generally not reported arises question of reliability on the results of crash prediction models. Hence, there is a necessity to develop proactive methods for safety evaluation where the present condition of the intersection can be analyzed without any requirement of past accident data.

Surrogate safety measures were developed to proactively study the present scenario of the un-signalized intersection. These surrogate safety measures also known as proximal safety indicators are based on study of conflict where accident occurrence is not necessary. Conflict study is able to identify nature as well as the occurrence of near accident and signifies a fast approach to estimate accident frequency and accident outcomes [1].

Time to Collision (TTC), Post Encroachment Time (PET), Deceleration Rate (DR), Deceleration-to-Safety Time (DST), Proportion to Stopping Distance (PSD), etc. are the proximal safety indicators used for safety evaluation. TTC and PET are more frequently used methods for safety evaluation of un-signalized intersections [3]. At un-signalized intersection, crossing conflicts are the major conflicts and PET is the most suitable proximal safety indicator to assess safety [4]. Pirdavani et al. [6] studied safety evaluation of un-signalized intersection using proximal safety indicators and microsimulation. Deepak and Vedagiri [2] conferred a unique strategy of measuring proximal safety indicator to assess the level of safety at an uncontrolled intersection for heterogeneous traffic conditions using microscopic simulation model, VISSIM. The concept of negative PET was introduced for the safety assessment of un-signalized intersection. Songchitruksa and Tarko [9] deliberated innovative solicitation of the extreme value theory in safety evaluation based on observed traffic characteristics using PET measure. Mishra et al. [5] adopted a hybrid approach to evaluate safety at four-legged un-signalized intersection. Crash frequency was estimated and sensitivity analysis was done to examine effect of change in traffic volume on PET values. Driving simulator was introduced in the study to analyze crash occurrence based on driving characteristics.

Review of literature reveals PET is the appropriate measure to assess safety at an un-signalized intersection. Effect of change in traffic parameters (traffic volume and composition) on the safety of the un-signalized intersection has been analyzed using Microsimulation tool VISSIM. Driving behaviour of road users while approaching un-signalized intersection is also analyzed. Also, PET at aggregate level, i.e. for the entire intersection is estimated. Conversely, the effect of change in driving environment (undivided and divided un-signalized intersection) on the probability of crash occurrence for different vehicle category as per approach leg at un-signalized intersection seems unreported. Based on this backdrop, the present study has been formulated to study probability of crash in accordance to vehicle category as per approach leg and the effect of change in driving environment on probable crash occurrence for the most critical right-turning collision at un-signalized T-intersection.

2 Methodology

Based on the brief literature review, the detailed methodology adopted for the current study is described broadly through Fig. 1. Primarily, PET for undivided un-signalized T-intersection and divided un-signalized T-intersection for each of the considered R-T movement was extracted. Thereafter, the probability of crash was estimated using GEV distribution. The probability of crash obtained for undivided and divided intersection was compared to comprehend the effect of driving environment on the safety of road users. Based on the results obtained, potential safety improvement measures were proposed.

2.1 Study Area

Two ideal intersections, i.e. undivided un-signalized intersection and divided un-signalized intersection comprise of two roads meeting at right angles with proper sight distances and visibility, with one road terminating at one end. Approach legs at both the intersections have similar lane width and lane configurations. Based on reconnaissance surveys of various intersections in the western frontier of India, an undivided un-signalized T-intersection in Mumbai as shown in Fig. 2a and divided un-signalized intersection in Surat as shown in Fig. 2b are identified as ideal intersections for this research study. Hydri Road, Police Station Road and Navsari-Palsana Road and S Zone Road are the major approaches whereas Lodha Road and Tulsi Road are the minor approaches of the undivided and divided intersections, respectively.

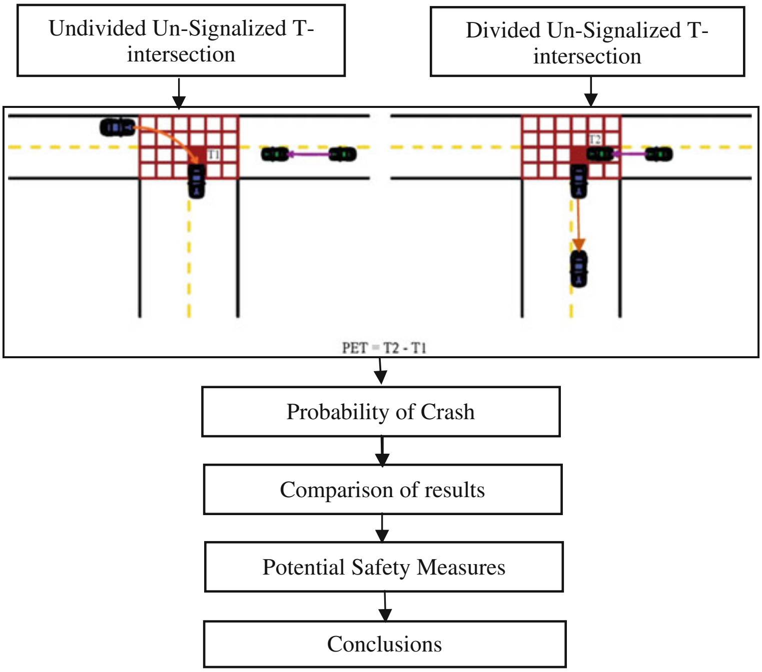


Fig. 1 Research methodology

2.2 Data Collection

Videography technique was adopted to capture and study the exact behaviour of drivers at the intersection. High-definition camera was placed on the terrace of the high-rise building in the vicinity of the study intersection, as a vantage point to record the traffic movement from all the possible directions. Videography was conducted on the normal working day during peak hours (capable of representing entire day scenario). On 16 November 2017 and on 5 January 2018, videographic data for undivided un-signalized T-intersection and divided un-signalized T-intersection were collected, respectively.

2.3 Data Extraction and Processing

Manually, data extraction was carried out from the recorded video file to evaluate the traffic flow characteristics like turning movements, vehicle composition and PET. Primarily, 12 and 14 m boundaries were marked on the field at undivided un-signalized T-intersection and 14 m and 14 m boundaries were marked on the field at divided un-signalized T-intersection to represent the area of the intersection with reference

Fig. 2 **a** Snapshot of study intersection in Mumbai; **b** snapshot of study intersection in Surat

to approach legs. This was performed during the free-flow conditions by restricting the traffic at the intersection for some time with the help of police authorities. An image of grid size 3 × 3.5 m (with reference to the respective lane marking of that approach leg) for undivided un-signalized T-intersection and 3.5 × 3.5 m for divided un-signalized T-intersection were drawn using AUTO CAD and were overlaid on the respective video file using Corel Video Studio Pro X10 software. Avidemux 2.6 with 0.04 s accuracy was used for data extraction. Fundamentally, PET is the time lapse between end of encroachment of turning vehicle and the time that the through vehicle actually arrives at the potential point of collision as shown in Eq. (1).

$$\text{PET} = \text{T2} - \text{T1} \tag{1}$$

where

T1 time of the offending vehicle leaves the conflict zone
T2 time of the conflicting vehicle enters the conflict zone

Conflicts analogous to PET values less than 6 s are considered for further analysis. This threshold value was anticipated based on the fact that for PET more than 6 s, there will be considerably less chance of near crash occurrence [10]. It was also observed that for one subject vehicle, there can be more than one value of PET and the minimum PET value was considered for analysis purpose.

3 Analysis and Results

Preliminary analysis revealed that on an average overall traffic composition at both the intersections for all three approach legs comprised of 50–60% of motorized two-wheelers followed by auto-rickshaws of 30–40% with 5–10% of cars. Combined composition of LCV, Trucks and Buses was observed to be less than 5%.

For un-signalized T-intersection, it is coherent that the severity due to Right-Turning (R-T) collision is high as compared to other movements at T-intersection. Thus, (R-T) interaction was given priority over other possible interactions and rear-end interactions were avoided. The PET values were considered as high as 6 s and as low as -1.5 s. Negative values of PET highlight that either the conflicting vehicles accelerated through the intersection or probably offending vehicle decelerated while manoeuvering through the conflict area. Relative frequency distribution for undivided and divided un-signalized T-intersection for R-T conflict as per approach leg for various vehicle categories were plotted as shown in Fig. 3. From relative frequency curve, it is observed that maximum relative frequency of PET value is around 0 s for every single dataset of undivided as well as divided T-intersection. The frequency of negative PET values at undivided T-intersection is comparatively more than divided T-intersection, unfolding the fact that conflicts are more critical at undivided T-intersection. Interestingly, PET values of minor approach are more as compared to major approach at both undivided as well as divided intersection indicating more critical conflicts through minor approach.

For the current study, extreme value theory is applied for estimating the probability of crash. For this, PET dataset of different vehicle category as per approach leg was tested for potential statistical distributions. Goodness-of-fit test results using K-S test showed that Generalized Extreme Value (GEV) is the best fitted distribution among potential statistical distributions.

Based on the premise that a PET value less than zero represents a crash, the probability of undergoing a crash in one-hour interval is equivalent to the probability that PET is zero or less as shown in Fig. 4. The probability of crash for different vehicle categories as per approach leg for undivided un-signalized T-intersection is shown in Table 1 and for divided un-signalized T-intersection is shown in Table 2.

From Tables 1 and 2, it can be noted that the probability of crash for car and for motorized two-wheelers is less than other vehicle categories for undivided and divided intersection. Overall probability of crash for Lodha Road and Tulsi Road is more as compared to Hydri Road and S Zone Road. Overall probability of crash for undivided and divided T-intersection at aggregate level is found to be 0.32 and 0.20, respectively.

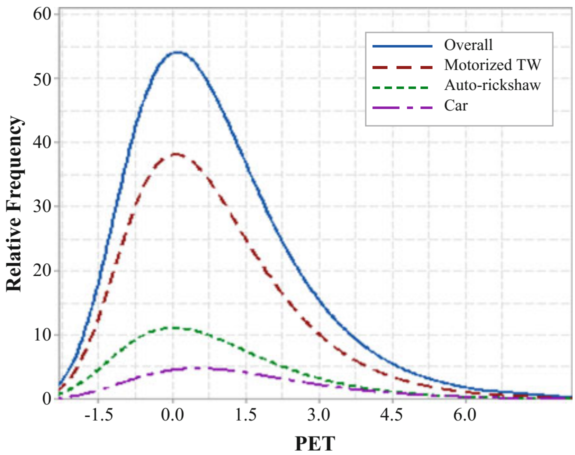


Fig. 3 Relative frequency curve for Hydri Road

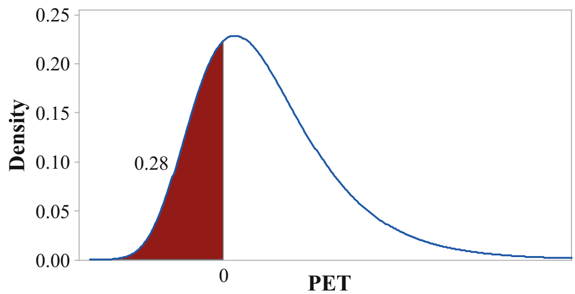


Fig. 4 Distribution plot and probability of crash for Lodha Road of car

Table 1 Probability of crash for undivided un-signalized T-intersection

Vehicle category	Hydri Road	Lodha Road
Motorized two-wheeler	0.31	0.34
Auto-rickshaw	0.32	0.35
Car	0.24	0.28
Overall	0.30	0.33

Table 2 Probability of crash for divided un-signalized T-intersection

Vehicle category	S Zone Road	Tulsi Road
Motorized two-wheeler	0.18	0.20
Auto-rickshaw	0.21	0.21
Car	0.26	0.25
Overall	0.20	0.21

4 Major Findings and Potential Safety Measures

1. Probability of crash for divided un-signalized T-intersection was observed to be less than that of undivided un-signalized T-intersection. This unfolds the fact that as the driving environment is improved, probability of crash at the intersection gets reduced.
2. Gap acceptance behaviour of drivers plays an important role while manoeuvring from minor to major approach. Regardless of vehicle category, drivers are unsafe if they take risk of accepting small gaps in through traffic [8]. It is observed that drivers from minor street accept small gap and thus there is high risk of conflict with through vehicle from major street. Due to this impatient behaviour of drivers, probability of crash for R-T vehicles from minor to major approach is more at both the intersections.
3. It is observed that although driving environment is improved at divided un-signalized T-intersection, rise and fall of crash probability of same vehicle category is found at undivided and divided intersection. This clearly indicates crash occurrence is very much based on driving behaviour of the drivers. Aggressive driving behaviour cannot be controlled but can be reduced up to certain extent. Warning and yield signs can be used to regulate the traffic approaching intersection. Speed breakers at certain distance from the intersection can be effectively used to reduce high-speed of the drivers [7].

5 Conclusions and Way Forward

The reported values of PET may vary for intersections with different traffic and geometric characteristics. But present study confronts some valuable information resembling the influence of driving environment on the overall safety of the intersection. Based on the findings of the study, traffic safety engineers can effectively improve the safety of the un-signalized intersection by taking short-term measures like installing sign boards and speed breakers at the approach legs to guide and control the traffic, respectively, to long-term measures like improving driving environment or improving intersection geometry, i.e. providing traffic flow regulators like small island or rotary can significantly contribute in crash reduction.

Further studies are required to be carried out on various un-signalized T-intersection with varying geometrics and driving environment to provide generalize measures based on the current condition of the intersection. The probability of crash according to offending vehicle category has been studied but change in probability of crash of offending vehicle category with respect to conflicting vehicle category can be studied to have a clear idea of drivers' change in behaviour, variation in the probability of crash with respect to conflicting vehicle category. Also, the study is required to be carried out considering aggressive behaviour of drivers (R-T drivers accepting small gaps) and their influence on the overall safety of drivers at the intersection.

References

1. Archer J (2000) Developing the potential of micro-simulation modeling for traffic safety assessment. In: Proceedings of ICTCT conference, Corfu
2. Deepak V, Vedagiri P (2014) Proactive evaluation of traffic safety at a un signalized intersection using Micro-Simulation. J Traffic Logist Eng 2(2):140–145
3. Gettman D, Head L (2003) Surrogate safety measures from traffic simulation models. Transp Res Rec J Transp Res Board 1840:104–115
4. Klunder G, Abdoelbasier A, Immers B (2004) Development of micro simulation model to predict road traffic safety on intersections with surrogate safety measures. Report TNO, Business Unit Mobility & Logistics, The Netherlands
5. Mishra A, Chepuri A, Arkatkar S, Maji A (2017) Safety evaluation of un-signalized intersection using hybrid approach involving empirical and simulation data sources. In: Presented at 97th annual meeting of Transportation Research Board, Washington, USA
6. Pirdavani A, Brijs T, Bellman's T, Wets G (2010) Evaluation of traffic safety at un-signalized intersections using micro simulation: a utilization of proximal safety indicators. Adv Transp Stud Int J Sect A 22:43–50
7. Reddy S, Chepuri A, Arkatkar S, Joshi GJ (2016) Developing proximal safety indicators for assessment of un-signalized intersection—a case study in Surat, In: 14th world conference on transport research, Tongji University, Shanghai, China, 10–15 July 2016
8. Shekhar Babu S, Vedagiri P (2016) Proactive safety evaluation of a multilane unsignalized intersection using surrogate measures. Transp Lett. https://doi.org/10.1080/19427867.2016.1230172
9. Songchitruksa P, Tarko A (2006) The extreme value theory approach to safety estimation. Acc Anal Prev 38:811–822
10. Vogel K (2003) A comparison of headway and time to collision as safety indicators. Accid Anal Prev 35:427–433

Human Evacuation Simulation During Disaster: A Web Tool

Guru Prakash Ramaguru and Venkata Dilip Kumar Pasupuleti

Abstract One of the most important steps after any disaster is evacuating people towards temporary shelters where minimum requirements for life are planned. Planning for the temporary locations and evacuating people towards them is always a challenging job for the government or any other organization which takes care of the post-disaster scenario. This is especially true for those places that are very remote or places that have been hit by a disaster for the first time. So, this arises an important study to be done for the simulation of evacuation scenarios within the stipulated time. In this study, a simple two-dimensional tool is developed which calculates the total evacuation time for a given scenario. This will also help the planners to choose the locations of temporary shelters so that people are equally distributed. Alternative paths for evacuating or moving people can also be simulated if locations of obstacles are incorporated in the input file of the program. As a case study, a small town of two thousand people is considered and evacuation simulations are carried out for various scenarios.

Keywords Disaster simulation · Agent evacuation · Tool development

1 Introduction

Population is growing at an alarming rate and the current average increase in population is 83 million people per year globally. For such huge population, the natural resources are exploited in terms of large clear spaces and the number of story's of building structures is increasing to accommodate larger group of people at the same

G. P. Ramaguru
Computer Science Engineering, International Institute of Information Technology, Hyderabad, India
e-mail: ramaguruprakash@gmail.com

V. D. K. Pasupuleti (✉)
School of Engineering Sciences, Mahindra Ecole Centrale, Hyderabad, India
e-mail: venkata.pasupuleti@mechyd.ac.in

D. Deb et al. (eds.), *Innovative Research in Transportation Infrastructure*,
Lecture Notes in Intelligent Transportation and Infrastructure,
https://doi.org/10.1007/978-981-13-2032-3_4

time. The common structures that where most people inherent are schools, colleges, malls, theaters, stadiums, religious places, exhibitions, etc. These huge structures usually have a very complex design which are esthetically pleasing and at the same time support huge number of people. It is clear that number of crowded places and frequency of crowd gatherings have significantly increased in the past decade. Since most of the natural disasters are unpredictable and deadly. It is increasingly important that these common structures are designed and planned in such a way that evacuation of people to safe places during the disasters is easier, efficient, and easy to identify informed. Proper institutions and laws have to be in place to ensure that the evacuation procedures are instilled in each and every structure.

World has experienced several life losses at different events due to improper planning of evacuation routes or management. Few of the most recent ones from India and abroad are 20 people died and 30 got injured during a stampede on a foot overbridge in Mumbai due to heavy rain on September 29, 2017, 29 people died due to stampede during Godavari Pushkaralu in Rajahmundary in Andhra Pradesh when large number of pilgrims rushed to take a holy dip in the river, on 14 July 2015. On 13 October 2013, Stampede occurred near Ratangarh temple in Datia, Madhya Pradesh leading to the death of 89 people and injured over 100 at a bridge leading to a remote Hindu temple. There are hundreds of such incidents in the history where a large number of people lost their lives because of poor infrastructure and mismanagement of crowd.

From past few years, there has been a lot of research work carried out to understand crowd behavior and to provide building designs for supporting faster and safe evacuation, planning during an emergency, simulation of crowds, etc. There are also various parameters which affect the crowd movement during evacuation, few of the prominent factors are size of the room, size of the door, location of door, signboards guiding towards evacuation area, shape of the building, etc. There is a strong requirement of crowd simulation tool that calculates the evacuation time and provides the simulation of evacuation for the given parameters like room size, location of door, number of doors, size of doors, and crowd size. Using the latest HTML5 technology a web-based tool is developed to simulate crowd evacuation or the given parameters mentioned above. We can easily see the evacuation patterns that can be used for better designing of the place as well as analyzing the important factors to be considered for safe evacuation.

2 Literature Review

Evacuation systems have to be properly set up at buildings and structures where there is a possibility of any hazard. By evacuation system, we mean that all the occupants of the building should be able to evacuate the place as quickly as possible during any disaster or hazard. To illustrate, let us consider the case of fire or earthquake, the established system should ensure that all the people present in the structure be evacuated before the occurrence of any casualties. For setting up such robust evacuation systems, it is essential to know about the congestion areas, improper door positions, and average time of evacuation of the current buildings. Since it is not possible to conduct mock drills for each and every scenario, realistic computer simulation system will be helpful to analyze and choose the best design for the evacuation. Before developing our own model of simulator, a background literature has been studied to understand various simulation models developed and their background principles.

The most widely used evacuation route planning for an evacuation simulation is the shortest route method [1–4]. Simulation tools developed and available for public are FPETool [5], EVACNET4 [6, 7], TIMETEX [8], WAYOUT [9], STEPS [10, 11], building EXODUS [12], ASERI [13], EXITT [14, 15], PEDROUTE / PAXPORT [16]. Simulation models which are available from a consultancy for a given scenario are PathFinder [17, 18], EESCAPE, Myraid [19]. There are many models which cater to only a particular scenario like fire accident, blocked exists and obstacles, agents with disabilities, elevators/lifts evacuation, counter flow, route choice of the occupants. There are a lot of AI based simulators which depend on real data to perform evacuation [20, 21].

Considering the survey conducted on Nagata Elementary community in Nagata Ward, Kobe. The people of this community suffered from the Great Hanshin-Awaji Earthquake in 1995 [22]. The outcome of the survey was really interesting. More than 84 percent of the people know the location of the nearest shelter. The survey also revealed that distance to the nearest shelter is a very important factor among the other 45 factors [23]. Surprising the people in the same neighborhood has planned to take different routes to the same shelter. From this, it can be concluded that, though the people may belong to the same community their evacuation plan during a hazard varies greatly based on their location, time at which they start to evacuate, their physical capabilities, ability to remain calm during calamity termed to be human behavior.

3 Proposed Tool Description

A simple web tool has been developed for calculating evacuation time and to see the routes from any given scenario, consisting plan of a town and number of people need to be evacuated to the nearest shelter or at times of earthquake towards an earthquake resistant structure, input data can also contain the percentages of different age groups or male, female, and children. Either the case, differentiation is made on speeds of a person.

3.1 Grid Methodology and Frame Work

The layout is modeled as grid of individual square blocks of size 0.5 m × 0.5 m. And an agent will occupy a grid point at any given time as defined by the user or

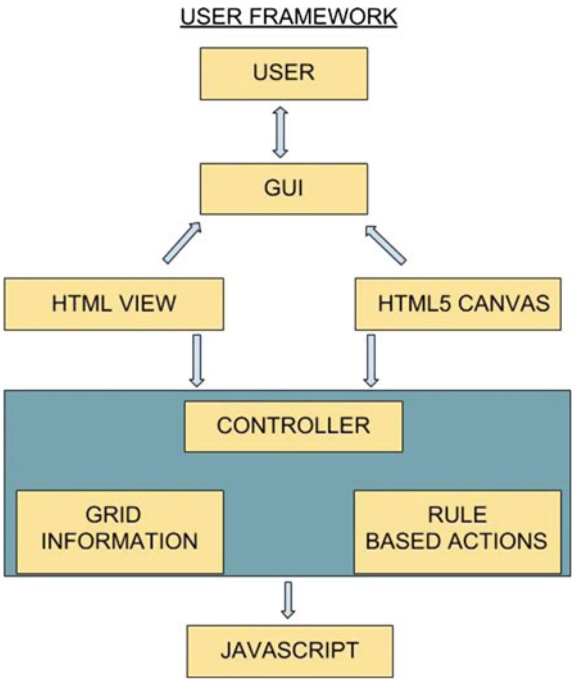


Fig. 1 Flow chart of the framework

random function, and the maximum agent velocity is taken as 1.5 m/s in case of male agent. This study primarily focuses on evacuating male agents, but the tool also has provision of simulating evacuation of female and child agents. The framework of the tool is represented in the form of flow chart as seen in the Fig. 1.

3.2 Agent Algorithm

Each agent moves independently and is fully aware of the structure, i.e., each agent knows the size of the grid, number, position of shelter, door, and obstacles. Each agent follows a set of rules for evacuation as detailed. a. Agents always move towards their nearest door/shelter irrespective of the number of obstacles and other agents in between, b. Whenever agent finds an obstacle in between door/shelter and itself, the agent tries to go around it in the smallest possible path as described sequentially in the Fig. 2, c. At any given time, two agents cannot be in the same grid position, d. All the agents at a distance of 1 grid position from the door of a shelter will enter simultaneously.

Flowchart in Fig. 3 explains the evacuation steps for each agent, in step-1, algorithm calculates the distance between agent and all the doors/shelters to be reached for, and then determines the nearest door of an shelter, in step-2, it will check for

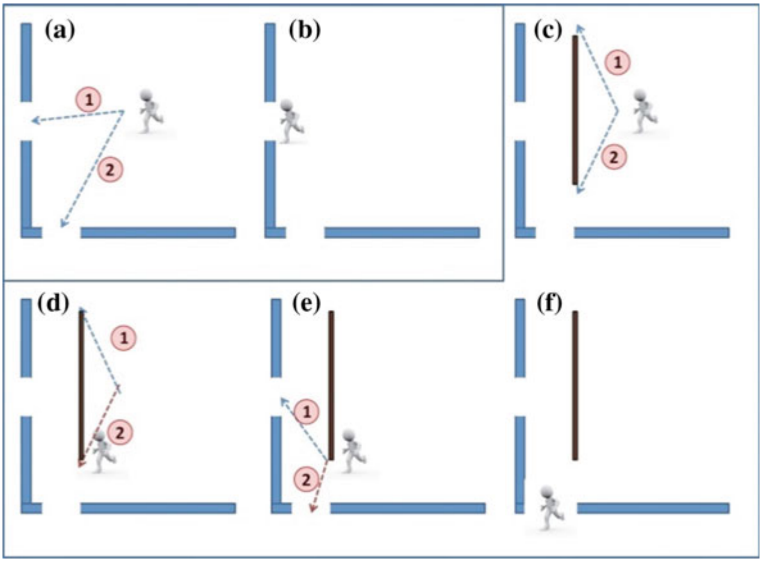


Fig. 2 Rule based agent movement

presence of an obstacle between agent and its nearest door, in step-3, it considers the nearest obstacle in case of multiple obstacles or the only obstacle and in step-4, it calculates the distances between agent and door from either sides of obstacle. In step-5, it considers the point next to the obstacle on the side by which the agent takes the least time and makes it a temporary door. In step-6, it checks the next position in the direction of the temporary door or the actual door in case of no obstacle. In step-7, in case of presence of wall or obstacle or other agent, it will check other four next nearest possible directions and if all the mentioned directions are filled with obstacle or wall or agents, the agent does not move. In step 8, algorithm goes to step-1 till agent is evacuated.

In the current developed tool, there are three types of agents and all are differentiated based on their velocity or speed. Male agents have a speed of 1.5 m/s, female agents have a speed of 1.2 m/s, and child agents have a speed of 0.8 m/s. It is assumed that all the agents will be moving independent. So no family groups are considered for evacuation scenario. It is also observed in reality that at the time panic, most of the people evacuate independently then getting attached to a group.

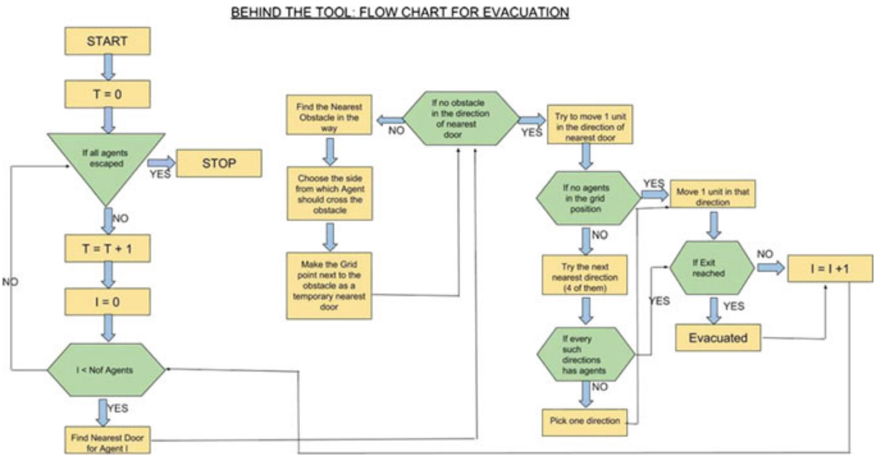


Fig. 3 Flow chart of methodology for an agent movement till complete evacuation

3.3 *Graphical User Interface (GUI)*

Figure 4 shows the snapshot of the web tool developed with a simple case study. It also includes the labels for the further explanation. Labels from 'a' to 'w' encircled are used to describe the functions of input boxes, buttons, and output texts as describe.

4 Case Study

A simple web tool has been developed for calculating evacuation time from any two-dimensional plan of a structure or a town plan with shelters. Details of the development framework in terms of grid, algorithm, and user interface have been explained in the following sections.

4.1 *Evacuation Towards an Opening Without Obstacles*

To understand the relation between location of the doors and evacuation time, we have simulated 16 different cases as seen in Figs. 5 and 6. Figure 5 shows the simulation of male agents evacuating form four doors of a hall with full capacity. This simulation has been showed to understand the evacuation process done through the abovementioned methodology. It gives one of the fastest ways of evacuation as it is free from the obstacles. Interpretation from the plots/graphs shown in Fig. 6, it clearly indicates the location of the door will directly affect the evacuation time.

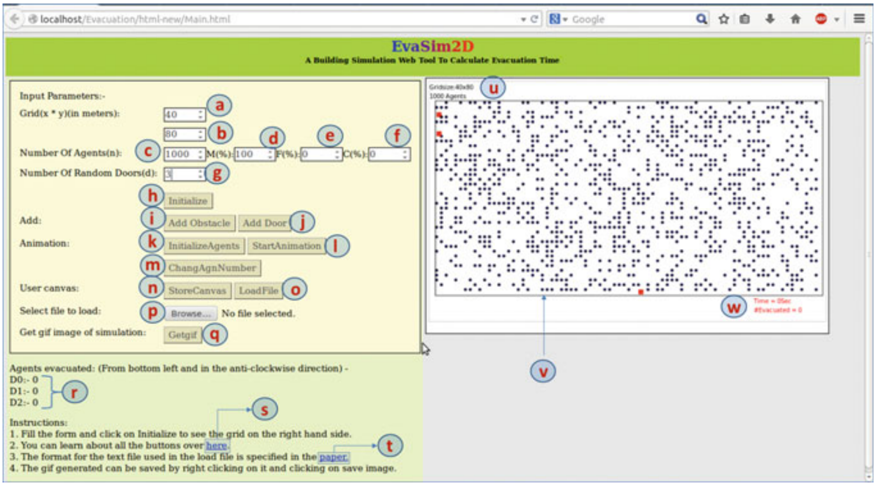


Fig. 4 Screen shot of user interface with labeled components. **a** Input for layout's vertical length in meters, **b** input for layout's horizontal length in meters, **c** number of agents, **d** percentage of male agents, **e** percentage of female agents, **f** percentage of child agents, **g** number of random doors, **h** initialize the grid using the values given above, **i** user defined doors, if (x2 = −1), continuous doors are formed (x1, y1) to (x1, y2 − 1), if (y2 = −1), continuous doors are formed (x1, y1) to (x2 − 1, y1), else doors will be added at (x1, y1) and at (x2, y2), **j** user defined rectangle obstacles, (x1, y1) will be the left bottom coordinates, (x2, y2) will be the right top coordinates, **k** simulation is seen in the window (v), **l** re-initialization of grid, **m** number of agents can be changed for the same configuration, **n** stores the current grid information in a text file, **o** loads the file chosen at (p) on to the grid, **p** browse to a file to be used by load canvas (o), **q** generates animation of current simulation in gif format, **r** number of agents evacuated at each door at any given point of time, **s** more details of GUI can be downloaded here in PDF format, **t** text format of file to be uploaded at 'p' can be downloaded at this link, **u** grid size and number of agents are shown, **v** simulation layout, **w** number of evacuees at simulation time

Evacuation will be faster if the door is located at the center of longer dimension of the plan, instead door at center of shorter dimension, if planned for a single door. Similar conclusion can be drawn for case-2 (Fig. 6b) having two doors for exit as seen in the figure. The doors located at the center of longer dimensions have faster evacuation when compared to other three locations considered. Similarly, simulations are carried for the three doors, the evacuation was faster when two of the doors were at the center of the longer dimension. But when multiple doors were present at the shorter and longer dimensions, the complete evacuation time is almost the same. In case of four doors, five cases were considered and simulation is carried out. Similar to all the cases described, even for this case evacuation is faster, if the doors are located at the center of shorter and longer dimensions.

Other important conclusion can be made from the simulations carried are if all the doors are located evenly then evacuation time is much faster when compared to other locations. Apart from that, if the all the doors are located on any one side of the hall, then the evacuation time is very high.

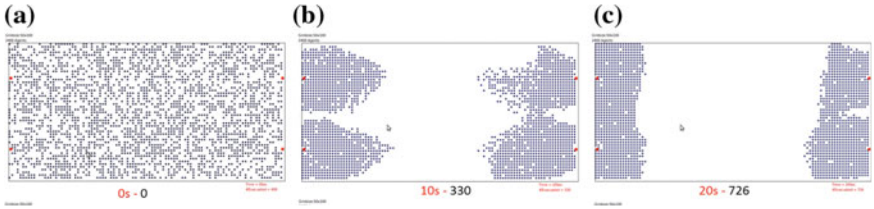


Fig. 5 Sequential simulation snapshots for 2400 agents with no obstacles

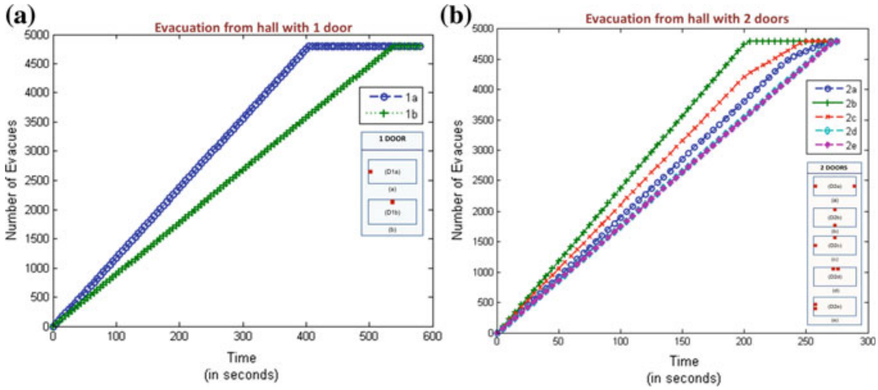


Fig. 6 Rate of evacuation of hall with full capacity for **a** single door at two opposite locations, **b** two doors at five different locations

4.2 Evacuation Simulation of People from Two Row of Houses Towards a Shelter

In this case, as shown in Fig. 7, two rows of houses are considered with maximum people of 1500. The total length of the considered evacuation scenario in this case is 40 m by 100 m. In terms of pixels, it is 80×200. As explained earlier, an agent needs 0.5×0.5 m to stand. The gray color indicates a group of houses, which might be individual houses or group of houses, the only assumption in this scenario is agents cannot move in between the gray color. All the agents have to come outside on to the road shown in white color and have to evacuate towards nearer to the shelter, which is shown in light gray color. Also, if clearly observed the agents used in this study are of three types, males, females, and children.

All three types of agents are represented with three different colors. Similar to previous results, Fig. 7a shows the evacuation at 11 s, where 134 agents have been moved into the shelter, in the same way, sequential evacuation at regular intervals have been showed in Fig. 7a–f. The total evacuation time for all the agents is 91 s or 1500 agents have been evacuated to temporary shelter in 94 s. This could be impossible in a given scenario but can be achieved if properly planned. And these

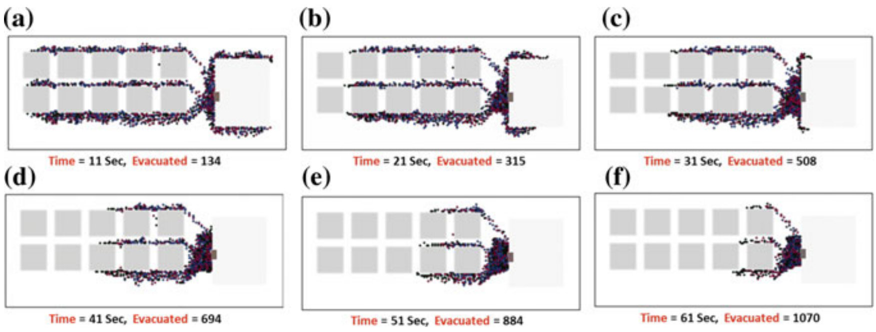


Fig. 7 Sequential simulation snapshots for 1500 agents

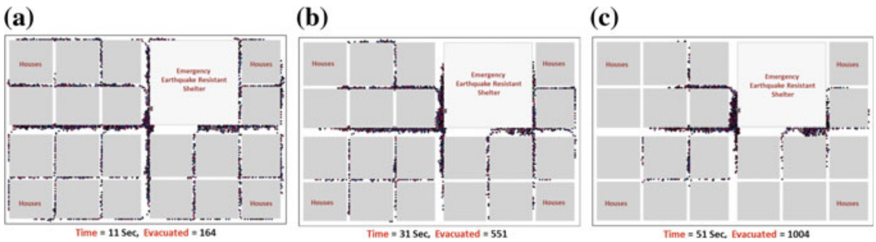


Fig. 8 Sequential simulation snapshots for 2000 agents

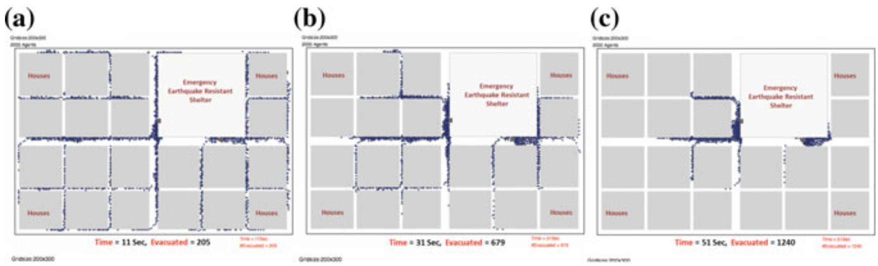


Fig. 9 Sequential simulation snapshots for 2000 agents consisting 100% males

simulation tools will help to solve in choosing the temporary location for a given town.

Figures 8 and 9 show two different cases for the assumed town consisting 2000 people. The town size is 100 × 150 m, or 200 × 300 pixels. In the case-1, the agents are divided into males, females, and children into 50%, 35%, and 15%, respectively. In this case, total evacuation time is calculated to be 174 s which is also ideal. But in the second case, same 2000 agents are considered with only male agents and total evacuation time is calculated to be 130 s. Comparing both the cases, there is difference in total evacuation time.

5 Conclusions

Evasim2D is a web application which helps in calculating the evacuation time of crowd in specified 2D spaces such as buildings, stadiums, open grounds, towns, etc. It also produces a simulation of the evacuation helping us to visualize how the evacuation happens over time. It can be used for finding the shortest routes towards a shelter during or after a disaster which would give the least evacuation time. The web tool is developed using HTML5, CSS, and Javascript. HTML5 canvas was used for rendering the simulation. An agent is evacuated based on set of rules. Each agent is moved independently and is fully aware of the structure in terms of size of the grid, position of doors and obstacles. As a preliminary study, a simple and square shaped town is planned for evacuation. But this tool has the capacity of simulating the evacuation from any given town. Finally, this tool can used by any person to calculate the evacuation time for various two-dimensional layouts. Future work of this project extends to apply for a real earthquake affected area to calculate the evacuation time towards a temporary shelter. This could also be used as a mobile application where users can find the temporary shelter and shortest path towards a shelter.

References

1. Chen X, Meaker J, Zhan F (2006) Agent-based modeling and analysis of hurricane evacuation procedures for the Florida Keys. Nat Haz J Int Soc Prev Mitig Nat Haz (Springer; International Society for the Prevention and Mitigation of Natural Hazards) 38(3):321–338
2. Takahashi TI, Nakagawa, Higashiyama J (1989) Research on evaluation of evacuation system considering dynamics in flooding water. Annu Disaster Prev Res Inst Kyoto Univ 32 B-2 757–780
3. Stern E, Sinuany-Stern Z, Holm ZS (1996) Congestion-related information and road network performance. J Transp Geogr 4(3):169–178
4. Katada T, Kuwasawa N, Yeh H (2004) Disaster education for Owase Citizen by using tsunami scenario simulator and evaluation of that method. Sci Technol Soc Rev 2:99–208
5. Nelson HE, Mowrer FW (2002) The SFPE Handbook of fire protection engineering. Bethesda, USA, National Fire Pratection Association, 367380
6. Kisko TM, Francis RL (1985) EVACNET+: a computer program to determine optimal evacuation plans. Fire Saf J 9(2):211–220
7. Kisko TM, Francis RL, Nobel CR (1998) EVACNET4 user's guide, version 10/29/98, University of Florida
8. Harrington SS (1996) TIMTEX: a hydraluic flow model for emergency egress. MSc Department of Fire Protection Engineering, University of Maryland
9. Shestopal VO, Grubits SJ (1994) Evacuation model for merging traffic flows in multi-room and multi-story buildings. In: Fire safety science—proceedings of the 4th international symposium, pp 625–632
10. MacDonald M (2003) STEPS simulation of transient evacuation and pedestrian movements user manual. Unpublished work 23
11. Wall JM, Waterson NP (2002) Predicting evacuation times—a comparison of the STEPS simulation approach with NFPA 130. In: Fire command studies, vol 1(1)
12. Gwynne S, Galea ER, Lawrence P, Filippidis L (1998) A systematic comparison of model predictions produced by the building EXODUS evacuation model and the tsukuba pavilion evacuation data. Appl Fire Sci 7:235–266

13. ASERI (Advance Simulation of Evacuation of Real Individuals) A model to simulate evacuation and egress movement based on individual behavioural response (2004). http://www.ist-net.de [On-line]
14. Levin BM (1988) EXITT—a simulation model of occupant decisions and actions in residential fires. In: Fire safety science—proceedings of the second international symposium, pp 561–570
15. Kendik E (1995) Methods of design for means of egress: towards a quantitative comparison of national code requirements. In: Fire safety science—proceedings of the 1st international symposium, pp 497–511
16. PAXPORT and PEDROUTE brochures (2004). http://www.halcrow.com [On-line]
17. Cappuccio PJ (2000) A computer-based timed egress simulation. Fire Prot Eng 8:11–12
18. Still GK (2004) VEgAS (virtual egress and analysis system). http://www.crowddynamics.com
19. Erica KD, Richard PD (2005) Review of building evacuation models
20. Song X, Shibasaki R, Yuan NJ, Xie X, Li T, Adachi R (2017) DeepMob: learning deep knowledge of human emergency behavior and mobility from big and heterogeneous data. ACM Trans Inf Syst 35:41:1–41:19
21. Tan Lu, Mingyuan Hu, Lin Hui (2015) Agent based simulation of building evacuation: combining human behavior with predictable spatial accessibility in a fire emergency. Inf Sci 295:53–66
22. Takeuchi Y, Xu W, Kajitani Y, Okada N (2006) Risk communication through communicative survey-case study of shelter planning in Nagata ward, Kobe. In: The 25th Annual Meeting of the Japan Society for Natural Disaster Science
23. Liu Y, Norio O, Yukiko T (2008) Dynamic route decision model-based multi-agent evacuation simulation: case study of Nagata Ward, Kobe. J Nat Disaster Sci 28:91–98

Efficient Road Asset Management with Output and Performance-Based Road Contract

Jaykumar Soni, Rajesh Gujar, Tejaskumar Thaker, Sagar Deshmukh and P. R. Patelia

Abstract Roads and highways are one of the most important assets for the consequential progress of any developing country. Traditional methods of road maintenance have certain lacunas due to which proper road maintenance is not carried out effectively. Improper road maintenance can lead towards a state of expensive rehabilitation and reconstruction, and the concept of managing roads as assets is not served. Proper maintenance and management of these roads is the need of the day. Output and Performance-Based Road Contracts is the innovative method for the maintenance and management of roads ensuring efficient and effective delivery of maintenance service and maintenance of roads as assets. Roads and Building Department, Government of Gujarat, is about to implement its first pilot OPRC project having a road network length of 103 km. This paper describes the effectiveness of Output and Performance-Based Road Contract with prepared service level criteria for the proposed region.

Keywords Road maintenance · Performance-based management · Service level criteria · Performance monitoring

J. Soni (✉) · R. Gujar · T. Thaker
Pandit Deendayal Petroleum University, Gandhinagar 382007, Gujarat, India
e-mail: jmsoni9@gmail.com

R. Gujar
e-mail: rajesh.gujar@sot.pdpu.ac.in

T. Thaker
e-mail: tejas.thaker@sot.pdpu.ac.in

S. Deshmukh
LEA Associates South Asia Pvt. Ltd., Gandhinagar 382008, Gujarat, India
e-mail: sagar@lasaindia.com

P. R. Patelia
Government of Gujarat, Gandhinagar 382010, Gujarat, India
e-mail: prpatelia@yahoo.com

D. Deb et al. (eds.), *Innovative Research in Transportation Infrastructure*,
Lecture Notes in Intelligent Transportation and Infrastructure,
https://doi.org/10.1007/978-981-13-2032-3_5

1 The Significance of Road Maintenance

The importance of roads in a country like India cannot be overlooked. Road connectivity is the most important factor for providing a good living standard for the people living in respective countries and for the significant development of any country as good road network forms the basic infrastructure facilities that motivate the overall development process. In addition, they are important in a way that they provide interlink between various other modes of transportation including airports, railway, ports, etc. [8]. Despite their importance to the Indian economy, the road network in India is inadequate and is unable to handle high traffic density at many places and has improper road maintenance and management [8].

Indian Road Congress (IRC) defines road maintenance as the routine task performed to preserve the road pavement, shoulders and all the required facilities provided in their conditions they were constructed [3]. In spite of the importance of roads, many countries spend less than 50% of the required road maintenance [8]. Poor road condition leads to high cost of road users and ultimately the higher overall spending results in high rehabilitation cost [8]. Postponing road maintenance results in high direct and indirect costs. It has been estimated that the ignorance of proper road maintenance for 3 years can lead to a total rise of 6 times of actual maintenance cost and if it is neglected for 5 years, it can rise up to 18 times of actual maintenance cost [8].

For the last many years, road authorities have been adopting traditional methods for a contract of road maintenance which include a classical arrangement between the Employer, the Concessionaire, and Consultants [8]. Hence, there is the need to consider the importance of road maintenance as a part of road asset management. Asset Management is the process of minimizing the life cycle cost of deteriorating road facilities by maintaining better service level criteria of roads to all the stakeholders and managing road condition as an asset (Fig. 1).

The objective of regular maintenance is to ensure the safety of prevailing roads in the short-span early decay of the roads [8] whereas, cyclic maintenance focuses on the tasks covered at relatively a large time span to preserve the structural integrity of

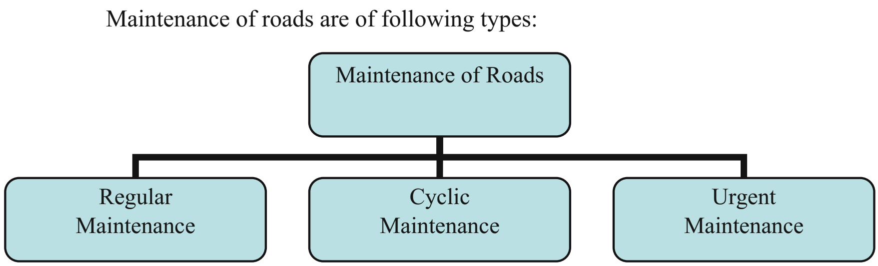


Fig. 1 Categories for road maintenance

the prevailing roads. Urgent maintenance deals with the unforeseen damages caused to roads due to natural calamities or act of God [8].

2 Output and Performance-Based Road Contracts: A Road Asset Management and Maintenance System

"Output and Performance-based Road Contracts" is a new contracting methodology for carrying out maintenance of existing as well as new roads and it significantly differs from other method based contracts that have been used to maintain roads [8]. The basic difference is that under OPRC most of the payment to be made to the contractor are based on measured "Outputs" reflecting the target condition of the roads under contracts expressed through service levels. Another major difference is that the contractor is fully responsible for the design of works necessary to reach the required levels [9]. It has its main focus on the performance reflected by the respective contractors [10]. The performance is measured by the mentioned Service Level Criteria in the bidding document which are tailored specifically according to the particular roads. Performance-Based Maintenance and Management of Road (PMMR) Contracts were introduced by World Bank (IBRD: International Bank of Reconstruction and Development) in 2002 which was then amended with certain improvements and modifications [8]. According to the World Bank Procurement Guidelines (2004), performance-based procurement is also called output-based procurement and refers to competitive procurement [5].

OPRC provides incentives to the concessionaire to satisfy the predetermined level of service which was stated as Performance-Based Maintenance Contracts (PBMC) in earlier days. The latest revised methodology is termed as Output and Performance-Based Road Contracts (OPRC) [2]. One of the main benefits of implementing OPRC for road maintenance and management is that the risk is equally shared between the employer and contractor, unlike other contracting methods where the employer is the only risk-bearing entity [3] (Fig. 2).

OPRC has been successfully implemented in the countries like New Zealand, Ukraine, United States of America, United Kingdom, Finland, Serbia Croatia and Chad (South Africa) [8]. It has been marked that the overall experience has been remarkable and countries like Argentina and Uruguay are now maintaining more than 50% of their national road networks with OPRC methodology [6].

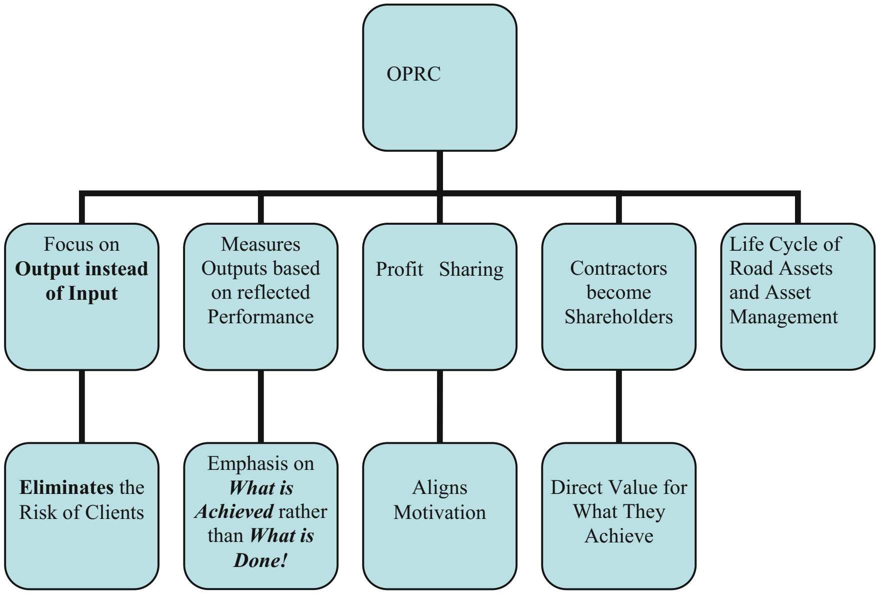


Fig. 2 Benefits of OPRC implementation [3]

Table 1 Difference between the traditional approach and performance-based approach

Traditional approach	OPRC approach
The road by road (fixing bad road)	Network management methodology
Project landing	Sector programme financing
Road engineering view	Road user view
Completion of work… payment… end	Provision of service level over long periods
Payment based on unit price	Payment based on reflected output

3 Benefits and Comparison of Output and Performance-Based Road Contracts over Other Contracting Methods

In traditional method based contracts, the road agency as a client normally specifies techniques, technologies, materials, and quantities of materials to be used, together with the time period during which the maintenance works should be executed [12]. In case of OPRC, the payment of contractor is directly interlinked to the performance he has reflected in the form of maintaining service level criteria [8], and the contractor is free to define the methodology and technology for carrying out the work and the role of government authority is limited to verify the compliance with the predefined performance indicators (Service Level Criteria) [5]. Table 1 states the difference between traditional and performance-based approach [8].

Table 2 Comparison with other contracting methods

FIDIC	PMMR	OPRC
Payment is linked to the input of measured progress	Deals with maintenance work of the single facility	Payment according to service level achieved
A separate contract for each entity i.e., design, maintenance, supervision	Limited to small-scale works	Better governance
Requires experienced and skilled staff	Requires experienced and skilled staff	Need small workforce
The employer bears all the risk	Payment according to service level achieved in terms of quality and quantity	Deals with all aspects from design to implementation

Table 2 shows the benefits of OPRC with other modes of a contracting method like FIDIC: The International Federation of Consulting Engineers Contracts, PMMR: Performance-based Management and Maintenance of Roads Contracts and OPRC: Output and Performance-based Road Contracts [8].

4 Global Experiences for Output and Performance-Based Road Contracts

The countries that have adopted OPRC have experienced saving in cost within the range of 10–40% compared to traditional method based contracts [8]. The countries where Performance-Based Contracts has been implemented successfully include New Zealand, United States of America, United Kingdom, Finland, Serbia, Croatia, and Ukraine [11].

In Estonia, 63% of the national road network is under OPRC. In 1999, the total administration staff and workers were 561 and 1485 respectively and in 2003 the workforce of administration and workers was reduced to 343 and 349, respectively [9]. PBC (Performance-Based Contracting for Roads) Approach has helped Argentina reduce the share of roads in poor condition from 25 to 5% in 1999 [1] (Table 3).

DoT (Department of Transportation) in Washington, D.C., has decided to apply this approach for management and maintenance of tunnels, roads, street lightings in Washington, D.C. Peru has expanded PBC of micro-enterprises from the rural to the national network. Argentina expanded PBC for national to provisional roads. Florida, DoT, increased to 28 from 19 in 2008 [8].

Table 3 Cost saving in various countries

Sr. no.	Country	Cost saving (%)
1	Norway	20–40
2	Sweden	±30
3	Finland	30–35
4	Holland	30–40
5	Britain	10 (min)
6	Australia	10–40
7	New Zealand	20–30
8	USA	10–15
9	Alberta	±20
10	Canada	±10

5 Pilot Output and Performance-Based Road Contract in Gujarat: Dhandhuka-Dholera, Dhandhuka-Paliyad, and Limbdi-Dhandhuka

OPRC has been executed in certain parts of India including Andhra Pradesh, Himachal Pradesh and Punjab with some very small-scale projects. Among these regions, the criticalities of "Service Level Criteria" are different according to the regional conditions. Here, "World Bank Standard Procurement Document (SPD) for OPRC" provides the guidelines for preparation of Service Level Criteria for a particular stretch of project roads. So, the SPD adopted are of different revisions for the preparation of format for Service Level Criteria.

Roads and Building Department of Gujarat (R&B Department, Government of Gujarat) is about to implement its first Pilot OPRC for maintenance and management of roads with 103 km of length. The successful implementation and completion of Output and Performance-based Road Contract (OPRC) depend on the satisfactory compliance of work completed according to the defined service level criteria [2]. The criteria are prepared with a tailored specific approach and hence, it differs from other regional projects with the consideration of (i) the "Type of OPRC selected" based on single or comprehensive facility management, (ii) On the basis of the "Equal weight of Affordability" and; (iii) "Economically and Realistic Approach" [13]. It assigns greater risks to concessionaire though there are chances to improve profit through incentives as a result of satisfactorily achieved service level criteria [7].

They must ideally cover all aspects of contracts and should be so prepared that it can be measured easily [4]. The Service Level Criteria should cover all the aspects, i.e., Road User Aspects, Road Serviceability Aspect and Road Durability Aspect. And they should be designed so that all stakeholders including Employer, Contractor, and Ultimate Road User should be benefitted in a balanced approach [8].

The project consists of the development of road network involving three sections, viz. Dhandhuka-Dholera (27 km), Dhandhuka-Paliyad (46 km) and Limbdi-Dhandhuka (29 km). The area under contract falls under the jurisdiction of Ahmed-

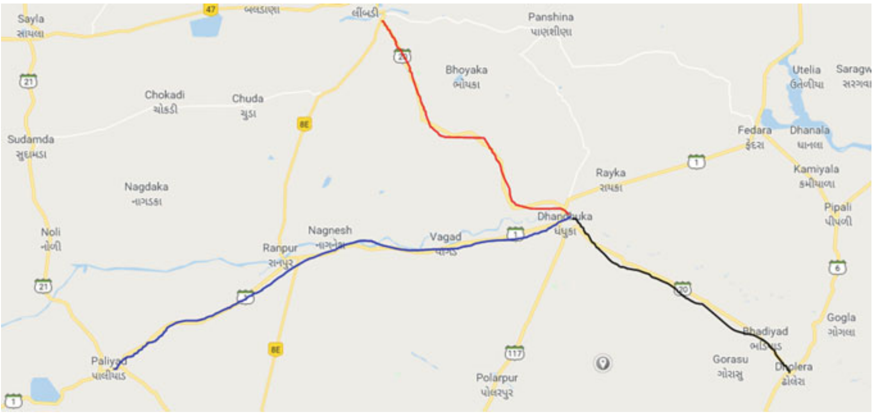


Fig. 3 Location of proposed Pilot OPRC Project in Gujarat (*Source* Roads and Building Department, Government of Gujarat)

Table 4 Pavement condition details

Condition	Dhandhuka-Dholera	Dhandhuka-Paliyad	Limbdi-Dhandhuka
	% of length	% of length	% of length
Good	82.04	95.47	93.05
Fair	4.07	0.54	0.34
Poor	13.89	3.99	6.61

Source LEA Associates South Asia Pvt. Ltd.

abad, Botad, and Surendranagar. The development consists of improvement, rehabilitation, strengthening and widening of the road network through Output and Performance-based Road Contract (OPRC) (Fig. 3).

The overall assessment of road has been done and it has been concluded that 82.04% of road stretch from Dhandhuka-Dholera, 95.47% from Dhandhuka-Paliyad and 93.05% from Limbdi-Dhandhuka are in good condition as mentioned in Table 4 (Figs. 4, 5, 6 and 7).

After the assessment of road condition and the inputs taken from important stakeholders including Technical Staff, Chief Engineer of Roads and Building Department, Government of Gujarat (R&B Department, Government of Gujarat), Patel Infrastructure Pvt. Ltd. (Concessionaire Authority) and LEA Associates South Asia Pvt. Ltd. (Project Management Constancy) the performance indicators (Service Level Criteria) have been prepared.

These Service Level Criteria for the proposed OPRC project are defined on the basis of three main categories including "Road Usability", "Road User Service" and "Comfort Measures" with the reference of World Bank Standard Procurement Document. Here, "Road Usability" will ensure that the road is open to traffic and free from interruptions at all times with permitted exceptions. "Road Serviceability

Fig. 4 Potholes (nonconformance)

Fig. 5 Edge seal drop (nonconformance)

Fig. 6 Pavement marking (nonconformance)

and Road Durability" deals with criteria like Potholes, Rutting, Settlement, Surface Defects (i.e., Rutting, etc.), Edge Break, Rain Cuts, etc.

The criteria covering all these aspects involve Potholes, Rutting, Settlement, Surface Defects (like Bleeding, Raveling/Disintegration, Streaking, Slippage, Cracking), Edge Break/Edge Crack, Pavement Surface Drainage, Edge Drop/Settlement, Rain Cuts/ Erosion, Vegetation Clearing, Maintaining Standard Width, Cleaning and

Fig. 7 Surface water ponding (nonconformance)

Table 5 Developed excel rating scale and adopted scale for road condition assessment

Category	Rating scale	Adopted scale
Very poor	0.0–2.0	1
Poor	2.1–4.0	3
Average	4.1–6.0	5
Good	6.1–8.0	7
Very good	8.1–10.0	9

Clearing of Waterway of all Drainage Works, Maintaining of Bridges, Stability and Dressing of Slopes, Cleaning and Upkeeping of Functionality of Road Side Drain, Traffic Signs and Maintenance, Pavement Marking and Raised Markers, Metal Beam Crash Barriers and Guard Rails, Maintenance for Speed Breakers, Upkeeping of Bus-Shelters, Upkeeping of Solar Lights, and Pavement Roughness and Pavement Deflection.

The performance will be measured by government officials at the defined time interval and if any noncompliance is found in existence then the respective contractor should repair the defect in permitted response time. If the contractor fails to comply with such requirement in given time, he will be penalized according to the time of a number of days of noncompliance exceeding the response time. Based on the assessment of road, the overall road condition will be assessed in categories with the rating scales of Very Poor (0–2), Poor (2–4), Average (4–6), Good (6–8) and Very Good (8–10).

Here, to make the rating of road conditions easy and convenient for inspection authority, the rating of the given scale is converted to Adopted Scale (Midpoint of given slab) with the views and opinions of experts as: For Very Poor Condition: Scale 0–2 will be marked as 1 (Midpoint of Slab 0–2) by the road inspection authority. Table 5 shows the Condition of Road, Rating Scale, and Adopted Scale for road condition assessment to be carried out by inspection authority.

6 Conclusion

Certain deficiencies of traditional road maintenance methods create obstacles in maintaining road assets. The advantages of “OPRC” make it different from other methods. The opportunity of getting incentives for early completion of work and the freedom of defining own methodology of work implementation improves the effectiveness of work carried out by the contractor. Moreover, the insecurity for payment reduction with noncompliance of work makes a contractor to adopt and apply sincere efforts to keep the pavement in the desired condition. Here, it is to be noted that creating assets is one-time activity but maintaining them is a real challenge for the government. The OPRC implementation in Gujarat will provide certain benefits like Reduction in Maintenance Cost, Improved Transparency, and Quality of Control Standards that will definitely improve the overall project road conditions. Hence, the project stakeholders, i.e., Employer, Contractor, and Road User will be satisfied with their respective concerns and the concept of maintaining and managing roads of Dhandhuka-Dholera, Dhandhuka-Paliyad, and Limbdi-Dhandhuka will be served efficiently with adequate road asset management concept.

References

1. Baquero P (2007) Forum T practical guidance to procure output- and performance-based road contracts (OPRC) under Bank-Financed Projects, pp 26–30
2. Bull M et al (2014) Lessons learned in output and performance-based road maintenance contracts, 1–4 October 2014
3. De Garza JM et al (2006) A framework for monitoring performance-based road maintenance contracts. Evaluation
4. Final P. Introducing performance based maintenance contracts to Indonesia Framework Document
5. Gericke B et al (2014) Review of performance-based contracting in the road sector phase 2: review of training materials and resources. World Bank Transp. Pap. 42C, 1–30 March 2014
6. Haque MS (2000) Privatization in developing countries: formal causes, critical reasons, and adverse impacts. Priv. or Public Enterp. Reform, pp 217–238 (2000)
7. Learned RL et al (2017) Performance-based maintenance contract (PBMC) under Second Bangladesh Rural Transport Improvement Project, July 2017
8. Lit P et al (2014) Part 1: Principles and rationale of output- and performance-based road contracts (OPRC). Evaluation 27
9. Radović N et al (2008) Output and performance-based road maintenance contracting-case study Serbia 3651:681–688
10. Rao KS (2014) Application of output and performance based road contracts in Serbia. Tech Gaz 21:3
11. Rohatgi R et al (2011) Output and performance based road contracts (OPRC): an alternate PPP model
12. Stankevich N et al (2005) Performance-based contracting for preservation and improvement of road assets. World Bank Transp Notes NoTN-27, 27 September 2005, pp 1–11
13. Sultana M (2012) Performance-based maintenance of road infrastructure by contracting—a challenge for developing countries. J Serv Sci Manag 5(2):118–123

An Innovative Approach to Assess Sustainability of Urban Mobility—Using Fuzzy MCDM Method

Partha Tripathy, Anjali K. Khambete and Krupesh A. Chauhan

Abstract Urban mobility is one of the toughest challenges faced by the cities in the developing world and mobility is a key dynamic of urbanization. Cities have been major contributors to greenhouse gas emissions and personal transport dependencies have been a concern. Government at federal level and state level have been trying to put in place a robust mobility system to control this menace. Without a proper performance measurement of urban mobility, it is difficult to identify and solve these problems. Ministry of Urban Development, Government of India have adopted a framework to benchmark cities designing a set of Service Level Benchmarks and aggregate them to find out an Index. In this paper, an attempt has been made to deliberate on creating a performance measurement framework for Urban Mobility Index (UMI) using a Fuzzy Multi-Criteria Decision-Making (MCDM) approach. A comparison of both the approach has been made by analyzing the UMI for 12 Indian cities. The paper identifies certain indicators which measure the sustainability as well as smartness of a city from the perspective of Urban Mobility. These indicators and the UMI can be used to asses the progress on city performance and corrective actions could be taken.

Keywords Sustainability · Mobility indicators · Mobility index · Fuzzy MCDM

1 Introduction

Rapid urbanization is also causing of deteriorating air quality, noise pollution, congested roads, and GHG emissions. In any city, mobility is a necessity for the other urban sectors and economy to perform. With the increase in urban populations, cities come across challenge to meet the rising demands for mobility subject to limited physical infrastructure capacity and resources.

P. Tripathy (✉) · A. K. Khambete · K. A. Chauhan
Civil Engineering Department, Sardar Vallabhbhai National Institute of Technology, Surat, India
e-mail: partha.tripathy@gmail.com

D. Deb et al. (eds.), *Innovative Research in Transportation Infrastructure*,
Lecture Notes in Intelligent Transportation and Infrastructure,
https://doi.org/10.1007/978-981-13-2032-3_6

Indian cities have experienced a rapid growth, and Government at all levels are taking steps to cater to service delivery. Government agencies have adopted performance indicator measuring framework as a tool to assess concerns periodically and take corrective measures. Authorities have also taken measures to set up, appropriate systems for information management, performance monitoring, and benchmarking.

And moreover, benchmarking has also been regarded as tool for introducing accountability in service delivery. But more importantly, performance measurement framework design is crucial as the theoretical framework to provide the basis for the selection and combination of single indicators into a truly representing composite indicator. While India is planning to develop Smart and Sustainable Cities, urban local bodies shall be required to build their framework for assessing the performances of individual components and one of them is urban mobility. Ministry of Urban Development (MoUD), Government of India has promulgated Service Level Benchmarks for certain critical aspects of urban infrastructure and services [1].

The Smart City Mission and Guidelines circulated by Government of India, states certain features of Indian Smart Cities. Regarding the transportation, the following has been emphasized [2]:

- Creating walkable localities;
- Promoting a variety of transport options—Transit-Oriented Development (TOD), public transport, and last mile para-transport connectivity;
- Continuous monitoring;
- Applying smart solutions like Intelligent Traffic Management System (Pan City Proposal);

This paper analyzes the theme of a Smart and Sustainable City and suggests the framework of Mobility Indicators and a composite Mobility index of an Indian Smart and Sustainable city using the practiced mathematical model in research and industry.

2 Fuzzy Set Theory and MCDM

2.1 Fuzzy Set

The concept of fuzzy set theory was introduced by Zadeh in 1965. A fuzzy set can be mathematically defined by assigning to each possible individual in the universe of discourse a value representing its grade of membership in the fuzzy set [3]. In which the grade represents the degree to which that individual is similar or compatible with the concept represented by the fuzzy set [3]. The fuzzy set introduces vagueness (with the aim of reducing complexity) by eliminating sharp boundary dividing members of the class from nonmembers since the transition of member from nonmember is gradual rather than abrupt [4].

2.2 Multi-Criteria Decision-Making

A multicriteria decision-making problem can generally be represented in a matrix format as

$$
\begin{array}{cc}
 & \begin{array}{ccc} c1 & c2 & \dots & cn \end{array} \\
D = \begin{array}{c} A1 \\ A2 \\ \vdots \\ Am \end{array} & \begin{bmatrix} x11 & x12 & \dots & x1n \\ x21 & x22 & \dots & x2n \\ \vdots & \vdots & \vdots & \vdots \\ xm1 & xm2 & \dots & xmn \end{bmatrix}
\end{array}
$$

$$W = [w1, w2, \dots wn]$$

where A1, A2, …, Am = alternatives; c1, c2, …, cn = criteria with which performances of alternatives are measured; x_{ij} = rating or score of alternative Ai with respect to criterion cj, and wj = weight of criterion cj. A Multiple-Criteria Decision-Making (MCDM) problem is to assess the overall importance values of the alternatives on some permissible scale. Alternatives are the ones evaluated first, explicitly with respect to each of the decision criteria to obtain some sort of criterion specific priority numbers which are then aggregated into overall performance values.

MCDM is making decisions in the presence of multiple criteria. For instance, when one purchases a car the criteria may be characterized in terms of price, size, style, safety, comfort, etc. In a business context, MCDM problems are more complicated and usually of large numbers of criteria. MCDM has been useful in discovering a single index and also in ranking. In this study, MCDM is used for getting the relative weightages of indicators and parameters. There are many methods available for solving MCDM problems, though some of the methods were criticized as ad hoc and to certain degree unjustified on theoretical and/or empirical grounds [5]. Christian et al. [6] have used Fuzzy MCDM to assess a composite index of air and water pollution potential of industries and a ranking of such industries has also been attempted. Khambete and Christian [7] have ranked sewerage treatment plants using MCDM approach.

MCDM is a fuzzy method for decision-making. This method has been used to find out the interrelationship between the indicators, and assess the weights and arriving at index values for mobility. Decision makers generally are faced to consider multiple, often conflicting, objectives to arrive on the right decisions. MCDM models have been quite helpful in handling such decision problems. A number of different models have been proposed to structure and solve MCDM problems and different computational methods developed for their applications. The problem considered in the study is to

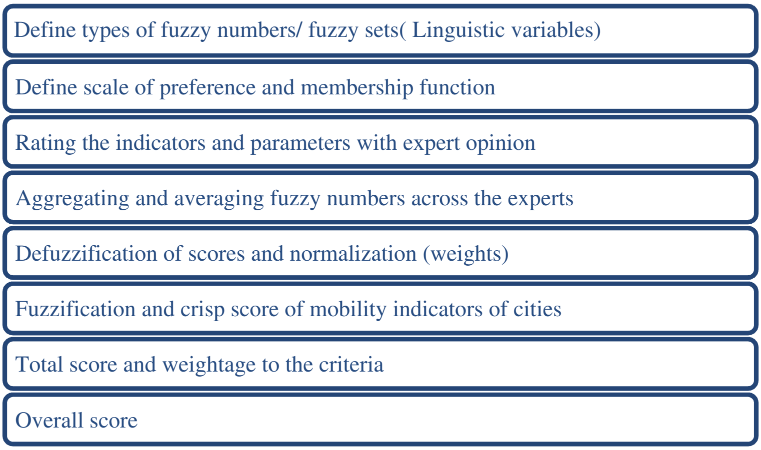


Fig. 1 Fuzzy process

develop a methodology to find the mobility index on the basis of mobility indicators of an Indian city. The study deals with assessing fuzzy weights based on expert's perception and decision-making. The methodology is shown in Fig. 1.

3 Sustainable Transport and Smartness

Sustainability generally refers to a balance of economic, social, and environmental goals. Sustainability reflects the fundamental desire of human being to protect and improve our universe. Objectives support the sustainability goals are, Improved Transport diversity, System integration, Affordability, Resource efficiency, Efficient pricing and prioritization, Smart Growth Land use Development, Operational efficiency, and Comprehensive and inclusive planning.

Generally, the above goals could be more specifically stated in the following manner:

- Improved transport system diversity.
- Smart growth land use development.
- Energy conservation and emission reductions.
- Efficient transport pricing.

A smart sustainable city generally adopts ICT to monitor and progress to enhance quality of life, bring in efficiency in services, and competitiveness, while it meets the sustainability concern of ensuring that it meets the needs of present and future generations with respect to economic, social, environmental as well as cultural aspects [8]. While a smart urban system is generally considered to be one which utilizes smart technologies in its operation and management. Smart transport infrastructures are technology-enabled and demonstrate interconnectivity, with assets in a network that communicates as well as respond to and shape demand and economic behavior. Smart is not necessarily entirely about the use of ICT only, but also it could be an innovative way of bringing together existing technology and resources to optimal utilization.

From the literature available, it is perceived that sustainability is the objective and the process to achieve through technological interventions has to be smart. Smart mobility interconnects systems to enhance urban mobility performance resulting benefits accruing to urban local bodies.

4 Indicators and Composite Index for Cities

Performance measurement is a process of collecting, analyzing and/or reporting information regarding the performance of an individual, group, organization, system, or a project. To evaluate parameters those are crucial to the success of an individual, group, organization, system, project, or component the metric used is called key performance indicator (KPI). Performance measurement is a part of monitoring and

- to monitor progress, by means of a commonly accepted and applied “framework”
- to objectively verify the impacts of projects
- to create trust in projects and solutions
- to build confidence that solutions can also be applied in other contexts and cities
- to enable stakeholders in projects or cities to learn from each other

It has been helpful to Urban Local Bodies (ULBs) and other agencies in identifying performance gaps and to intervene for improvements through the sharing of information and best practices, resulting in better performance and service. Ministry of Urban Development (MoUD) has also promulgated Service Level Benchmarks for certain critical aspects of urban infrastructure and services. Accordingly, all the cities those availed support under JNNURM (Jawaharlal Nehru National Urban Renewal Mission) scheme of federal government, were advised to undertake the process of service level benchmarking. In addition, this initiative has facilitated development of Performance Improvement Plans using information generated by the benchmarking exercise. This benchmarking exercise has enabled cities to understand the gaps and monitor the progress in each of the sectors towards the desired service level. It has also brought in a sense of competition in the system in intercity which also gives boost to urban development by City Authorities as well as citizens in owning their city and performing to improve their overall score. The performance measurement framework design is key as the theoretical framework should be developed to provide the basis for the selection and combination of single indicators into a meaningful composite indicator under a fitness-for-purpose principle. Certain principles as laid down by ITU (International Telecommunication Union) [9] include comprehensiveness, comparability, availability, independence, simplicity, and timeliness.

Government of India in the year 2014 launched a federal level mission "Smart City Mission" to develop Smart cities in the country, where cities to avail the scheme were required to participate in a challenge competition. The proposals sent by 100 cities competing for Smart Cities Challenge, most of them had suggested projects which would bring in improvement in mobility in the cities. Which portrays that Indian cities are grappled with concerns in the urban transportation sector. The lack of proper concepts and indicators could be one of the reasons for not performing comprehensive benchmarking studies on smart urban mobility. Measuring the performance of urban mobility as indicators can help the cities to learn and compare each other. The comparison of urban mobility of cities could open opportunities for cities to assess a city's growth potential and to sharpen its profile among other cities.

Government of India have given a guideline for service level benchmark of urban transport. It is felt that the indicators which are stated in the service level benchmarking guideline suggested by MoUD are not adequate for measuring the urban mobility for a Smart City. Due to this lack of some indicators, SLB indicators cannot give a particular idea about the mobility of a city. ISO 37120:2014 defines and establishes methodologies for a set of indicators to steer and measure the performance of city services and quality of life. ISO 37120:2014 is applicable to any city, municipality or local government that undertakes to measure its performance in a comparable and verifiable manner, irrespective of size and location. When we look at the guiding principles of Smart City Features of Indian Cities, the following seem to be desirable from any Smart Cities:

- Increase Walkability
- Promoting a variety of transport options—Enhance the use of Public Transport;
- Applying smart solutions like Intelligent Traffic Management System; and
- Devise a system which does Continuous monitoring

5 Mobility Indicators and a Framework for Mobility Index

Benchmarking is now well recognized as an important mechanism for introducing accountability in service delivery. MoUD has suggested certain parameters to be assessed by cities to assess and improve their performances. There are in total 10 parameters which could be measured and in total 36 indicators [1]. These indicator values and level of services will help to understand the present performance level of the city and for the comparison of cities. This comparative study can help the cities to improve their service level and they can adopt good facilities and strategies from other cities. LoS 1 is the best and it decreases till 4 (4 being the worst). If we look at the performance of Cities cited above sections of the paper, certain observations are quite pertinent:

- While cities have adequate fleets for public transport except Surat, area of coverage and service levels are poor resulting in high waiting time. (Real-time assessment of passengers and bus schedule allocation.)

- Promoting NMT the cities lack infrastructure and remove encroachment. (Vulnerable locations to be identified and real-time monitoring through cameras.)
- Pedestrianization challenges include inadequate infrastructure as well as signaling at junctions.
- Air quality monitoring on a real-time basis and integrated with traffic planning on a real-time manner address the issues.
- Score in parking has been poor and enforcement through surveillance cameras could possibly improve the parking.

On an average, it is observed that the best city out the 12 cities assessed the performance is below LoS 2 (Table 1), which is a matter of concern as benchmarking with the best shall also not yield good results. Similar attempts have been made by other countries which have suggested a generic model with providing weights almost equal to all the parameters. The second concern is based on the vision, targets are decided, and to achieve the targets, indicators are built to monitor the progress.

On the contrary, MCDM method could also be used to prepare the mobility index for a city. MCDM is a fuzzy method for decision-making activity. This method will help to find the interrelationship between the indicators and to find the index values for mobility. The problem considered in the study is to develop a methodology to find the mobility index on the basis of mobility indicators. The methodology stated in Fig. 1 was followed to arrive at the urban mobility index. The crisp numbers of indicators of all the 12 cities were collected, and they were normalized, and expert opinion was taken for all the sub-indicator and indicators and weights were arrived. These weights are fuzzy weights and the same were applied to normalized variable numbers and then aggregated to arrive at results. A comparison of UMI arrived using equal weights and using Fuzzy MCDM is presented in Table 2.

6 Conclusion

This study comprised the evolution of a new index called the Urban Mobility index for Indian Cities using fuzzy MCDM method. The weights of individual parameters are crucial while building a composite index. It provides a simple representation of the extensive and complex variables that govern the overall quality of Urban Mobility. Based on expert opinions and Service Level Benchmarks indicators prescribed by MoUD 36 mobility parameters were considered as the significant indicator parameters of UMI to assess the quality of urban mobility in an Indian City. Based on the expert opinion and applying fuzzy MCDM technique, the composite index Urban Mobility Index was assessed for each city which gives an indication the Urban mobility condition. The new index is believed to assist decision makers in assessing the quality of mobility in a particular city and taking corrective actions on such parameters where the city has scored low. Fuzzy logic concepts have been extensively used in Multi-Criteria Decision-Making problems in water and air quality, building environment index of cities, and its suitable for assessing the quality of urban mobility

Table 1 Urban Mobility Index (UMI) using the equal weights

Cities	Parameters									UMI
	A	B	C	D	E	F	G	H	I	
Mysore	0.75	0.29	0.00	0.49	1.00	0.31	0.57	0.67	0.53	**0.51**
Bhubaneswar	0.69	0.46	0.51	0.22	0.84	0.48	0.35	0.41	0.55	**0.51**
Kohima	0.68	0.52	NA	0.00	0.82	0.49	0.55	0.59	0.29	**0.44**
Ahmadabad	0.62	0.49	0.42	0.53	1.00	0.22	0.31	0.61	0.82	**0.57**
Surat	0.29	0.46	0.46	0.24	0.98	0.40	0.56	0.70	0.84	**0.55**
Bangalore	0.77	0.54	0.33	0.02	0.67	0.13	0.36	0.50	0.57	**0.44**
Jaipur	0.32	0.28	0.49	0.06	0.83	0.23	0.13	0.36	0.55	**0.37**
Nanded	0.64	0.21	0.75	0.06	0.83	0.63	0.11	0.55	0.54	**0.49**
Patna	0.33	0.71	0.55	0.01	0.54	0.11	0.00	0.34	0.70	**0.38**
Vijayawada	0.77	0.01	0.50	0.10	0.83	0.46	0.11	0.47	0.56	**0.43**
Delhi	0.79	0.40	0.39	0.15	0.54	0.07	0.24	0.54	0.76	**0.44**
Kochi	0.58	0.44	0.33	0.03	0.90	0.48	0.51	0.81	0.44	**0.50**

Table 2 Results showing UMI calculated using equal weights and fuzzy weights

Cities	UMI with equal weights	UMI using fuzzy weights
Mysore	0.521	0.51
Bhubaneswar	0.487	0.51
Kohima	0.447	0.44
Ahmadabad	0.556	0.57
Surat	0.533	0.55
Bangalore	0.423	0.44
Jaipur	0.355	0.37
Nanded	0.452	0.49
Patna	0.345	0.38
Vijayawada	0.446	0.43
Delhi	0.450	0.44
Kochi	0.499	0.50

of a city. Authors believe that logically, UMI could be an effective tool for most of the Urban Transport policy matters and guide improving them.

Acknowledgements The authors would like to acknowledge the contribution of Mr. Rajeev K R, Research Student, M Tech Urban Planning, SVNIT (2014–16).

References

1. Ministry of Urban Development and G. of I. N. Delhi (2015) Service level benchmarking in urban transport for Indian cities
2. Smart City_Reference Framework For India [Online]. http://niti.gov.in/mgov_file/CSTEPReportSmartCitiesFramework.pdf. Accessed 01 Dec 2015
3. Singh D, Tiong RLK (2005) A fuzzy decision framework for contractor selection. J Constr Eng Manag 131(1):62–70
4. Klir GJ, Folger TA (1988) Fuzzy sets, uncertainty, and information
5. Chen VYC, Lien H-P, Liu C-H, Liou JJH, Tzeng G-H, Yang L-S (2011) Fuzzy MCDM approach for selecting the best environment-watershed plan. Appl Soft Comput 11(1):265–275
6. Lad RK, Christian RA, Deshpande AW (2008) A fuzzy MCDM framework for the environmental pollution potential of industries focusing on air pollution. WIT Trans Ecol Environ 116:617–626
7. Khambete MAK, Christian RA (2014) Ranking sewage treatment plants with the application of fuzzy composite programming. Int J Sci Eng Technol 3(2):116–120
8. Chor H, Kumar A, Kong H, Use L, Hong T, Chin HC, Debnath AK, Yuen B (2010) The concept of smart cities
9. ITU (2015) Key performance indicators related to the use of information and communication technology in smart sustainable cities. In: Proceedings of the international conference on sustainable urbanization, 15–17 December 2010

Determinants of Public–Private Partnership in Infrastructure: Empirical Evidences from India

Pravin Jadhav and Rahul Nath Choudhury

Abstract This study explores important determinants of Public–Private Partnership (PPP) in Indian Infrastructure. This study used secondary data for a period of eleven years (2005–2016) to observe the important determinants in PPP in Infrastructure in India. This study also examines the infrastructure scenario in India and its global comparison and tries to evaluate the impact of PPP on Infrastructure development. This study uses secondary data from various sources like, World Bank, Global Competitiveness Report, Department of Economic Affairs, PPP Cell, and Infrastructure Division to identify various factors to attract more PPP in Indian Infrastructure Sector. The findings from determinants of PPP analysis yield several insights about attracting PPP in Infrastructure sector and indicate that market size measured by Real GDP, Macroeconomic stability, Exchange Rate, Governance has a significant impact on determinants of PPP in Infrastructure sector.

Keywords PPP · Infrastructure · Policy · India

1 Introduction

Infrastructure development plays a vital role in Economic growth and development of a country and it has been widely accepted in the academic literature [2, 7, 9, 10, 19, 22, 28]. Better infrastructure increases productivity and reduces the overall production cost [25]. It is commonly apparent that infrastructure development in a country increases competitiveness and reduces the cost of business and increases the rate of return from the investment. Therefore, quality of infrastructure is important determinant of Foreign Direct Investment made by Multinational Companies [3, 8]. Similarly, social infrastructure viewed in terms of education and health-related facilities con-

P. Jadhav (✉)
Institute of Infrastructure Technology Research and Management, Ahmedabad, India
e-mail: pravinjadhav@iitram.ac.in

R. N. Choudhury
Institute of South Asian Studies (NUS), Singapore, Singapore

D. Deb et al. (eds.), *Innovative Research in Transportation Infrastructure*,
Lecture Notes in Intelligent Transportation and Infrastructure,
https://doi.org/10.1007/978-981-13-2032-3_7

tribute significantly to human capital formation and hence affect investment through several mechanisms. On the one hand, healthy and educated workforce enhances the productivity of the workers. On the other hand, lack of health and education infrastructure facilities can raise health-related costs when the investors need to develop or significantly subsidize health care and education system for their employees. Such increasing costs of education and health are likely to affect investors' return adversely. Infrastructure is an important element in judging a country's regional development. Being a rapidly growing nation and various regions, the Indian government is giving considerable importance to the infrastructure sector by allocating substantial fund under different five-year plans on development of airports, ports, roads, and railway infrastructure.

The key challenge and constraint for the infrastructure development in India is access to financing (World Economic Forum, 2015–16). As per, Economic survey by the year 2040, India will face a $ 526 billion of investment gap for the infrastructure development. Therefore, Indian government currently raising finance through private sector investment and now government is encouraging various infrastructure projects via Public–Private Partnerships (PPPs) mode. Public–Private Partnership is defined as a legal agreement between public and private sector entity that offers the delivery of physical infrastructure and services to the society in specific time duration. PPPs can play important role in infrastructure development of India as it will bring non-debt creating capital flows, better management practices, and technology for efficient delivery of projects. Therefore, the government of India should focus on various factors and improve various policies that can attract more PPPs in Infrastructure. PPPs can one of the sources of investment which can accelerate the process of infrastructure development by bringing more capital flows, in India. PPP in Infrastructure sector in India will develop overall quality of Infrastructure in India which can lead to more economic growth and development for the economy.

2 Infrastructure Scenario in India: Cross-Country Comparison

As Per, Global Competitiveness Index 2016–17, infrastructure is one of the important pillars of competitiveness of any country. Improvement in quality of infrastructure is crucial for ensuring the comprehensive growth and development of the business activities in the economy. Enhancement in transport infrastructure reduces the distance between counties and integrate the various regions. This also facilitates movement of workers, goods and services in a timely manner. Therefore, well-developed infrastructure improves international trade and investments by shifting production in low-cost location. In addition, improvement in communication infrastructure is important factors for improvement in flow of information and it connects emerging and underdeveloped economies with developed economies. Improvement and development of business activities also depend on electricity connectivity and availability which free from interruptions and shortages.

According to Global Competitiveness Index (GCI), 2016–17, the most problematic factors for doing business in India depicted that inadequate supply of infrastructure is eight important factors that influence overall attraction in doing business in India. Thus, infrastructure development is very crucial for attracting foreign as well as domestic companies in increasing business activities in India. According to GCI, India ranks 39 on the GCI out of 138 countries. With respect to Infrastructure, India is ranking 68 out of 138 countries which indicate that overall quality of infrastructure is not good in India. Overall score of infrastructure in India is 4.0 out of total 7 score means infrastructure development in India is stagnant in Median. According to different indicators of Infrastructure, India is ranking far below with 138 countries in the work compiled by global competitiveness index 2016–17 (Table 1). India ranks 51 out of 138 in the quality of overall infrastructure with the value of 4.5. Overall quality of roads, railroad port, and air transport Infrastructure India is ranking 51, 23, 48, and 63, respectively. Railway infrastructure is comparatively advance in India compare to road port and air infrastructure. Available airline seat km per week is 4324.2 million and India is ranking 8 out 138 countries. With respect to quality of electric supply India is ranking 88 which is far behind than other emerging economies like Brazil, China, and Russia. Availability of communication infrastructure is also not adequate in India as it ranks 123 and 114 with respect to mobile telephone subscription and fixed telephone line per 100 populations.

3 Trend in Public–Private Partnership in India: Where Infrastructure Stand?

The Government of India recognized PPP model as a mode for developing the country's infrastructure development. After liberalization of the Indian economy in 1991, there were various attempts to promote PPPs by Indian Government. However, most of the sectors, it failed to attract PPP. India was observed as too uncertain and there was substantial resistance to private sector involvement. It is only in the middle of the 2000s that the first PPPs were signed and implemented (Table 2).

The above data indicates that there is fluctuating trend in PPP involvement in Indian Infrastructure in the selected time. The total value of the PPP was highest (57854.97 Rs. Cr) in the year 2009–10 which dropped in 2010–11. After 2013–14, there is significant decline in the PPP in Indian Infrastructure (Table 3).

Projects recommended by the Public Private Partnership Appraisal Committee (PPPAC) indicates that Road sector is attracting most of the PPP in India followed by Ports, Railways, Housing, and Tourism. Road sector attracted around 287275.09 Cr. Rs. of PPP from 20th December, 2005–28th October, 2016. Whereas port sector attracted around 48677.96 Cr. Rs Airports and sports sector are not able to attract significant investment under PPP model.

Table 1 Quality of infrastructure in India: a global comparison

S. no.	Indicator of infrastructure	Value (1–7) 2016–17	Rank (out of 144) 2016–17	Value (1–7) 2015–16	Rank (out of 144) 2015–16
1	Quality of overall infrastructure	4.5	51	4.0	74
2	Quality of roads	4.4	51	4.1	61
3	Quality of railroad infrastructure	4.5	23	4.1	29
4	Quality of Port infrastructure	4.5	48	4.2	60
5	Quality of air transport infrastructure	4.5	63	4.3	71
6	Available airline seat km/week, millions*/week	4324.2	8	3726.6	11
7	Quality of electric supply	4.3	88	3.7	98
8	Mobile telephone subscriptions/100 pop*	78.8	123	74.5	121
9	Fixed telephone lines/100 pop*	2.0	114	2.1	116

Source Global Competitiveness Index, 2016–17, World Economic Forum
*The best possible outcome

PPP in Infrastructure in India is mostly attracted by road sector and ports but sectors like Railways, housing, and airports are not able to attract more PPP hence government needs to undertake policy reforms to attract more PPP in these sectors (Table 4).

State-Wise Summary of Projects recommended by the Public Private Partnership Appraisal Committee (PPPAC) reveals that there is again uneven distribution of PPP projects in India. Only selected states in India attracted most of the PPP projects like Maharashtra, Uttar Pradesh, Odisha, and Tamil Nadu.

Table 2 Projects recommended by the Public Private Partnership Appraisal Committee: Year Wise Summary

S. no.	Financial year	Number of projects approved	Total project cost (in Rs. Crore)
1	2016–2017	5	5140.15
2	2015–2016	17	28465.76
3	2014–2015	18	29070.77
4	2013–2014	25	55326.29
5	2012–2013	25	25641.53
6	2011–2012	52	53248.6
7	2010–2011	33	26010.24
8	2009–2010	53	57854.97
9	2008–2009	48	53381.78
10	2007–2008	13	11227.46
	Total	**304**	**351901.09**

Source Department of Economic Affairs, PPP Cell, Infrastructure Division (From 20th December, 2007–28th October, 2016)

Table 3 Projects recommended by the Public Private Partnership Appraisal Committee: Sector wise Summary

S. no.	Sector	No of projects approved	Total project cost (In Rs. Crore)
1	Airports	4	0
2	Housing	8	7299.17
3	Ports	36	48677.96
4	Railways	1	8500
5	Roads	249	287275.09
6	Sports	5	0
7	Tourism	1	148.87
	Total	**304**	**351901.09**

Source Department of Economic Affairs, PPP Cell, Infrastructure Division (From 20th December, 2005–28th October, 2016)

4 Literature on Determinants of PPP in Infrastructure

There is abundant empirical literature on factors that potentially influencing private investment and Foreign Direct Investment (FDI) but there is very limited literature with respect to determinants of PPPs. The determining factors include stable macroeconomic conditions, openness of the government, government budget constraints, market size and institutional factors like effective rule of law, political stability, corruption, etc. [5, 11, 13, 24]. Most of the studies find that effective macroeconomic conditions and better institutional quality are positively related to PPP in Infras-

Table 4 Projects recommended by the Public Private Partnership Appraisal Committee: State Wise Summary

S. no.	State	Number of projects approved	Total project cost (in Rs. Crore)
1	Andhra Pradesh	20	17541.84
2	Bihar	13	12262.44
3	Delhi	8	9492.58
4	Goa	5	4727.96
5	Gujarat	14	18524.8
6	Haryana	12	16046.2
7	Jammu and Kashmir	8	20927.55
8	Karnataka	20	14846.48
9	Kerala	11	10056.44
10	Madhya Pradesh	20	20758.9
11	Maharashtra	29	51176.94
12	Odisha	20	22411.82
13	Punjab	12	10981.37
14	Rajasthan	20	17001.77
15	Tamil Nadu	26	21879.95
16	Uttar Pradesh	22	27506.23
17	West Bengal	13	14072.41
	Total	**304**	**351901.09**

Source Department of Economic Affairs, PPP Cell, Infrastructure Division (From 20th December, 2005–28th October, 2016)

tructure. However, factors such as budget restraints of government and government efficiency might have negative influences on the PPP in Infrastructure [13].

According to empirical studies lower and stable inflation rate, interest rate and exchange rate may decrease the cost of production. Macroeconomic stability in country is very important for the private sector because most of the PPPs project usually have long duration and high initial cost in the starting of the project and often require more time to generate revenue [11]. Some of the studies have revealed that the openness of the country is positively related with increased private investments as openness of the country means there are fewer restrictions for private investment [3, 18]. Market size is another important factor which attracts more PPP in the infrastructure sector. If the size of the market is higher then, there will be more demand for transport, electricity, ports, airport, and telecommunication-related infrastructure. The demand for public infrastructure will be even more when the GDP per capita is higher and people have more purchasing power [12, 13].

Business decisions by private sector player may largely be influenced by the institutional factors like governance, business environment, political structure, etc. Several papers have shown that inefficient institutions as measured by corruption, political instability, and weak enforcement of contracts deter PPPs [4, 5, 16, 21, 27, 17, 15]. Some of the studies have taken institutional factors like political stability, effective rule of Law and regulatory quality, Government Effectiveness, Control of Corruption, and empirically proved that effective institutions quality attract more private investments [1, 14, 23]. In contrast, if the quality of institutions is weak then it decreases private investment and PPPs as it increases the cost of project and decreases profit of private investor [6, 20, 26, 27].

5 Model Specification and Estimation

To find out the relationship between different determinants of PPP in Infrastructure, the following panel data model is specified:

$$Y_{it} = \alpha_{it} + \sum_{k=1}^{k} \beta_{kit} X_{kit} + u_{it}$$

where

i 1, 2…N (refers to cross-sectional units)
t 1, 2…T (refers to a given time period)
k 1, 2…K (refers to number of explanatory variables)

Thus, Y_{it} represent the PPP in the sector i at time t and X kit is the values of such determinants as market size, trade openness, for the individual i at time t. The analysis begins by estimating pooled regression model assuming that there is no significant country or temporal effects then this study estimate fixed effects model (FEM) and the random effects model (REM) to control country-specific and temporal effects, if any. This study performs F test, LM test, and Hausman test for Selection of Appropriate Model.

Accordingly, the equation is estimated as:

$$FDI_{i,t} = \alpha + \beta 1ms_{i,t} + \beta 2to_{i,t} + \beta 3mas + \beta 4tax_{i,t} + \beta 5reer_{i,t} + \beta 6be_{i,t} + \beta 7GI_{i,t} + \varepsilon_{i,t}$$

5.1 Data

The data used for analysis are annual PPP data with observations from 2005 to 2016 for 5 important sectors of Infrastructure, but most results focus on the last 11 years due to limits on data availability for Sectoral PPP and institutional/qualitative variables. The analysis focuses on five important sectors of Infrastructure accounting for most of PPPs in Infrastructure. Data on PPP is taken for Housing, Ports, Railways, Roads, and

Table 5 Explanatory variables

Explanatory variables	Indicators	Sign	Data sources
Economic variables	Market size: real GDP	+	RBI
	Trade openness: trade/GDP ratio	±	World Bank
	Macroeconomic stability: Inflation rate	–	RBI
	Tax rate: total tax rate (% of commercial profits)	–	World Bank
	Exchange rate: real effective exchange rate	±	RBI
Policy variables (0 = worst, 100 = freest business environment)	Business environment: overall indicator of the efficiency of government regulation of business	+	Index of Economic Freedom, Heritage Foundation
Governance index [Institutional quality (0 = low level of governance, 100 = better governance)]	Control on corruption, rule of law, political stability and no violence, government effectiveness, regulatory quality	+	World Governance Indicators, World Bank

Source Authors calculations

Airports are collected from Department of Economic Affairs, PPP Cell, Infrastructure Division (From 20th December, 2005–28th October, 2016). The dependent variable in the specifications below is the inflow of PPP broken down into five different sectors of infrastructure.

The independent variables in our estimation include (Table 5) Real GDP for market size, Trade to GDP ratio for trade openness, Inflation rate for Macroeconomic stability, Total tax rate as a percentage of commercial profits for tax rate, Real Effective exchange rate for Exchange rate, and Business Environment. This study also crated Governance index including six variables of Governance, i.e., Voice and Accountability, Political Stability and Lack of Violence, Government Effectiveness, Regulatory Quality, Rule of Law, and Control of Corruption to evaluate the impact of good governance on PPP in Infrastructure.

5.2 Results

This study firstly checks suitable model comparing FEM and REM and pooled regression. F test, LM test, and Hausman test indicate that fixed effect model is appropriate

Table 6 Macro level panel data analysis: fixed effect model

Variable	Fixed effect model
Market size	0.35 (0.00)***
Trade openness	−0.563 (0.5)
Macroeconomic stability	−2.106 (0.06)*
Tax rate	0.02 (0.5)
Exchange rate	−0.120 (0.01)***
Governance	−0.58 (0.06)*
Business environment	−0.28 (0.12)
Constant	131636.8 (0.00)***
F = 5.75(0.00) Nobs, Nvar (55,7)	$R^2 = 0.68$

Note Against each variable, coefficient followed by P value in the parenthesis
*Significant at 10%; **Significant at 5%; ***Significant at 1%

in this model. The empirical results (Table 6) obtained from Fixed Effect model specify that R2 of the model is 68% which indicates that variables of the model explain around 68 percent of the variation in PPP in Infrastructure in India. Overall the model is statistically significant indicated by F-statistic which is 5.75 and the probability of the F-statistic is 0.0000.

The result further indicates that at macro level Market size, Macroeconomic stability, Exchange Rate, and Governance have significant impact on PPP. Market Size measured by Real GDP indicates that it is positively related to PPP in Infrastructure. The main reason for this is higher Real GDP leads to more production within economy which requires more infrastructure facilities. Higher inflation rate negatively influences on PPP in infrastructure. The main reason for this, higher inflation increase cost of raw material and overall project cost. Real effective exchange rate is negatively associated with PPP in infrastructure; it indicates that when local currency devaluate it increases the PPP inflow as devaluation of currency make infrastructure projects profitable.

Governance/Institutional quality is measured by effective Rule of Law, Political Stability and No Violence, Government Effectiveness and Regulatory Quality negatively associated with PPP; it indicates that governance quality is not a relatively important variable in India for attracting more PPP in infrastructure.

6 Conclusion

Adequate level of Infrastructure is essential for the economic development of a country. Therefore, every governments create appropriate policies to attract more investment in the sectors such as transport, power, telecommunications, water supply, sanitation and sewerage, education and training, health and empowerment to increase to quality of infrastructure. The overall results indicate that infrastructure quality is not adequate in India as India ranking 87 out of 144 countries in infrastructure quality. Thus, the government needs to undertake proactive policy reforms to developed infrastructure quality in India. Overall score of infrastructure in India is 3.8 out of total 7 score means infrastructure development in India is stagnant in Median.

PPP in Infrastructure in India is mostly attracted by road sector and ports but sectors like Railways, housing, and airports are not able to attract more PPP hence government needs to undertake policy reforms to attract more PPP in these sectors. The findings from PPP determinants analysis yield several insights about attracting PPP in Infrastructure sector. Market size measured by Real GDP, Macroeconomic stability, Exchange Rate, and Governance has significant impact on determinants of PPP. Macroeconomic stability and exchange rate have significant impact on determinants of PPP This result provides a hint of the significance of monetary policies to attract more PPP keeping lower inflation rate and exchange rate to attract more PPP in Infrastructure.

Although overall institutional and governance factor do not impact on PPP in Infrastructure significantly in the long-run these markets need to improve institutional and governance quality to attract additional inflow of PPP into Infrastructure. Thus, India needs to address various policies in the path of institutional and governance reforms to attract additional PPP in infrastructure in the long run.

References

1. Acemoglu D, Johnson S (2005) Unbundling institutions. J Polit Econ 113:949–995
2. Aschauer DA (1989) Is public expenditure productive? J Monet Econ 23(2):177–200
3. Asiedu E (2002) On the determinants of foreign direct investment to developing countries: is Africa different? World Dev 30:107–118
4. Asiedu E (2006) Foreign direct investment in Africa: the role of natural resources, market size, government policy, institutions and political instability. World Econ 29(1):63–77
5. Banerjee G, Oetzel J, Ranganathan R (2006) Private provision of infrastructure in emerging markets: do institutions matter? Dev Policy Rev 24(2):175–202
6. Busse M, Carsten H (2007) Political risk, institutions and foreign direct investment. Eur J Polit Econ 23:397–415
7. Canning D, Pedroni P (2004) The effect of infrastructure on long-run economic growth (mimeo). Harvard University, Cambridge, MA
8. Cheng LK, Kwan YK (2000) What are the determinants of the location of FDI? The Chinese experience. J Int Econ 51:379–400
9. Calderon C, Serven L (2003) The output cost of Latin America's infrastructure gap. In: Easterly W, Serven L (eds) The limits of stabilization: infrastructure, public deficits, and growth in Latin America. Stanford University Press and World Bank, Palo Alto, CA, pp 95–118
10. Fedderke JW, Perkins P, Luiz JM (2006) Infrastructural investment in long-run economic growth: South Africa 1875–2001. World Dev 34:1037–1059
11. Hammami M, Ruhashyankiko J, Yehoue E (2006) Determinants of public-private partnerships in infrastructure. IMF Working Paper, no 06/99
12. Harris C (2003) Private participation in infrastructure in developing countries: trends, impacts, and policy lessons. World Bank Working Paper, no 5

13. Kasri RA, Wibowo FA (2015) Determinants of public-private partnerships in infrastructure provision: evidence from muslim developing countries. J Econ Cooperation Dev 36(2):1–34
14. Kaufmann D, Kraay A (2002) Growth without Governance. World Bank Policy Research Working Paper, no 2928
15. Kirkpatrick C, Parker D, Zhang YF (2006) Foreign direct investment in infrastructure in developing countries: does regulation make a difference? Transnational Corporations 15(1):143–171
16. La Porta R, Lopez-de-Silanes F, Shleifer A, Vishny RW (1997) Legal determinants of external finance. J Financ 52(3):1131–1150
17. La Porta R, Lopez-de-Silanes F, Shleifer A, Vishny R (1998) Law and Finance. J Polit Econ 106:1113–1155
18. Morrisset J (2000) Foreign direct investment to Africa: policies also matter. Transnatl Corp 9:107–125
19. Munnell AH (1990) Why has productivity growth declined? Productivity and public investment. N Engl Econ Rev 3–22
20. Naudé W, Krugell W (2007) Investigation as determinants of foreign direct investment in Africa using panel data. Appl Econ 39:1223–1233
21. Pragal S (2003) Regulation and private sector participation in infrastructure. Policy research Working Paper, no 3037
22. Roller LH, Waverman L (2001) Telecommunications infrastructure and economic development: a simultaneous approach. Am Econ Rev 91(4):909–923
23. Rodrik D, Subramanian A (2003) The primacy of institutions (and what this does and does not mean). Finance Dev 40:31–34
24. Sharma C (2012) Determinants of PPP in infrastructure in developing economies. Transforming Government: People, Process and Policy 6(2):149–166
25. Sahoo P, Dash RK (2009) Infrastructure development and economic growth in India. J Asia Pac Econ 14(4):351–365
26. Shleifer A, Vishny R (1993) Corruption. Quart J Econ 108:599–617
27. Wei S-J (2000) How taxing is corruption on international investors. Rev Econ Stat 82(1):1–11
28. World Bank (1994) World development report 1994: infrastructure for development. Oxford University Press, New York

In-vehicle Adaptive Traffic Collision Impact System for Next-Generation Traffic

Jashvi Mehta, Yashwant Dadi, Deep Patel, Jiten Shah and Dipankar Deb

Abstract Various technologies have been developed for safer and more comfortable road travel. Intelligent Transportation Systems (ITS) are being adopted for numerous purposes to solve traffic problems. In this paper, an in-vehicle system capable of avoiding or lessening the impact of collision is designed, developed, and validated. Analysis has also been done on an Indian road to check the reliability of the data obtained. The system detects the obstacles around the vehicle and issues warning to the driver. Study provides in-depth analysis and methodology in order to warn about safe distance, which will help in decision-making of driver to reduce the impact of collision. Impact Reduction Scheme also provides cause of accidents which may help in formulating an effective, verifiable, and justified insurance claim and redress system.

Keywords Intelligent transportation systems (ITS) · In-vehicle system · Sensors GPS · Collision impact reduction

J. Mehta · Y. Dadi · J. Shah (✉) · D. Deb
Institute of Infrastructure Technology Research and Management,
Ahmedabad 380026, Gujarat, India
e-mail: jitenshah@iitram.ac.in

J. Mehta
e-mail: mehta.jashvi@iitram.ac.in

Y. Dadi
e-mail: dadi.yashwant@iitram.ac.in

D. Deb
e-mail: dipankardeb@iitram.ac.in

D. Patel
Georgia Institute of Technology, North Avenue, Atlanta, GA 30332, USA

D. Deb et al. (eds.), *Innovative Research in Transportation Infrastructure*,
Lecture Notes in Intelligent Transportation and Infrastructure,
https://doi.org/10.1007/978-981-13-2032-3_8

1 Introduction

Road journeys have gained a lot of popularity in the recent times. The advantage of the roadways over other means of transportation lies in its flexibility and convenience resulting in a drastic increase in the number of vehicles and users. Consequently, the number of fatal accidents has also increased manifold, thereby creating a socioeconomic challenge. Most of these accidents are caused due to lack of road-sense and negligence in strict adherence to traffic rules and regulations. The safety of the passenger is a key issue and hence continuous efforts are made by the scientists to come up with solutions for road safety and traffic management.

As of 2013, there are over 1.2 million deaths per year on roads all over the world. Road accidents are the leading cause of deaths among age group 15–29 [1]. These cause great trauma to the families of the deceased. Moreover, the global loss in GDP because of such accidents is estimated to be about 3%. All countries of the world face this issue, but the magnitudes vary. A countrywise accident statistics are presented in Table 1.

Table 1 revealed that countries with higher income (per-capita) have lesser accident rates and GDP losses than the low and middle-income countries. Most of the lower/ middle-income countries face serious traffic issues like safety and congestion which in turn cause loss to people and economy of country and hence, innovative and economical solutions to these problems are an attractive proposition for all concerned. The United Nations has resolved to improve road safety and save lives [2]. They have declared the decade 2011–2020 as the Decade of Action for Road Safety (May 11, 2011). Further, many efforts have been carried out to increase road safety involving driver assistance systems. Although vehicles caught in accidents owe to various issues such as over speeding, lane change behavior, heavy traffic during rush hours, and mostly narrow lanes [3].

In the last few decades, researchers have been carried out the studies on road accident and developed the system to prevent the accidents which includes safety

Table 1 Statistics about road accidents around the world

Country	Rate per 0.1 million	Estimated fatalities	GDP loss (%)
USA	10.6	34,064	1.9
UK	2.9	1827	1.0
Russian Federation	18.9	17,025	2.2–2.6
Australia	5.4	1252	2.1
Norway	3.8	192	1.0
Japan	4.7	5971	1.3
India	16.6	207,551	3.0
China	*18.8*	261,367	–
Pakistan	*14.2*	7636	–
South Africa	*25.1*	13,273	7.8

warning system, intelligent driver assistance systems, etc. involving many interdisciplinary research fields few of them are computer science, traffic engineering, automobile, signal system, and control systems. Various attempts have been carried out in order to understand navigation system and different ontology models are developed to satisfy the basic needs, however very few of them are focused on road safety issues. Saravanan et al. [4] proposed an integrated system for safety situation by sensing phase. Vehicle proximity from obstruction has been used as a parameter to decide vehicle safety. Chen [5] and Sindle [6] used these short-range sensors in their inventions. Authors (US005170858A) stated that when the distance reduces beneath a certain limit the detection of obstruction on the front end of the vehicle can be done by using ultrasonic emitter and receiver and automatic braking mechanism by boosting brake oil to the two cylinders to stop the front and rear wheels automatically [5]. Whereas Sindle, in US005173881A, discussed the use of energy transmitting–receiving distance detecting devices which are to be placed around the vehicle to detect obstructions. The driver is alerted when distance decreases beneath a designed value. By means of different colored signals and even a proposed audible warning. It is basically a microprocessor-based system which processes the data obtained and then feeds them to signaling circuit to execute the warning whenever needed [6].

Shyu [7] and Davidian [8] used space or distance sensors along with speed sensors to issue alarm and suggested methods for collision avoidance. Shyu, in US005091726A, along with distance measurement, had developed algorithms for flashing of light and changing cruise control settings in critical situations [7]. Davidian, in US005357438A, mentioned about developing an anti-collision system which uses speed sensors and space sensors along with some environmental parameters to calculate the probable collision distance using microcomputer and the final actuation of an alarm [8].

Geographic Positioning System (GPS) is another useful component for traffic-related studies. Xu and Jin [9] used the GPS to get the location-based data to a traffic service center, from the vehicles fitted with the device. They used this data to provide real-time traffic forecasts. Desai et al. [10] have claimed a collision warning system by using motion sensors, in the form of speedometer or accelerometer wherein the collision avoidance is done by first of all having position of the vehicle by GPS or GIS and having a future scope of communicating with other vehicles and slowing down of one of the vehicles.

Many Black Box systems have also been designed for road vehicles to serve as event data recorders with real-time vehicular information, and in case of an accident, it freezes the time window and stores all the data for posterity [11]. Nowadays, many cars are designed to avoid collision or move along the road in a given situation considering the external environment which is of function-specific automation or combined function automation. Companies like Volvo are designing semiautomatic cars with requisite safety features. Moreover, technologies like the V-box and black box which can be retrofitted in vehicles are very popular in the USA, UK, and Australia. However, these solutions are expensive and not suitable for the rest of the world. Microcontroller-based in-vehicle systems are gaining popularity these days

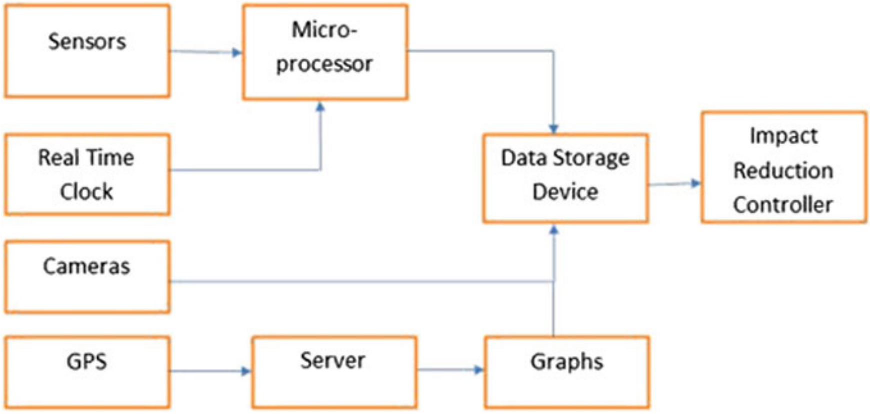


Fig. 1 System architecture

due to low cost and easy interface with other components, especially in the developing countries. Microcontrollers with ultrasonic sensors were proposed to detect objects around the vehicle and take measures to decelerate in order to avoid or reduce the impact of collision [12–15]. Electromagnetism for stopping the vehicle along with ultrasonic range finder is also used to prevent or reduce the impact of collision [16].

In the present paper, an intelligent in-vehicle system with sensors and GPS was incorporated with an infrastructure-based system. The results were simulated with an aim to reduce collisions, improve road safety, and reduce pollutant emissions [4]. In order to handle the issue of road safety, the present paper explains the detailed methodology of collision impact reduction system with validation.

1.1 System Outline

The proposed collision reduction systems allowed to take appropriate decision to avoid the collision completely or partially. The system consists of real-time clock (RTC), multiple ultrasonic sensors, cameras, telematics system, microcontroller, data storage, web server, and impact reduction controller. The sensors and RTC are connected to the microcontroller and the data is saved in storage card with the help of a shield used along with the microcontroller. The cameras are connected to a Digital Video Recorder (DVR) which stores the data. A GPS module is also utilized to constantly send real-time data to a web server which is accessible in real time and also stored for posterity. The flow of data can be easily understood by Fig. 1.

The complete setup basically consists of five main features as under:

1. Proximity Sensing System
2. Telematics Control Unit
3. Video Recording

4. Collision Warning System
5. Impact Reduction Controller

1.2 Proximity Sensing System

The system consists of ultrasonic sensors positioned on all sides of the vehicle, which can provide the mutual distance between the vehicle under study and the adjacent vehicle. The range of operation of the sensor is 2–400 cm. Continuous data of adjacent objects are logged a storage card which facilitates to analyze further traffic flow as well.

1.3 Telematics Control Unit

A GPS logger is installed to give the full journey data of position, speed, and distance traveled. It will serve as a vehicle tracking device. It gives an overspeed alert and that data can be sent to predefined mobile numbers. It acts like a double-check for the driver as well as a way of monitoring for the family members or the owner of the vehicle. The trip reports are also generated and sent to the user via e-mail. It has a provision for creating a geo-fence. If a vehicle exits the fence, the concerned person is alerted via an SMS.

1.4 Video Recording

The video recording setup consists of multiple cameras and a Digital Video Recorder (DVR). The cameras are attached on two sides; front and back of the vehicle and recording would take place as long as the ignition starts. The recorded data will be accommodating further analyses causes of accident.

1.5 Collision Warning System

The microcontroller used in the circuit is attached to the ultrasonic sensors, and is programmed such that when a vehicle is closed to (less than safe distance) any obstacle/vehicle, it will detect and inform the driver (in the form of; a red light, audible warning, etc.) to prevent from potential accidental risk. The safe distance can be varied using a look-up table based on the severity of the expected collisions as per the surrounding environment. In the present case, it would 1 m.

2 Impact Reduction Controller

The Impact Reduction Controller (IRC) consists of a warning system and a mechanism for control transfer. The warning is issued in the form of flashing of a red LED in front of the driver in case the obstruction is nearer than the 'safe distance'. The impact reduction controller works in collusion with the cruise controller of the vehicle. The control transfer mechanism is conceptualized to have an electrical control system which transfers the control of vehicle to the cruise controller supposed to be already in the vehicle. In case a vehicle does not have a cruise controller, the control transfer mechanism will have a void effect.

The functioning of the cruise controller is briefly described herewith. Instead of frequent checking of the speedometer and adjustment of pressure on the brake, the vehicular speed is maintained at a constant value set by the driver. The input to the Cruise control system includes the set buttons on steering wheel, gas pedal, brake, clutch, and the feedback signal. There is a centralized processor to control the vehicular speed and provide the throttle position as the output. The cruise control system accelerates to the desired speed without overshooting and maintains the speed with minor deviations, even when the vehicle is driving up or down a steep hill. The process of sending the current speed continues as long as the cruise control is engaged so that the processor can maintain the desired speed. A functional diagram of a cruise controlled system is shown in Fig. 2.

The Impact Reduction Controller consists of the warning system for the driver as well as a control transfer system to cruise control in order to reduce the impact of collision. In the first case, if the distance is less than 1 m, a warning will be given to driver. By adding a control system, a second case would exist in which deceleration of vehicle can take place in case distance is less than some predefined value. In situations where no major obstructions are present, the vehicle can move at same speed. This can be done with the help of cruise control system. Detail algorithm for impact reduction controller is presented in Fig. 3.

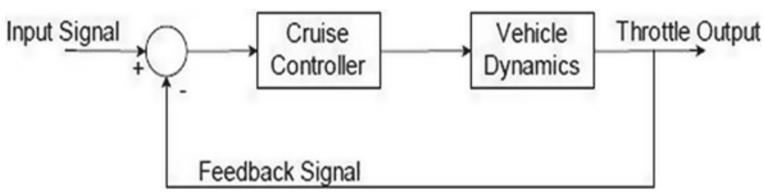


Fig. 2 Functional diagram of a cruise control system

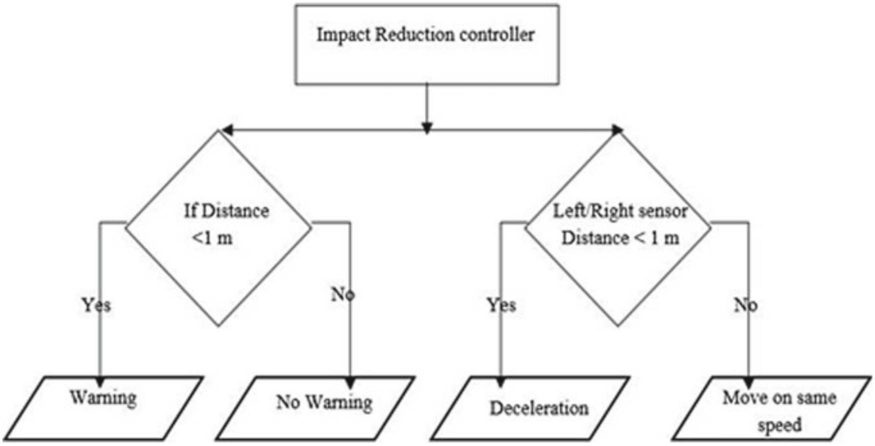


Fig. 3 Algorithm for impact reduction

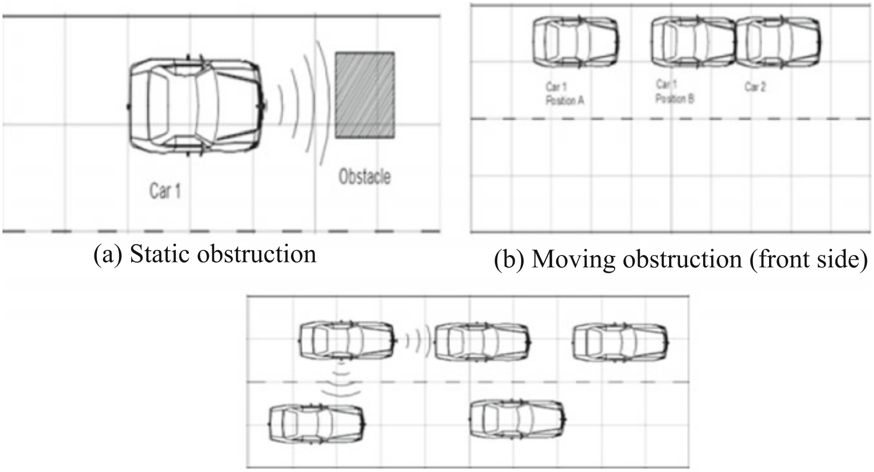
3 Application of the System in Different Scenarios

During course of journey, the device approaches the static obstacle from either sides, the proximity of the vehicle with respect to static obstacle is computed and based on the reading, if the obstacle is closer than the 'safe distance', the device is triggered and a warning is given to the driver, which eventually helps the driver avoid collision. Figure 4a shows the tracking of static obstacle. Figure 4b, c shows the application of a device for moving vehicles in the same lane. While the moving vehicle approaches reference vehicle, the relative distance is computed and if this distance becomes less than the 'safe distance', the device triggers a warning to the driver informing about the impending crash. Further, the system has been validated for distance measurement and global positioning of the reference vehicle.

4 Validation of Distance Measurement

This section provides functional validation of sensors (Static and Dynamic), and validation of global positioning. The accuracy of the system is measured with accuracy of 0.01 cm–4 m. The laboratory-based distance measurement was carried out. The value of distance measured by the sensor at various distance points was further validated with the actual measurement of distance at site. The correlation of the detected values and actual values was plotted as shown in Figs. 5.

Further, in order to check the stirring measurement while vehicle running on road, the reference vehicle is tracking the different vehicles along the path that data is stored for the corresponding distance measurement at roadside. The roadside measurement



(a) Static obstruction

(b) Moving obstruction (front side)

(c) Moving obstruction on either side

Fig. 4 Tracking of different scenarios

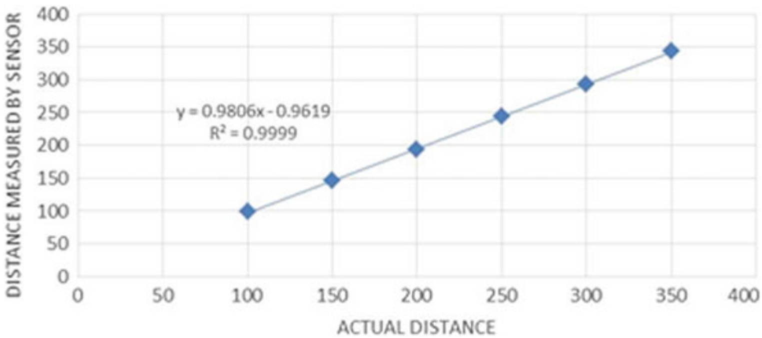


Fig. 5 Correlation between actual and sensed distances

was carried out by overhead camera positioned at vantage point in order to track the different movement of reference vehicle and surrounded vehicle as well.

From Fig. 6, it reveals that the sensors having good sensing capability with the system adopted. Further, the speed of the vehicles during course of journey is also tracked with GPS system and also with the help of different time frame which provides measurement of speed for a given vehicle on road (Fig. 7).

The above plot shows a correlation of 0.8514. It means there is a considerable deviation of about 15%. However, it can also notice that because of very few anomalous points, there is a difference in the overall value of correlation. In addition GPS based positioning.

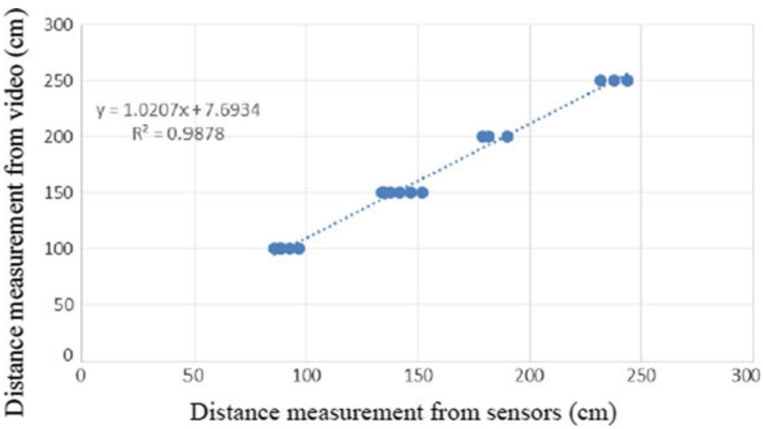


Fig. 6 Relation between sensor based and actual distance on site

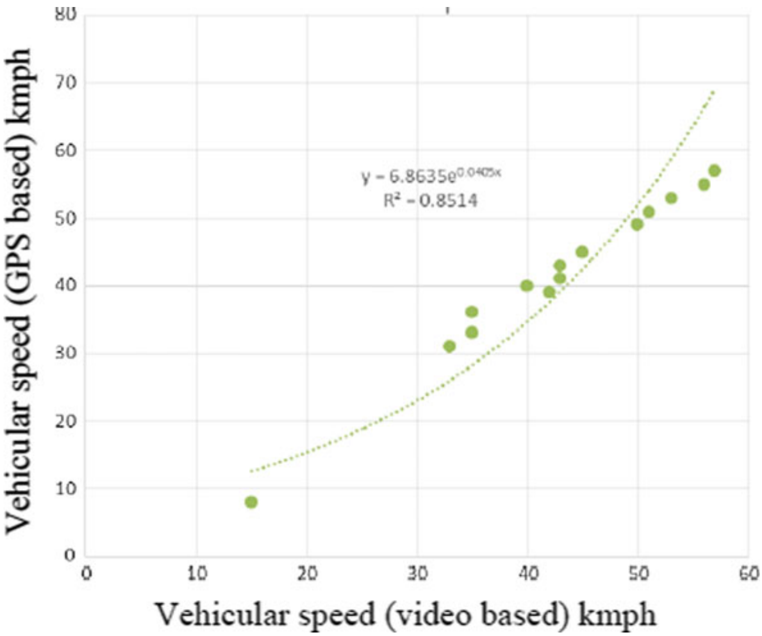


Fig. 7 Relation of vehicular speed

5 Sensitivity Analysis of the Collision Impact Reduction System

The analysis was carried out on NH 8 near Ahmedabad, Gujarat. The safety warnings system is depicted to show the response time graph. The Y-axis indicates the time at which the control system is invoked and on X-axis indicates the time at which the

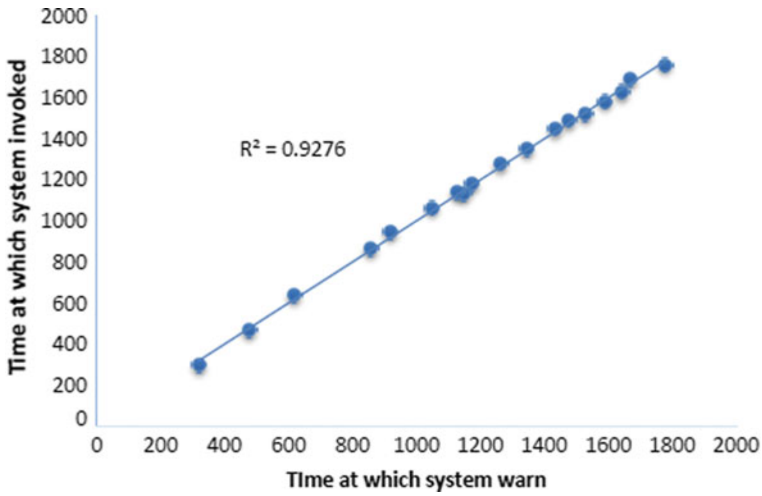


Fig. 8 Active warning system of algorithm

warnings are generated. The response time is measured in milliseconds between the time of control system is invoked to the time the warning arises is shown in Fig. 8.

Based on the analysis and validation of the system, it revealed that the response time for safety warning generated for various roadside situation invokes the control system immediately with low mean absolute percentage error (MAPE) value of 12%. However, before concluding the accuracy and quick response of system, the data was first checked goodness-of-fit between time values at which system invoked and system warned. The results show that the MAPE is found to be low of 13%. Hence, it can be concluded that the designed system has a constant response time for safety warnings generated for many of the contexts that invoke the control systems immediately and within constraint period of time. Thus, the system would have a feasibility of implementing in real-time warning system for quick decision to avoid potential impact of collision between obstacles.

6 Conclusion and Future Scope

The paper focused on the issues and challenges of safety warning system at the roadway. Algorithm has been developed to avoid the collision impact during journey. Further, the performance of each systems comprising of telematics control, collision warning system, and positioning was adopted in order to check the accuracy and reliability of the system at real time. The results were also checked through statistical tool. Validation gives a promising result for the reliability of the system to reduce impact of potential collision. The results and demonstration of system will help in decision-making of driver to reduce the impact of collision. Impact Reduction

Scheme also provides cause of accidents which may help in formulating an effective, verifiable and justified insurance claim and redress system. Future work will be concerned with a more comprehensive extension of the adaptive control of the system with base knowledge of cruise control during process of decision-making of shift from all sides.

References

1. Global status report on road safety, World Health Organization (WHO) (2015)
2. Resolution adopted by the General Assembly, United Nations, 2 March 2010
3. Shah J, Deb D, Mehta J, Patel D, Dadi Y (2016) Device and method for traffic data acquisition and their control system. IN201621041894 A, 23 December 2016
4. Saravanan K, Thangavelu A, Rameshbabu K (2009) A middleware architectural framework for vehicular safety over VANET (InVANET). In: First international conference on networks and communications, pp 277–282
5. Chen G (1992) Automatic braking apparatus with ultrasonic detector. US005170858A, 15 December 1992
6. Sindle T (1992) Vehicular proximity sensing system. US005173881A, 22 December 1992
7. Shyu J (1992) Vehicle anti-collision system. US005091726A, 25 February 1992
8. Davidian D (1994) Anti-collision system for vehicles. US005357438A, 18 October 1994
9. Xu Y, Jin Y (2002) Remote road traffic data collection and intelligent highway system. US006401027B1, 4 June 2002
10. Desai U, Merchant S, Sivaraman S, Agarwal M (2011) Collision avoidance system and method. US20110106442A1, 5 May 2011
11. Yousefi N, Kim Y, Walley J, Chen S, Diab W, Ilyadis N (2012) Vehicle black box. US20120109447A1, 3 May 2012
12. Shinde T, Pawar B (2013) Car anti-collision and intercommunication system using communication protocol (a prototype model). Int J Eng Sci Res Technol
13. Shabadi A, Patil D, Rolli M, Sangolagi A, Veni S (2016) Accident controller using ATmeg328P microcontroller and ultrasonic sensors. Int J Eng Appl Sci Technol
14. Rajarajan R, Rahuman A, Harish S, Bharath M (2011) A design and implementation of collision avoidance system (CAS) for automobiles using embedded system. In: International conference on circuits, system and simulation, Singapore
15. Dubey S, Ansari A (2013) Design and development of vehicle anti-collision system using electromagnet and ultrasonic sensors. Int J Theor Appl Res Mech Eng (IJTARME)
16. Jang J, Kim H, Cho H (2011) Smart roadside system for driver assistance and safety warnings: framework and applications. Sensors

Analysis of Truck Trips Generated from Port Infrastructure Based on Trip Length Distribution

S. C. Rathod and H. R. Varia

Abstract Share of transport sector in Indian Gross Domestic Product (GDP) is about 6.4%. Predominantly road infrastructure carries about a share of 5.4% in GDP (Planning commission, of India 2013). There has been an average growth of 8.87% in export cargo and 7.68% in import cargo at Kandla port from 2004–2014 (Rathod and Varia in Freight transport modelling-issues and challenges: a case study of Kandla port, 2016 [1]; Rathod and Varia in Category analysis of truck trips observed at Samakhiyali Check Post, Gujarat, 2016 [2]). In the present paper, an attempt is made to analyze the generated truck trips based on trip length distribution (TLD). TLD is examined based on commodity and tonnage. The data is collected from single point entry and exit of regional area of Kandla port. The analysis depicts variation in terms of trip length and time. A rise is observed due to seasonal variation by 20.61%. Most of the trips observed are in the range of 0–1200 km.

Keywords Trip length distribution (TLD) · Freight · Trip · Trip length

1 Introduction

Seaports are considered as the gateways of national and international trade. One of the main characteristics of freight transport is its phenomenal diversity. Vehicles, and delivery times, size of shipments may even vary according to each business or customer region wise. Demand forecasting is very complex in freight traffic. Road freight demand is derived demand because it depends on country's economic

S. C. Rathod (✉)
School of Engineering, R. K. University, Rajkot, Gujarat, India
e-mail: scrathod@gmail.com

S. C. Rathod
Civil Engineering Department, L. D. Engineering College, Ahmedabad, Gujarat, India

H. R. Varia
Tatva Institute of Technological Studies, Modasa, Gujarat, India
e-mail: hr7varia@yahoo.co.in

D. Deb et al. (eds.), *Innovative Research in Transportation Infrastructure*,
Lecture Notes in Intelligent Transportation and Infrastructure,
https://doi.org/10.1007/978-981-13-2032-3_9

production. Some other parameters that affect transport demand are the location of industry and situation of consumption center. Road freight demand is also dependent on mode and method of distribution, trade between countries and quality of goods. Severe problem of availability of data arise in case of developing countries against the developed countries where freight and O-D surveys are carried out on regular basis [3]. Ports have always been a part of marine transport. Ports of India carry about 95% of total volume and 70% in value in international trade. India has 12 major ports and 187 nonmajor ports (Planning Commission, Govt. of India, 2011) [4]. In the decision-making process of port planning, a model to estimate the total distance traveled by vehicles in transport these import and export containers is helpful. Organization of this paper is as follows: Sect. 2 deals with the literature review about the survey methods in practice. A brief introduction about study area (Kandla port) is presented in Sect. 3. Data collection and brief data analysis are presented in Sect. 4. Trip length distribution is presented in Sect. 5. Section 6 concludes the paper.

2 Literature Review

Guo [5] carried out the reform and pilot study of the survey methodology for road freight transport. Two methods were adopted for data collection. On-site questionnaire survey was adopted for goods and vehicles and commercial vehicle typical enterprise survey was adopted for noncommercial vehicle study.

Serag and Al-Tony [6] in their study modeled international freight transport through lands and sea ports of Arab countries for the duration 1997–2001. For the data collection, parameters like delivery time, shipping time, transport time, and custom process time were included and statistically tested.

Chu [7] has formulated some models truck-trip generation for hauling containers at a major international seaport. The model adopted was internal–external truck-trip forecast model. Factors considered were based on monthly data like natural disaster, economic growth attributes, and regional and freight activity attributes. The final forecasting model was determined by comparing the prediction accuracy of a multiple regression model, time series models, and a neural network model.

Demand forecasting models developed by Patil and Sahu [4] for Mumbai port were developed based on inbound and outbound demand forecasting. Additive regressive and time series techniques were used in model. The significant parameters were found to be economic indicators, Gross Domestic Product (GDP) and Crude Oil Production (CRLP) in regression analysis.

For the port of Miami, truck trip generation model for container and trailer operation was developed by Al-Deek et al. [8]. The major factors identified were particular weekday of operation and amount and direction of the cargo vessel. For predicting freight trip generation models, regression analysis and backpropagation neural (BPN) models were employed. Out of two techniques, BPN model was found to be more accurate.

Holguin Veras and Thorson [9] examined trip length distributions (TLD) based on tonnage and freight demand for Guatemala. The data was collected through a questionnaire survey. The study revealed that major TLDs were affected by freight generators. The shape of TLD was governed by the type of movement being considered.

3 Study Area

Kandla is a seaport in Kachchh district of Gujarat state in western India. It is located on the Gulf of Kachchh on the northwestern coast of India. The pot is well connected by National Highway (NH 8). Hinterland of Kandla port is extended up to Rajasthan, Punjab, Haryana, and Delhi. Desire line diagram is shown in Fig. 1.

4 Data Collection

Due to the geographical complexity of region, the data was collected from single entry and exit point Samakhiyali junction which is 55 km away from the Kandla port. The data was collected by conducting a roadside interview survey with the help of five enumerators located at two different check posts.

The data collected was comprised of vehicular details like registration number, type of vehicle based on Axle, commodity-related information, i.e., name of commodity, Shipment characteristics (Loose, Packaged or Tanker), Trip load (per trip), and origin and destination of trip and journey time. Data was collected in two groups, Inward and Outward trips. Totally, 1055 truck drivers (160 inward and 895 outward) were interviewed during data collection.

4.1 Geographical Location of Survey Spot

• Type of road: 6 lane divided national highway (Toll road), NH No.: 8-A, Road Number: 161 (Fig. 2).

Data is analyzed with respect to a total number of truck trips per day, percentage share of trips from Kandla, average trip length, average time, average load, classification based on axle, shipment characteristics, commoditywise share of trips, statewise share of trip, and distancewise trips. For the purpose of this paper, characteristics related to trip length is discussed.

Fig. 1 Desire line diagram of truck trips from Kandla port

4.2 Trip Characteristics

Characteristics of trips were studied with respect to average of trip length, travel time and load (Table 1). The total tonnage is distributed as follows: 3 axle (3A) vehicles, 4.46%; 4-axle (4A) trucks, 15.75%; with the multi-axle (MA) capturing the rest 79.44%. The results are presented in Table 2.

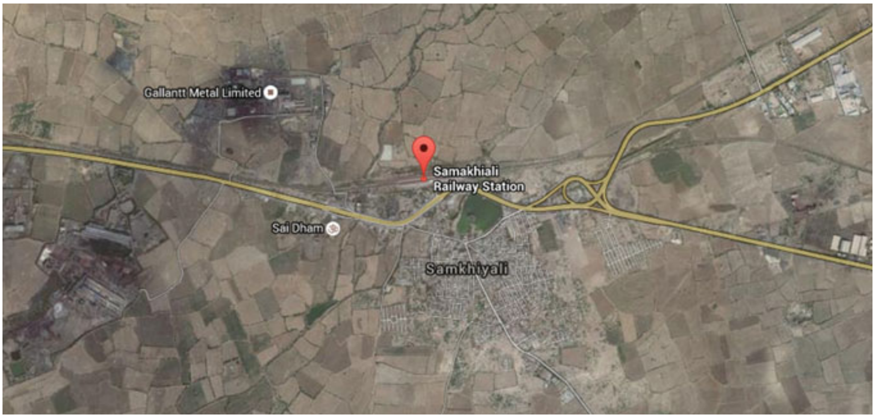


Fig. 2 Location of survey spot (*Source* Google map)

Table 1 Average of trip length, travel time and load

	Outward trips	Inward trips
Average trip length (km)	1023.08	895.16
Average time (h)	67.16	50.71
Average load (Ton)	26.58	25.10

5 Characteristics of Trip Length on Different Criteria

Only loaded trucks were considered for the study. An outward trip is a trip going away from port and vice versa is considered as inward trip. As can be seen from Fig. 3 that majority of the trips are attracted from a distance of 1000–1300 km range because the hinterland of the port is extended up to Hariyana in the North India and Tamilnadu in South India. It can be seen from Fig. 3 that the highest share is about 20% of trips in distance range of 1100–1200 km.

Major of the inward trips from a distance of 1200 km. Distribution of goods depends on demand of the commodity from the nearby state. Since major data collection is for outward trips, only outward trips are considered for analysis of trip length in next sections. Figure 4 shows the percentage frequency of trip length range (km) for inward trips.

As can be seen from a combined TLD versus frequency chart in Fig. 5, trips beyond range of 500–1300 km has similar characteristics for both inward and outward trips. Short trips within distance range of 0–400 km are more due to export of commodity like wheat, rice, etc. Short trips in distance range of 100 km are observed due to the survey spot located near the bay of Kutch having number of salt pans producing the huge quantity of raw salt which is sent for processing in nearby plants.

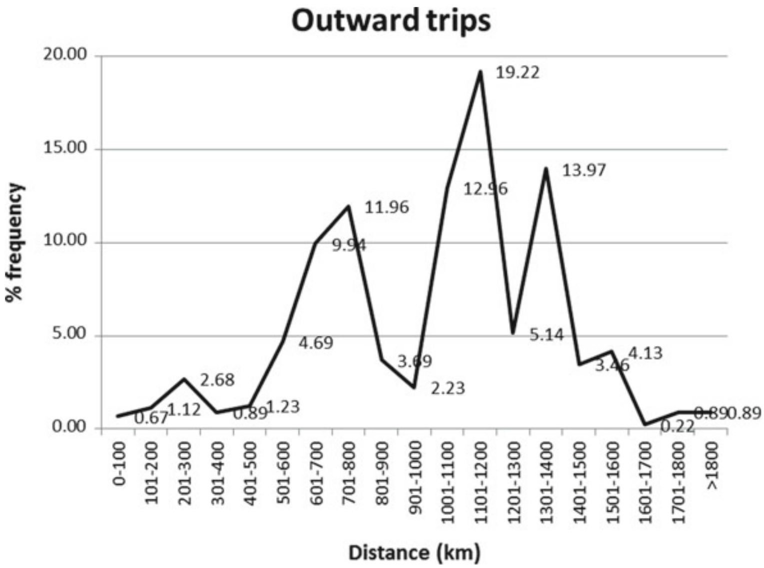


Fig. 3 Percentage frequency of trip length range (km) for outward trips

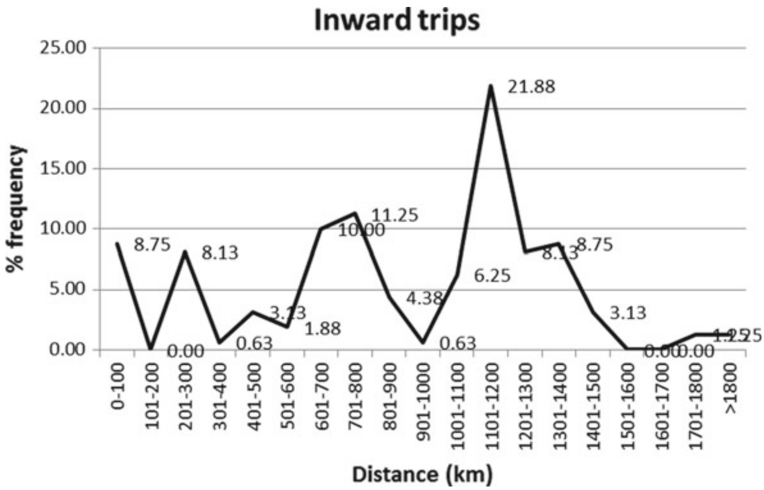


Fig. 4 Percentage frequency of trip length range (km) for inward trips

5.1 Trip Length Based on Shipping Characteristics

In this section, TLDs according to types of shipping are discussed. As can be seen from Fig. 6 that major of the commodities are shipped in packages as these are trans-

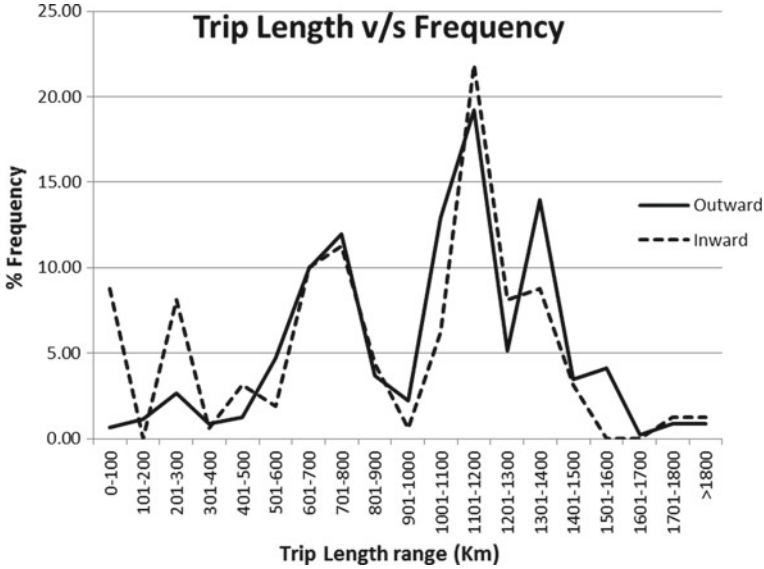


Fig. 5 Combined percentage frequency of trip length range (km) for both trips

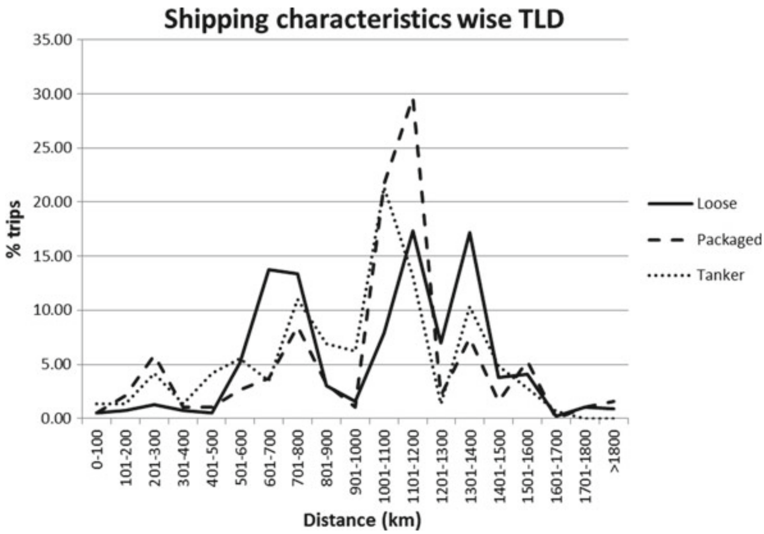


Fig. 6 Percentage frequency of trip length range (km) for outward trips

ported to a long distance more than 1000 km. This happens because the destinations in the study area are located at far distances from the origin Kandla Port.

For the given categories of average journey hours trip length is shown in Fig. 7.

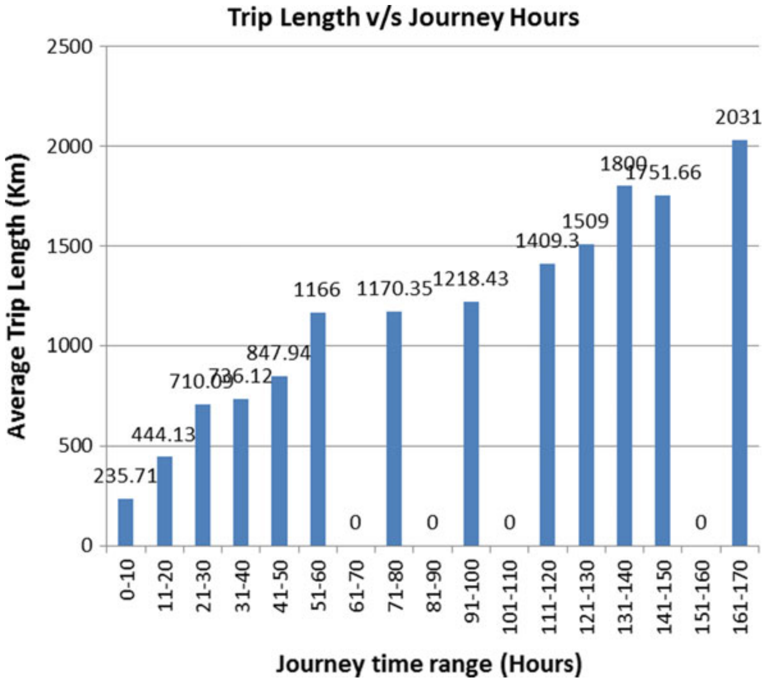


Fig. 7 Average trip length corresponding to journey hours

Table 2 Vehicle type and percentage frequency

Vehicle type	Frequency	% Frequency
Multi-axle	711	79.44
4 Axle	141	15.75
3 Axle	40	4.47
2 Axle	3	0.34

5.2 *Trip Length Based on Vehicle Type*

This section analyzes the TLDs for different categories of vehicles. The analysis focuses only type of axle as shown in Table 2 and Fig. 8. As can be seen, the TLDs are different with shapes and ranges that are governed by the vehicle size. Concluding that TLDs depend upon the type of vehicle and the corresponding carrying capacity. This will help truck operators to operate the type of vehicle which gives optimum return.

This is supported by Fig. 8 which shows the percentage frequency of trips at various distance intervals, by specific groups of vehicles. The TLDs of 4 Axle trucks shown in Fig. 8 exhibit a peak around 400 km, which corresponds to flows to and from the Kandla port. However, the TLDs of 3 Axle trucks do not exhibit such behavior because they are used to serve for a short distance range by 300 km. This

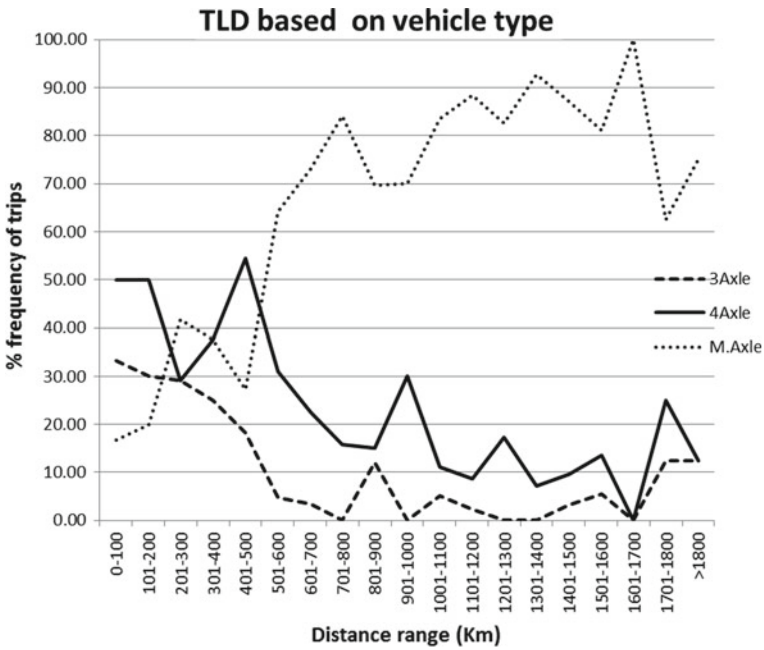


Fig. 8 Vehicle type TLD

indicates that major generators produce differential impacts upon vehicle classes, the magnitude of which depends upon the type of vehicle serving the generators.

5.3 Trip Length Based on Commodity Group

This section shows the analysis of TLDs for the main commodity groups observed in the O-D survey (Fig. 9). The tonnage distribution transported by the different types of vehicles includes (a) coal, 36.81%; (b) oil, 15.34%; (c) wood, 10.12%; (d) gypsum, 9.51%; (e) chemicals, 3.68%; (f) steel, 10.43% and (g) others, 14.11%.

5.4 Number of Trips Estimated by Weighted Tonnage

Four categories of vehicles are observed in survey data. Load carrying capacity of different vehicles depends on number of axle. So, weighted tonnage is worked out base on formula,

$$\text{Weighted tonnage } W = ((n1 \times w1) + (n2 \times w2) + (n3 \times w3))/(n1 + n2 + n3)$$

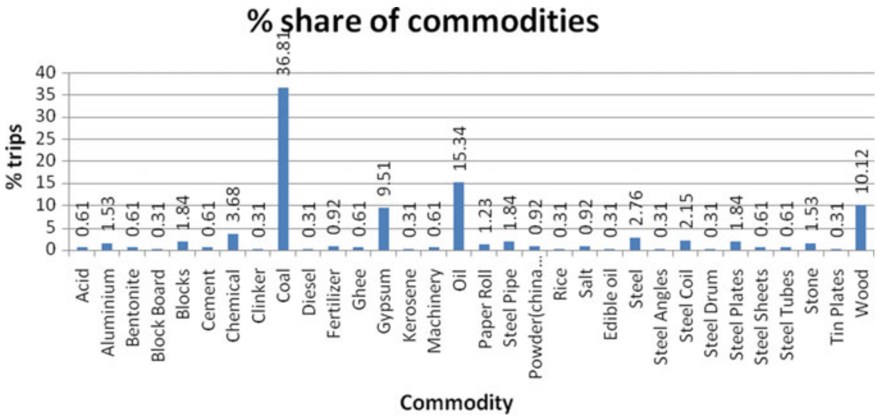


Fig. 9 Commodity based trips

where, $n1$, $n2$, and $n3$ = No. of 3 axle, 4 axle and multi-axle trucks, respectively and $w1$, $w2$ and $w3$ are average tonnage of respective category.

From above, weighted tonnage W comes out to be 26.62 tons.

Weighted tonnage is used to estimate total number of trips generated from Kandla port in respective year (Table 3).

Trend equations are generated using above data as mentioned below.

Following polynomial equations are best suited to observations.

For Export cargo, $y = -18840x^2 + 42325x + 1 \times 10^6$ with $R^2 = 0.971$ and
For Import cargo, $y = -20094x^2 + 35850x + 72317$ with $R^2 = 0.959$, where x is ith year.

6 Conclusions

Kandla port handles about 16% of the total seaport freight. The study is aimed to analyze the truck trips by trip length frequency distribution. This paper conducted a review about freight movements based on commodity and trip length.

- It is found that trip length distribution can be categorized by tonnage and volume as well as vehicle type.
- In this study, about 20% trips (outward as well as inward) have been found for the trip length range of 1100–1200 km.
- About 30% trips of commodities are shipped by packaging found for the range of 1000–1200 km trip length.
- Multi-axle trucks shared about 79% trips and that for the long distances.
- In the trip distribution stage vehicle based and tonnage based relationship will be required.

Table 3 Trip generation estimation from Kandla port using weighted tonnage

Cargo export										
Year	2004–05	2005–06	2006–07	2007–08	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14
MT	41,551,131	45,906,922	52,982,104	64,920,284	72,224,910	79,500,074	81,880,311	82,501,302	93,618,887	87,004,752
Trips	1,560,899	1,724,527	1,990,312	2,438,779	2,713,182	2,986,479	3,075,894	3,099,222	3,516,863	3,268,398
Import cargo										
Year	2004–05	2005–06	2006–07	2007–08	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14
MT	31,386,825	34,780,151	39,984,724	46,706,445	53,159,873	61,650,972	60,995,908	60,102,848	63,193,352	59,492,091
Trips	1,179,069	1,306,542	1,502,056	1,754,562	1,996,990	2,315,964	2,291,356	2,257,808	2,373,905	2,234,864

MT metric ton

References

1. Rathod SC, Varia HR (2016) Freight transport modelling-issues and challenges: a case study of Kandla port. In: International conference on transportation planning methodology for developing countries, IIT Bombay, paper ID 98
2. Rathod SC, Varia HR (2016) Category analysis of truck trips observed at Samakhiyali Check Post, Gujarat. In: International conference on research & entrepreneurship, R. K. University, Rajkot, Gujarat, India. ISBN: 978-93-5254-061-7
3. Ministry of Road Transport and Highway, India, passenger and freight traffic assessment and adequacy of fleet and data collection and use of IT in transport sector in the twelfth five year plan (2012–17)
4. Patil G, Sahu P (2015) Estimation of freight demand at Mumbai Port using regression and time series models. KSCE J Civ Eng 20(5):2022–2032. https://doi.org/10.1007/s12205-015-0386-0
5. Guo H (2010) The reform and pilot study of survey methodology for road freight transport. In: ICLEM 2010: logistics for sustained economic development 2010 ASCE
6. Serag MS (2013) Al-Tony modeling international freight transport through ports and lands of Arab countries. Alexandra Eng J 52:433–445
7. Chu H-C (2011) Empirical method for predicting internal-external truck trips at a major port. ASCE J Transp Eng 137(7)
8. Al-Deek MH, Johnson G, Mohamed A, EI-Maghraby A (2000) Truck trip generation models for seaports with container and trailer operation. Transp Res Rec 1719:1–9. https://doi.org/10.3141/1719-01
9. Holguin-Veras J, Thorson E (2000) An investigation of the relationships between the trip length distributions in commodity-based and trip-based freight demand modeling. Transp Res Rec 1707:37–48

Multimodal of Lateral Transport System: A Case Study of Successful Cities Worldwide

Nandan Dawda, Gaurang Joshi, Shriniwas Arkatkar and N. Vasudevan

Abstract These days, inefficient utilization of transportation network has turned out to be one of the significant issues for fast growing urban regions. Numerous initiatives are taken by the governments keeping in mind the end goal to evolve sustainable transportation by increasing the mode share of public transportation system; particularly the bus services. The major deficiency with the present public transport system is lack of proper first and last mile connectivity, delays of buses due to traffic density, improper route management of buses, etc. Past studies have demonstrated that coordinated planning and usage of multimodal transport system may prompt increment in mode share of public transport and may enhance effectiveness of transportation network. In this context, the present paper is an endeavor to examine the current multimodal transportation framework running effectively in the global cities, London, Hong Kong, and Singapore, with exemplary multimodal transport systems The five noteworthy mainstays of the multimodal transport that is physical joining, operational incorporation, informational integration, toll coordination, and institutional combination are reviewed briefly for each the selected urban areas. Focus of the present paper is simply to see how the idea of multimodal transportation framework can help the local authority to run the transportation system in a productive way.

Keywords Multimodal transport · Informational integration · Operational incorporation · Sustainable infrastructure

N. Dawda (✉) · G. Joshi · S. Arkatkar · N. Vasudevan
Civil Engineering Department, Sardar Vallabhbhai National Institute of Technology, Surat, Surat 395007, India
e-mail: nandandawda@gmail.com

G. Joshi
e-mail: gjsvnit92@gmail.com

S. Arkatkar
e-mail: sarkatkar@gmail.com

N. Vasudevan
e-mail: vasudevan.narayan0510@gmail.com

D. Deb et al. (eds.), *Innovative Research in Transportation Infrastructure*, Lecture Notes in Intelligent Transportation and Infrastructure,
https://doi.org/10.1007/978-981-13-2032-3_10

1 Introduction

In the contemporary time, larger part of the Indian urban communities is portrayed as urban territories having higher densities; organically developed (dishonorable land utilize control); the absence of sufficient physical and social infrastructure and several other reasons attributable to political system, government and the community. Particularly, the transport network suffers from absence of adequate road facilities, insufficient bus transport, lack of individual discipline, and so on. Urban transport frameworks in most of Indian cities are under overwhelming strain, and have adversely influenced the personal satisfaction of urban population [1]. Facilities of mass travel in the urban areas are proving to be inadequate and inefficient due to availability of quick, convenient and advantageous travel by private vehicle. This has brought about substantial move of daily travelers from buses to cars and as an outcome there is colossal increment in individual vehicle possession. The resultant impacts are increased traffic congestion and transport-born pollution, heavy fuel consumption and lesser option for mode choice to the suburbanites. Nevertheless, in any case of cites with more than one million population produce more travel requests, which is not completely met by private modes of transportation, as an outcome, the city emerges out to have mass transport system, in order to provide better, effective and quality travel to all captive riders. All things considered, the proficiency and viability of mass travels depend on openness of different modes in the city, incoming flow of pedestrians at station, the frequency of service, outline, and accessibility, etc. Subsequently, in order to sustainably meet the ceaseless needs of commuters, planners attempt to join at least two or more transportation modes, to accomplish simple, seamless, and continuous travel in the urban areas. The resultant procedure, which has developed out of this, is Integrated Multimodal Transport System (IMMTS) that includes combined utilization of various modes in an attempt to win the battle against street congestion, longer travel time, and air contamination due to vehicles. Therefore, for the present time, joining of various modes is considered as the most economical arrangement in order to achieve goals of sustainable transportation. Number of nations (USA, UK, Canada) throughout the world have acknowledged the reality and began to implement the idea of Multimodal transportation system (MMTS). In the context of the cargo transport, “a multimodal transport system is a corridor which connects producing and supply points of the particular product or items which consists of equipment’s of railway stations, road stations and marine terminals intelligence” [2]. But with reference to urban transport system, MMTS is “A transport system having numbers of modes for providing a seamless and door to door service to the passengers as well as goods” [3]. Basically, Integrated Multimodal Transport System (IMMTS) comprises of one trip that involves two or more than two different modes of transportation like bus, metro, car, tram, etc., either government or privately operated; where in-between passengers transfer from one mode to the other mode. Some modes of transportation have always been depended on other modes [4]. In straightforward words, multimodal transportation is a framework which comprises of inclusion of more than one mode of travel with a specific end goal to give a consistent travel to the products and passengers subjected to the requirement of ideal cost and time. If we look to the worldwide level, we have numerous examples of overcoming adversity where multimodal transportation came about to be the most effective framework for satisfying the request of existing transport users. The majority of the administration everywhere throughout the world are more concentrating on improvement of multimodal transport framework. In India, National Urban Transport Policy (NUTP), National Mission of Sustainable Habitat (NMSH) and twelfth five year plan recommend the need and significance of multimodal transport infrastructure for Indian urban areas. Consequently, in time, it is especially critical to comprehend the lessons that we gain from the urban communities which have executed multimodal transport framework and get the conclusion from it. The present paper makes an attempt to examine about the five noteworthy understanding required for the multimodal transport framework. The global cities of London, Hong Kong, and Singapore are reviewed in detail with reference to all the five noteworthy pillars of multimodal integration.

2 Understanding Multimodal Transport System

The importance of multimodal transport system has been recognized worldwide and numerous of research efforts are made regarding it. In context to Indian scenario, the Ministry of Urban Development came out with the National Urban Transport Policy [5] which clearly states that all modes ought to be coordinated to give consistent trip for suburbanite. Such a multimodal framework focuses on minimum cost and most ideal monetary viability and consequently moderateness and maintainability. According to NUTP, “Multimodal integration has different modes working together in order to ensure continuous travel of commuters”. It is not necessarily restricted to combination of buses with Metro or light rail transit system. It includes coordinating private methods of transport, i.e., cycle, autos, and two-wheelers and para travel modes, i.e., private buses, cars, small-scale transport and cycle rickshaw to the mass fast travel organize [5]. In order to promote fare integration, it is recommended that the urban communities/states would likewise be urged to embrace National Common Mobility Card named “More” which assures to be the single medium for payments irrespective of modes as well as operator. Further, as the user’s dislikes changing modes and it is difficult and has a period punishment. Hence, in this manner, the fundamental test in multimodal combination is to design the interchange in such a manner that it reduces the time punishment. Be that as it may, the most essential component to limit time punishment and most hard to accomplish is the physical incorporation of modes. This needs to have an incorporated arrangement at idea level in terms of operational point of view of all the modes that will bring the multimodal citywide transport in an organized manner. Further, it also acquires the significance of institutional setup for effective integration among all the modes of travel in the cities.

In India as well as different endeavors across the globe have been made for accomplishing the multimodal transport network. It should have incorporated institutional, systems, stations, patron data, and toll installment frameworks [6]. Litman [6] talked about every mode profiles (walking, bicycle, fixed route transit, paratransit, auto driver, motorcycle, ride sharing, car sharing) in view of its accessibility, speed, density, loads, costs, potential clients, confinement, and usages. In order to promote the detailed analysis of the modes, activities and distinctive kinds of transit modes were studied in detail and gave the non-mechanized and transit level of service rating factors. At long last, every one of the components influencing the availability of multimodular transport framework were talked about quickly. Along with the study on operational aspects of travel modes of multimodal system, the analysis of user's attitude towards the complex system of all the modes is necessary. Hence, Clauss [7] Performed 60 interviews utilizing repertory network system for comprehension and drawing out the view of the users for going in various modes. The components like protection, adaptability, self-sufficiency, expenses, and time proficiency assumed significant part in choosing the method of movement. The 28 determinants were spoken to in six perceptual measurements, i.e., influence, comfort, push, singularity, cost, and adaptability. By surveying the significance of specific determinants of movement mode decision, it was recognized that protection, independence, stresslessness, and adaptable course decision as full of feeling, and manageability as instrumental key determinants of movement mode decision. At last, different conventional and creative and in addition monomodal and multimodal travel factors were portrayed by contrasting them and each other and with perfect modes [7].

In a nutshell, the significance of the multimodal transport system has been recognized by the Indian government as well as throughout the globe and as a consequence of it many policies, recommendation, detail analysis of factors influencing the multimodal transport network, development of level of service for IMMTS, and so forth have been attempted by various researchers. Even though it seems that greatest number of developing nations are battling with the transport issues and it appears that still the field of the IMMTS is by all accounts unexplored and very little work has been done in the developing nations.

3 Success Stories Worldwide

In the event that we look everywhere throughout the world then London, Hong Kong, and Singapore are thought to be one of the urban areas of the world which have executed the idea of multimodal incorporation and attempted to work together with the transport framework at institutional, operational, informational, fare and physical level. The details of every city have been clarified in the following sections.

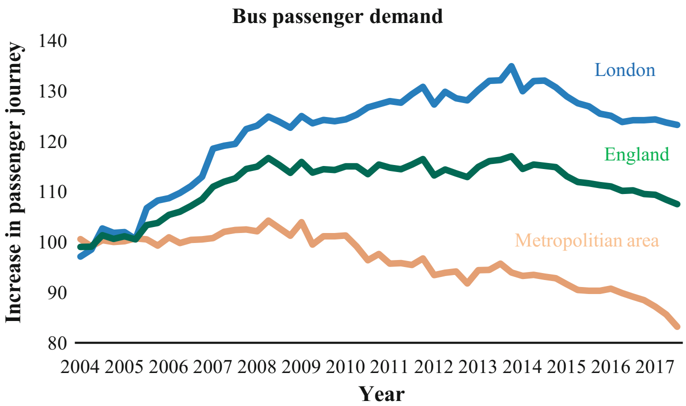


Fig. 1 Bus passenger demand for Great Britain

3.1 London

City of London is known for the multimodal integrated system since 2000.Controlled by a board whose individuals are selected by the Mayor of London as per the London Authority Act, Transport for London (TfL) goes about as authority and an immediate administrator, liable for all mode of public transport and in charge of both the vital street system and paratransit mode of transport. The Transport for London is the main expert in charge of running London's underground rail system, London Rail, London Busses, London Dial a ride, street benefit, roads congestion charge, open carriage office, Cycling Center of Excellence, Walking, London Road Safety Unit, Metropolitan Police Service, Transport Operational Summon Unit (TOCU), the British Transport police and Freight Unit. Hence, TfL is considered to be only one integrated institute of transport of London. The city covers a territory of 1572 km^2 including 8.3 million of tenant, while the metropolitan zone covers 8382 km^2 with in excess of 15 Million occupants as per Mayor of London [8]. The public transport system in London is known for its perfect blend of historical and modern transport infrastructure network (the heavy rail network, the London underground, Docklands Light Rail and Croydon Light Rail) with bus and ferry services. The statistics reveal that after implementation of the multimodal system, there has been an increase in demand of public transport system. Figure 1 shows the increase in passenger journeys on local bus service by metropolitan areas of Great Britain by considering demand in 2004–05 as index 100.

Not only in reference to the overground transport, but the increase in demand of other transit family has been witnessed. Figure 2 shows the progressive growth in demand for light rail transit system in terms of passenger kilometers for the city of London in last 17 years. One of the potential reason for such a hike in demand is the introduction of the multimodal system.

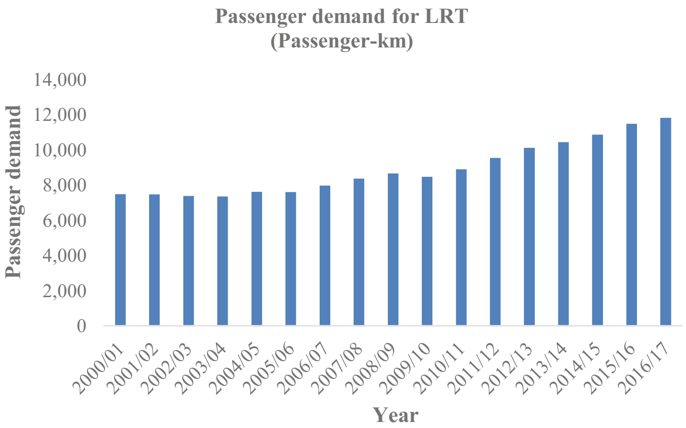


Fig. 2 Passenger—km traveled by LRT for London city

In spite of such a complex transport system, the noteworthy thing is that at all the major stations, transport professions have been created to be inside strolling separation of the railroad and underground stations, frequently kept an eye on by transport station staff and renewed with constant data frameworks. Such an integrated infrastructure formation resulted in increase in current ridership of bus usage of 31billion journeys/year which has reduced the traffic in central London by 20%. Also, a modal shift of 5% from cars to nonmotorized transport has been witnessed in London.

3.2 Hong Kong

When it comes to accessibility needs, the transportation system of the Hongkong city has set an example for the world by achieving 905 of the daily trips performed by public transport. Each day around 12.9 million users travel in buses, trams, railways, minibuses, ferry services, and taxis. The city has showcased a very low car ownership of 50 cars per thousand populations. In spite of having numbers of modes of travel, all of them are well coordinated, schedule and integrated with each other. It is discovered that railways are run by the MTR Corporation Limited (MTRCL), which carried about 4.62 million passenger trips per day in March 2015. The Airport Express Line (AEL), carried about 41,400 passenger trips per day in March 2015 and Light Rail about 479,000 passenger trips every day at the same time. While, City Bus, in 2014 carried about 648,000 passengers a day [9].

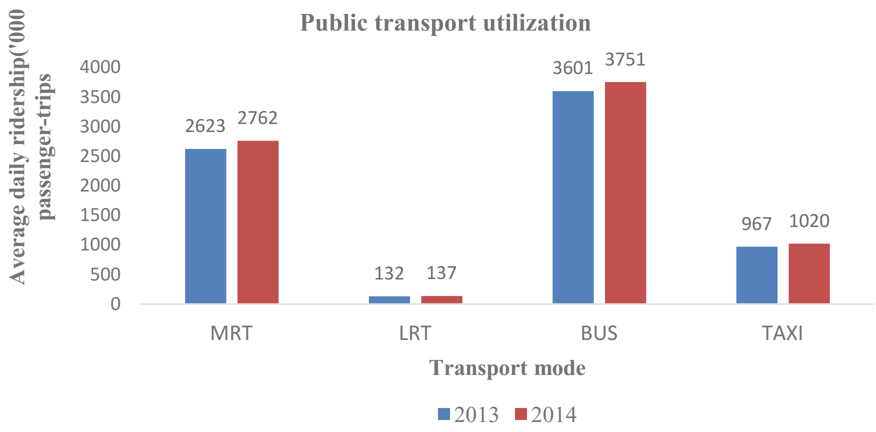


Fig. 3 Public transport utilization of Singapore city

3.3 Singapore

Apart from the above cities, Singapore is also among one of the rare cities of world which has set an international benchmark in the field of the integrated transport system. Area Licensing Scheme (ALS) and subsequent Electronic Road Pricing (ERP) system; Vehicle Quota System—quota for new vehicles kept fixed at 3% of the previous year's vehicle population are the few eye-catching policies implemented by Singapore city which has a very small population of 5.4 million habitants [10]. The government of the city is so conscious regarding the field of transport and as an outcome, it is targeted to reach a modal split target of 75% of all the trips. Figure 3 shows the average daily ridership of public transport modes for the year of 2013 and 2014. It could be clearly witnessed that the public utilization rate of all the modes has been increased notably. The major reason for the same is the working of efficient multimodal transport system for the cities.

4 Major Findings in Context to Multimodal Transport System

The cities have been successful only because of integrating all the modes of transport of the cities. The features of the multimodal integrated transport system of these cities are explained as follows [11].

Physical integration in London city constitutes transport hubs and center points with embedded exchange facilities like island, interchanges, covert walkways and retail focuses whereas; in Hong Kong, various government ventures are established

Fig. 4 Multimodal hub at king cross station in London

to encourage the integration of high and light rail routes. In case of Singapore, new and secured walkways are offered in stations for the physical integration of modes.

The typical picture of the multimodal hub in London has been shown in Fig. 4. The network integration in London city is very strong for air, rail and road transport. The "turn-up-and-go" service is meant for bus transit; "airport express" is for air transit. Integrated rail stations in London deals with different types of rail transit systems. In Hong Kong, well-designed nodes/hubs are connected to several networks for easy transfer of different modes. Buses and mini-buses are well scheduled to connect trains and MRT. Whereas in the case of Singapore, travelers are advised to use Bus or LRT system which works as secondary support to MRT in order to reduce congestion on arterial roads. This policy is more suitable in Singapore city because 50% of its population lives within 500 m of an MRT station. The typical integrated public transportation plan of the London city is as shown in Fig. 5.

The informational parameter of Multimodal integration in London has been recognized worldwide by developing public transport signage for all the modes of public transport. "Hong Kong e-Transport" Mobile Application has established in the city of Hong Kong while; an "I-Transport platform"—IT platform that integrates traffic information from road-based ITS measures and transit-based measures are suggested in Singapore. Figure 6 shows the public transport journey planner used by the commuters of London in order to optimize their travel time.

The fare integration is a unique feature of multimodal transport system. smart card based fare integration is in full function in all the three mentioned cities. London uses Oyster card since 2007 whereas Hong Kong uses Octopus card since 1997, while in Singapore use of EZ card is been made. Transport for London (TfL) is the institute which looks behind all modes of transfer. Similarly, in Hong Kong, a single authority helps to coordinate all the modes with a minimum of political obstacles. While in Singapore, cooperation form SMRT and SBS corporate manages the multimodal system.

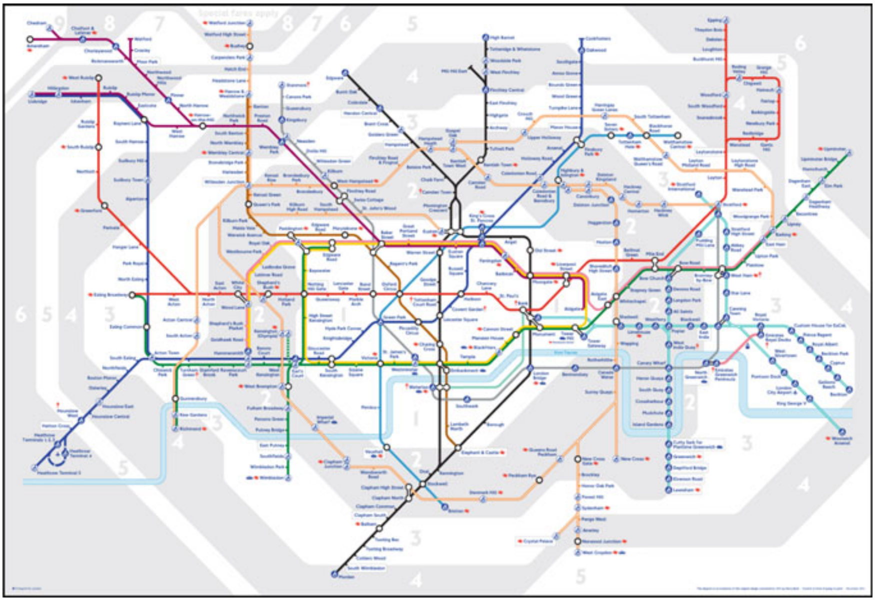


Fig. 5 Integrated network plan of public transport in London

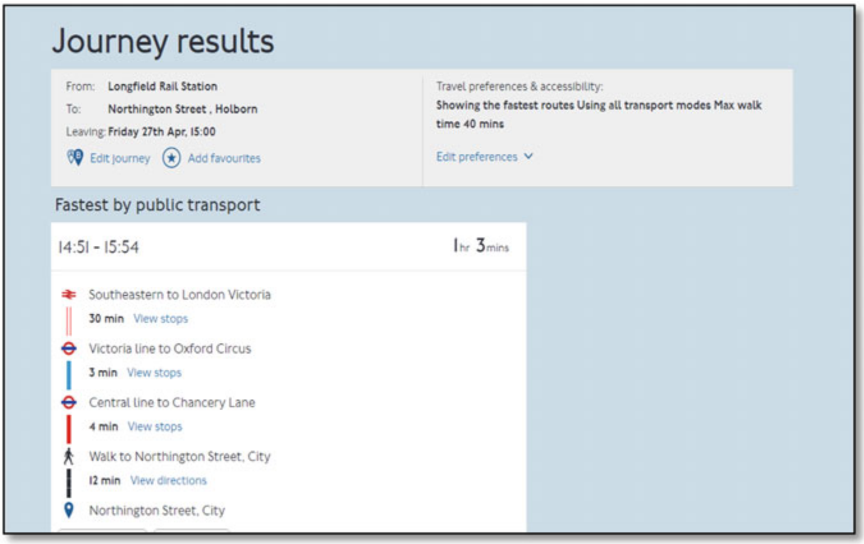


Fig. 6 Comprehensive journey planner application for London

5 Conclusions and Way Forward

The best practice cases are illustrated so as to highlight the high level of integration over all the five pillars of the integration for the three major cities worldwide. In more functional terms, a major lesson that could be derived are as follows:

1. The inclusive interchange service needs to be designed for collecting tickets so that the money spent by the users of changing modes is restricted or dispensed.
2. Consistent and appropriate signage should be planned for the benefit of the commuter which provides real-time travel data.
3. Disincentive to the private vehicle users should be done in terms of congestion charge, taxation, limiting parking facilities or fixing of number of vehicles per household.
4. Providing a sheltered, safe and well-organized services (from the user's point of view) could be ensured by integrating all modes of transport at each parameter.
5. A high-recurrence/non-timetabled benefit or a coordinated timetable of the modes at exchange hubs are intended to ensure an efficient usage of interchange.

References

1. Varma A, Sreenivasulu S, Dash N (2010) Achieving sustainable transportation system for Indian cities. Curr Sci 100(9):1328–1339
2. Yin Q, Yan H, Zhao H (2012) Evaluation on index system of multimodal transport corridor. In: ICLEM 2012: logistics for sustained economic development—technology and management for efficiency, pp 847–853
3. Kemenristek (2006) Buku Putih: Penelitian, Pengembangan dan Penerapan Ilmu Pengetahuan dan Teknologi Bidang Teknologi dan Manajemen Transportasi, Jakarta
4. Rawal T, Devdasa V, Kumar N (2014) Integrated multi-modal transportation in India. In: Changing spectrum of human settlements and planning education, pp 197–203. ISBN 978-93-5053-361-1
5. National Urban Transport Policy (2014) Ministry of Urban Development, Government of India
6. Litman T (2014) A report on Introduction to multimodal transportation planning. Victoria Transport Policy Institute (2014)
7. Clauss T (2016) Why do urban travelers select multimodal travel options: a repertory grid analysis. Transp Res Part A 93–116
8. Mayor of London (2015) Annual report and statement of accounts Transport for London
9. Key statistics. www.td.gov.hk
10. Report on Singapore land transport statistics in brief, Land transport authority
11. Tool kit on City wide Multimodal Integrated transport plan. Institute of Urban transport of India

An Infrastructure Review of Public Bicycle Sharing System (PBSS): Global and Indian Scenario

Samir J. Patel and Chetan R. Patel

Abstract The present study discusses the historical overview of the Public bicycle sharing program from way back to its introduction in Amsterdam in the year 1965 to the present fourth-generation systems in developed and developing countries. In this paper, it is highlighted the various PBS system operated and popularly known for bringing radical changes in transportation systems. In India, due to smart city mission, most of the city has the PBS project. The analysis of the performance evaluation of existing PBS system and best practices definitely brings research insight for PBSS projects in India. This compendium of the research will help the planners and researchers to open the new avenue in the recent era of climate change also. At the concluding remark, this study analysis brings the interesting facts about the PBS system which one should know being a transport planner.

Keywords Public bicycle sharing · Sustainable transport · Non-motorized transport · Bicycling

1 Introduction

The Public Bicycle Sharing System (PBSS) has been renowned as an alternate best evergreen transportation mode in the family of sustainable transportation systems, since its introduction in Amsterdam in the year 1965. Initially, the system is started as the first generation PBSS is now expanded to a latest fourth-generation system which has a fully automated dock less system, real-time big data application, and many more features [15]. Within 50 years of its development, PBSS got a huge success and took their own space in an urban environment in worlds' cities, as an only option for a sustainable mode of transport. Very few articles are presently available to get handy information regarding PBSS worldwide and still a requirement

S. J. Patel (✉) · C. R. Patel
Department of Civil Engineering, Sardar Vallabhbhai National Institute of Technology, Surat, Surat 395007, India
e-mail: patelsamir141@ymail.com

D. Deb et al. (eds.), *Innovative Research in Transportation Infrastructure*, Lecture Notes in Intelligent Transportation and Infrastructure,
https://doi.org/10.1007/978-981-13-2032-3_11

Table 1 Public bicycle sharing system worldwide

Continent	Number of PBSS	Docking station	Fleet size
Africa	1	3	30
America	74	5787	59,264
Asia	84	18,618	486,592
Asia Pacific	6	203	7776
Europe	200	11,001	124,329
Middle East	4	75	2000
North America	1	11	50
Total	370*	35,698*	680,041*

*Various source claims different fleet size (*Source* Authors calculation from bicycle world map)

for the comprehensive study on this topic is recognized which covers all available literature in a single article. In line with this point, this paper gives a brief about Public Bicycle Sharing System (PBSS) worldwide including Indian initiative as well as bicycle rental scheme and examined different parameter of PBSS adoption as a prime mode for transport in urban zones. Also, it discusses the various initiatives taken in past and present by the government in encouraging PBSS as a transport mode in Indian cities.

A PBSS widely also know as public bicycle system, bicycle sharing system or bike share scheme, in which bicycles are provided on sharing basis to the users for a limited time period at an affordable rent. Bike share schemes allow people to borrow a bike from one station and return it at other in the city. Public Bicycle Sharing (PBS) is a high-quality bicycle based public transport system that includes Bicycles; Key locations; closely spaced network of stations; tracking of bicycles; allows the short-term shared use of bicycles. A user checks out the bicycle from one location ride bicycle to the destination and drops the bicycle to another location. The operators coordinate the redistribution of bicycles and ensure availability of cycles at locations with the highest demand at any given time. Globally around 600 cities have operational bicycle share systems, and still more programs are starting every year [1]. The largest systems are in China (Hangzhou, Shanghai, and others), Paris, London, and Washington D.C. to name a few. Table 1 shows numbers of a PBS program operated, numbers of the docking station and fleet size. However, some literature claims, fleet size, bicycle sharing programmers, etc., are more in numbers but it is not considered due to unavailability of documented information.

Figure 1 shows that after 2008, PBSS growth was exponentially increased in most of the parts of the world which were previously restricted only to few European cities [11]. As PBSS having numbers of direct and indirect benefits, adoption of this system as transportation mode is frequently practiced in the various urban area. Table 2 gives an idea about PBSS direct and indirect benefits reported in the book “Bicycle Sharing 101: Getting the Wheels Turning” by Bradley Schroeder [14].

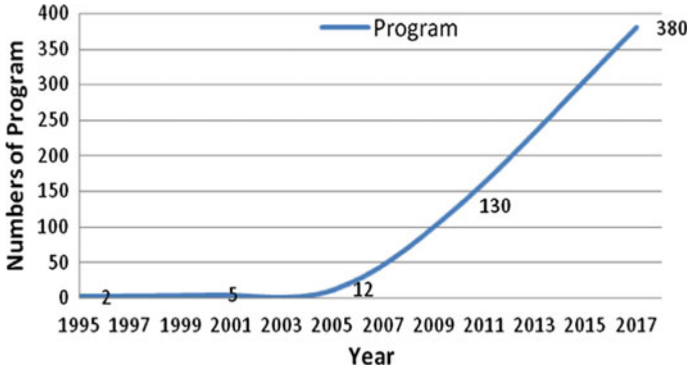


Fig. 1 Development of PBS Program in worlds' cities

Table 2 Direct and indirect benefits of bicycle sharing

Direct benefits	Maximizes resources: more trips per bicycle per day
	Convenience for user: access when needed without the hassle of ownership, Maintenance or storage of a bicycle
	Flexible, tailored, point-to-point Personal Public Transport option. Efficient and organized use of public space by controlling parking
	Solves the "last mile" problem: acts as a feeder system to other PT/IPT
	The solution for short trips: eases the strain on existing public transport systems, Decreasing congestion and improving service
	Reduces the necessity for private bicycle parking facilities: space is used for the general well-being of a community rather than private parking
	Eases entry into cycling: attracts new or latent users to bicycle use, with consequent benefits associated with increased cycling
Indirect benefits	Provides citizens with a healthy, active transport option for short trips
	Decrease in tailpipe emissions and noise pollution
	Solves the "chicken-and-egg" scenario by providing users to justify the investment into supporting bicycle infrastructure
	Improves cycling safety: more cyclists mean more awareness by motorists
	Increases property values through TOD and fosters urban revitalization
	Improves the city's image in terms of "sustainability" and "livability"

Source Book chapter published by Bradley Schroeder

Apart from this, there are many hidden benefits to the society. Upscaling to higher levels like automated system and E-bikes is the essential move for integration of PBSS with Public transportation in urban areas. National policies, resource provision for infrastructure, and for altering the perceptions of citizens with respect to status and financial benefits of PBS will add more attractiveness.

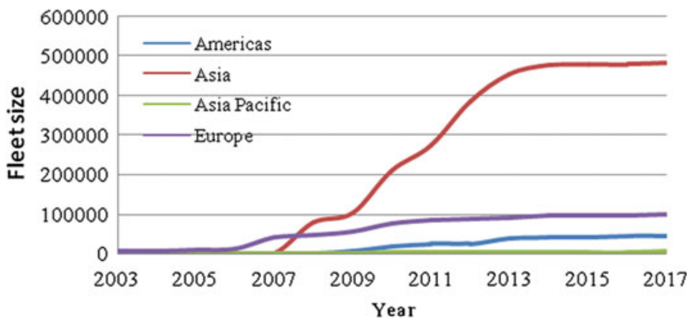


Fig. 2 Growth of PBSS fleet size in worlds' cities as on Dec-2017

2 PBS System Performance in Worlds' Cities

A very first introduction of public bicycle share system was initiated by Councilman Luud Schimmelpennink in the year 1965 in Amsterdam. Initially, a free system with fleet size around 20,000 white bicycles was introduced to improve Non-motorized traffic in the city [8]. Afterward, in the year 1993, the cities of La Rochelle (France) and Cambridge (England) also implement a free bicycle sharing systems that had limited use and limited coverage range; a rental scheme was available in which users had to return bicycles to the stations where they hired. The system was generally used for who makes only round trips. The first Automatic system by means of technology for check-in/check-out, smart card system, allowing the point-to-point trips was introduced in two French cities, Rennes and Lyons in 1998 and 2001, respectively. Both systems give their successful presence in the urban environment, and the cycling culture began to increase in attractiveness. After 2006 adoption of bicycle share in urban environment increasing exponentially. As on Dec-2017, more than 600 cities operates public bicycle sharing system with bicycle fleet size more than 20,00,000. Figure 2 shows a historical growth pattern of PBSS worldwide with respect to fleet size.

The Institute for transportation and development policy (ITDP) U.S. provides two dimension analyses for measuring whether a bicycle sharing system is reliable, efficient, and cost-effective [7, 8]. An average numbers of daily trips per bicycle consider as a first dimension and average bicycle trips per thousand resident per day within the system coverage area were consider as a second dimension for measuring reliability of bicycle sharing. Table 3 shows the average trip and trips per bicycle in worlds' cities.

Barcelona operates average 10.8 trips per bicycle that present the uses for the shorter tips with a most available bicycle but having low uses per residents [6]. Paris, Montreal and Rio de Janeiro having average 6.7–6.8 trips per bicycle even trips per residents are less. On the other side, Mexico city is operating with highest trips per capita with less trip per bicycle that shows the dense network and people are using for long distance.

Table 3 Top 7 cities in bicycle sharing operation in the world

S. no.	City	Avg. trips per bicycle (km)	Trips per 1000 residents
1	Barcelona	10.8	67.9
2	Lyon	8.3	55.1
3	Mexico City	5.5	158.2
4	Montreal	6.8	113.8
5	New York city	8.3	42.7
6	Paris	6.7	38.4
7	Rio de Janeiro	6.9	44.2

Source ITDP [7]

3 Beginning of PBSS in Indian Cities

This section discusses the initiative taken by the various towns planning authority for adoption of PBSS system in various Indian cities. The role of India's public bicycle rental scheme plays a very important role in bringing the basic idea of the PBS implementation practice in many Indian cities. In other words, the public rental scheme becomes a pioneer for introducing PBS system in many urban areas in India.

Some of the initiatives are recently adopted in many of Indian cities such as PBS in Bhopal, and Mysore and many more (see Table 4), while some of them were implemented in past as a rental scheme but not got much success and after implementation they getting close. Before commenting on the performance of various systems and the success of the system, it is necessary to know about the background of statistical information, properties of systems, various parameters, etc., of the system.

3.1 Bicycle Rental Programs in India: Breakthrough for PBSS

One of the initiatives were taken by Delhi government under "Delhi Integrated Multimodal Transport Vision 2021" (DIMTV 2021), which includes a widespread network of Metro rail network and Bus Rapid Transit system (BRTS). To achieve a safe and successful multimodal system, a system should have last mile connectivity and for that, it is necessary to give an effective network of feeder services from the transit stations. A study was conducted by IIT Delhi and it was recommended that some of the bus stops of BRT Corridor require a cycling facility, and this would significantly help the BRT commuters for last mile connectivity, and also increasing the ridership of the BRT system.

With this goal mind joint venture Company of the Government of National Capital Territory of Delhi and the Corridor Manager for the Delhi BRT System form Delhi Integrated Multimodal Transport System (DIMTS), in October 2009. DIMTS launch

Table 4 PBS system in Indian cities

S. no.	City	State	System	Fleet size in no.	Docking station in no.	Capital cost INR	Opt cost INR
1	Mysore	Karnataka	Bicycle sharing	450	52	5.6 Cr.	0.83 Cr.
2	Bhopal	Madhya Pradesh	Bicycle sharing	500	50	5.2 Cr.	1.6 Cr.
3	Bangalore	Karnataka	Bicycle sharing	45	09	NA	NA
4	Vadodara[a]	Gujarat	Bicycle sharing	1000	62	26 Cr.	4.17 Cr.
5	Panjim[a]	Goa	Bicycle Rental	1040	66	16 Cr.	1.6 Cr.
6	Ahmedabad	Gujarat	Bicycle Rental	2000	9	NA	NA
7	Gandhinagar	Gujarat	Bicycle sharing	1430	104	14.3 Cr.	1.43 Cr.
8	Chennai	Tamil Nadu	Bicycle sharing	3000	200	NA	NA
9	Surat[a]	Gujarat	Bicycle sharing	1200	40	13 Cr.	NIL

[a]DPR ready

bicycle rental scheme along the BRT corridor which known as "GreenBIKE—Cycle Feeder and Rental Scheme". The bicycle rental facility was initially started at five BRT stations with the fleet size of 10–12 cycles. The guard was provided at each station from 08:00 a.m. to 08:00 p.m., who have a responsibility to complete the registration process. Through providing a valid Indian ID card, voter card, or driving license users can rent a bicycle from the station, I-card was returned when users returned or check-in bicycle at the station [4]. The bicycles rental was charged at INR 10 for 4 h, and after 4 h additional INR 5 charged per every extra hour. One year membership fee was charged at INR 100 only. Daily approximately approx 50 persons used the rental service and revenue generated per day by the system was nearly INR 200–250 [3]. To function this system, an contract was given to Planet Advertising Pvt. Ltd. to assemble, operate, and keep up the bicycle rental stations all through the BRT corridor for a time of 5 years. The administrator/operator compensated INR 20,000 every month for each station and creates income by offering the ad space accessible at bicycle station. However, the revenues from the user registration charge insufficient to cover the compensation of the station attendants, the scheme primarily relied on ad space gave at the stations as a source of income [4].

In February 2010, the German Technical Cooperation (GTZ) in helping with DIMTS led a user's perception study with taking a substantial sample size of 116 for the registered users along the pilot BRT Corridor in Delhi [2, 3, 5].

The findings from this study give positive as well as negative consequences, as compared with positive benefits, negative practices are much. For example, from the study, it is noted that average rental time by users identified as 174 min, which was a very high compared to other rental schemes in the world. The other point is the bicycle occupancy rate of 1.1, which was quite inefficient. The reason behind this inefficient performance by the system is lack of knowledge for planning about the system, provision of inadequate fleet size for the system and due to the restrictions like "cycles should be brought to its original rental station" imposed by service providers.

Similar to the "GreenBike" at BRT corridor, approximately 8 metro stations had also given a facility to the users to rent a bicycle. The same company having the contract to operate a bicycle rental facility around a metro system. To support the bicycle rental system, the smart card holders of Delhi Metro can park their bicycles free of cost, while others would have to pay a nominal rent as parking fees. Due to unreasonable users response, these rental facilities were not operated as the way it required. As of now, the rental scheme is operated at 8 metro stations by Greenolution Company and system is closed at BRTS corridor. As of now, bicycle rental schemes in India are not getting much success. Apart from the first initiative of rental scheme by Delhi corporation another cities like Mumbai and Bangalore also initiated to operate the system with 2 numbers of station and 30 numbers of fleet size and 9 station and 45 numbers of fleet size respectively. In Ahmedabad private operator operate Rental scheme known as "My Bike" at 9 locations along with BRTS corridor with 2000 numbers of fleet size. Gandhinagar also operates the rental scheme, the system claims 104 stations operate with a fleet size of 1430 numbers of bicycles. Panji, Chennai had also completed planning stage for bicycle rental system and in near future that will be implemented.

3.2 Bicycle Sharing Schemes in India

"TrinTrin", the PBS of Mysuru is first PBSS in India which is operated by Green Wheel Ride, a company who engaged in manufacturing of eco-friendly battery-operated bicycles in a Mysuru city. The city initiates this project with aim of promoting the concept and culture of cycling. At present, the system is in operation with 52 stations with a fleet size of 450 bicycles. Public Bicycle Sharing project launched on 4 June 2017 and successfully achieve total ridership around 850 per day and up to now, 7,286 users are registered in the system. The total cost of the project amounts to INR 20.5 Cr, and the initial investment comes nearly to INR 8 Cr, with the remaining funds being earmarked for operation and maintenance for the next six years. A first-time user has to register at any of the registration centers or through the PBS App or through the website by one-time payment of INR 350 (including a refundable security deposit of INR 250) and collect a smart card from the registration centers preloaded with a usable value of INR 50. A user can then go any docking station, tap the smart card at the docking station port, and take the cycle. As part of promotional offer, up to 1 h, it will be free while up to two hours the charges will be INR 5, up to 3 h, it will be INR 10, up to 12 h 150 and greater than 12 h, it will be INR 250. The cycles will be available from 6 am to 10 pm.

In 25th June 2017, Bhopal introduced India's first fully automated 4th generation PBS system with 11 km (6.8 miles) of exclusive bicycle lanes, which will help in increasing rider safety and to save lives. The system having 500 GPS-enabled bicycles imported from Germany and a network of 60 docking stations in the city. Within five months after the inauguration of the system, operator claims more than 25,000 users registered for the system out of that more than half of them are identified as female users which can be inspiring other cities to promote and launch similar kind of projects in their urban space. By getting an unexpected response of citizens Bhopal city government expand bicycle lane network more than 50 km in next few years. System capital cost is INR 2.95 Cr. while operating cost is calculated INR 6.7 lac per month. A user charge of the system is also attractive with a yearly membership fee of INR 999 which includes INR 500 as refundable amount. The registered users will get benefit of free ride for first 30 min and for additional ride a charge of INR 10 per every 30 min will required to pay.

Mysore and Bhopal PBSS system is a very first initiative taken by the government and implemented successfully, after getting reasonable success many Indian cities are following the same line and plan PBSS. As of today, Vadodara, Surat, Ranchi, Pune, Bhuvneshwar, Amaravati, etc. cities either completed planning stage and some of them may be near to the implementation.

Table 4 shows some Indian cities which either implement PBS system or near the implementation stage. Apart from this various rental and sharing schemes proposed by different cities the universities are also operating the system for their users within their campus.

As of today, around 9 Indian cities had implemented PBSS and rental system with more than 650 docking station and fleet size of more than 10,000 bicycles.

4 Factors Influencing for Bicycling as Transportation Mode

As PBSS is known as one of the different forms of cycling. So that some of the fundamental characteristics of PBSS are same as the characteristics of cycling. But the role of PBSS in the urban environment need to be considered as a separate mode then the other bicycling trips. Hence while making calculations related to the performance, and carbon foot prints estimation PBSS must be taken separate entity. It is noted that study on cycling mostly conducted based on user's perception and with help of this, influential factors were identified [16] but it is observed that very few studies, in fact, no study is conducted with reference to PBSS. The section discussed some study conducted to identify user's perception and factors influencing for bicycling and it could help in the future research for PBSS.

User perception strongly influences transportation mode choice [10, 13]. However, due to Rapid urbanization in developing countries such as India is causing a significant fluctuation for demand–supply disproportion in numerous sectors, urban transportation being one of them [9]. According to Yang et al. [18], short-haul travel by non-motor transport is frequently being replaced by motorist trips in smaller cities, the factors behind this pattern can be insufficient public transport, lack of safe, and secure non-motor transport infrastructure and increasing earnings of commuters [17]. A study by Majumdar and Mitra [9] consider the effects of urban characteristics like socioeconomic analysis, demographic pattern of users, city populations, structure of city, etc. to analyze users' perception of bicycle mode choice for two cities, Kharagpur and Asansol in India. There are 18 factors are identified which influence the mode choice by bicycle, either as motivators or as deterrents. A study conducted by Majumdar and Mitra [9] has presented a comprehensive list of motivators and detergents influencing the selection of cycling mode based on literature review. A study conducted by Stinson and Bhat [16] identifies motivators, deterrents and link level factors which influence the decision to cycle. Studies reported at national and international level also identified factor influencing choice of bicycle as a mode of travel, for more details refer article of [9]. If the discouraging factors like negative perception towards cycling and poor tech savvy are resolved at the beginning of the project then half of the success will be achieved by the system [12]. The expert-based MCDM technique could be the best option to solve the challenging barriers to implementing PBS projects.

Most of literature reported a study using quantitative approach to identifying factors influence to cycling as a mode of transport but very limited studies are with qualitative approach. To overcome this gap, it is advisable to apply qualitative approach to study factors influencing cycling as mode of transport individually for a bicycle sharing and personnel cycling.

5 Way Forward for PBSS Development in India

Indians are using cycle since long back and still in many cities cycling is used for the daily delivery system from newspaper and vegetable grocer to milkman to those children riding bicycles to schools. The improved lifestyle of the people and wealthy status changes the mode shift to private mode in most of the cities. The PBSS is performing very well in various urban areas throughout the world and solves mainly the last mile to first-mile connectivity issues. The background for the implementation of PBSS strengthened up slowly from year's back 2008 and an introduction of the rental scheme in India gives support to PBSS significantly.

The role of various factors is directly affecting the implementation of PBSS in an urban area like social factors, political factors, travel characteristics, infrastructural factors, etc. Apart from that, the effective wider area coverage is most important in Indian context which catches the riders from door to door as well as serve the last mile connectivity. For the citywide network, funding is the other issue in many cities. In absence of sufficient funding, the partially developed network does not bring encouragement to the citizen. Further, the funding shall not be given randomly as many cities do not have the even basic infrastructure for bicycling. Hence ranking or city indexing is required which prioritize the PBS infrastructure and asses city readiness to adopt PBS system. The use of ICT, big data, and IoT can become more effective where riders behavior is unpredictable. The PBSS can be future mode of transport in Indian context by designing bicycle oriented policy rather than car-oriented approach.

References

1. DeMaio P (2009) Bike-sharing: history, impacts, models of provision, and future. J Publ Transp 12(4)
2. Dhingra C, Kodukula S (2010) Public bicycle schemes: applying the concept in developing cities. GTZ Sustainable Urban Project, New Delhi, 32 pp
3. DIMTS (2010) Green bike—cycle rental and feeder scheme. Integration of BRT with an emission-free non-motorized public transport feeder network
4. GTZ (2010) Bicycle sharing in Delhi—users evaluation report. Report prepared by Sebastian Schlebusch, Intern, German Technical Cooperation (GTZ)-ASEM, New Delhi, March 2010
5. I-CE and GTZ (2009) Cycling-inclusive policy development: a handbook, interface for cycling expertise (I-CE)
6. IDAE (2007) Guía metodológica para la implantación de sistemas de bicicletas públicas en España. Instituto para la Diversificación y el Ahorro de Energía, Madrid
7. Institute for Transportation & Development Policy (2013) The bike-share planning guide
8. ITDP Report (2013) Seven world-class cities are riding tall in the bike-share boom; "The last mile" can be solved without cars in more places than ever before, 5 December 2013
9. Majumdar BB, Mitra S (2013) Investigating the relative influence of various factors in bicycle mode choice. Procedia Soc Behav Sci 104:1120–1129
10. Meddin R (2013) The bike-sharing world—last week of January 2013, on The Bike-Sharing Blog 26 Jan 2013
11. Midgley P (2011) Bicycle-sharing schemes: enhancing sustainable mobility in urban areas. UN Department of Economic and Social Affairs, New York
12. Petersen T (2010) Identification of key attributes for bike sharing systems report. In: OBIS WP3, 31 Oct 2010
13. Schipper MA (2004) Supplemental data for 2001 NHTS. In: Presented at the 83rd annual meeting of the Transportation Research Board, Washington DC
14. Schroeder B. Bicycle sharing 101: getting the wheels turning. https://bicyclesharing101.com/contact/
15. Shaheen S, Guzman S, Zhang H (2010) Bikesharing in Europe, the Americas, an Asia: past, present, and future. In: Transportation Research Board annual meeting, Washington D.C.
16. Stinson MA, Bhat CR (2003) Commuter bicyclist route choice analysis: using a stated preference survey. Transp Res Rec J Transp Res Board 1828:107–115
17. Tiwari G, Jain H (2008) 'Bicycles in urban India' in position papers on bicycling in Asia, interface for cycling expertise, pp 3–20
18. Yang L et al (2011) The health risks and benefits of cycling in urban environments compared with car use: health impact assessment study. BMJ 343:d4521

Use of Fibre Reinforcement in Soil for Sustainable Solution of Infrastructure

Maharshi Shukla, Jiten Shah and Trudeep Dave

Abstract Roads are an inevitable component of the economic development of the city and fetch important social benefits. The present study represents the sustainable solution for transportation infrastructure. It shows that effective construction and maintenance of road infrastructure is essential to preserve and enhance those benefits. However, poor construction caused irreversible deterioration of the road network. To overcome the issue, the present paper focused on the sustainable solution for distress in the flexible pavement which has a major share in total roadway system. The structural and functional distresses are the key failure categories in the pavement. Insufficient compaction, subgrade settlement, and moisture infiltration are the main reasons to cause the distresses. To enhance the performance of soil, stabilizer is only the solution for a specific category of soil subgrade. Synthetic fibre, act as reinforcement is one of the finest material for soil stabilization and in turn improve strength properties. This paper also includes the one past incident of pavement failure with its solution. The soil-fibre matrix represents actual orientation of fibre in soil with stressed and unstressed configuration. Tensile resistance is generated due to shearing of soil along shear plane after adding the fibre in the soil which results mobilized tensile strength per unit area. This paper reflects the study of pavement distresses, various fibre reinforcement, soil-fibre matrix hypotheses and its properties in transportation infrastructure.

Keywords Flexible pavement · Fibre-reinforced soil · Soil-fibre matrix · Tensile strength · Shear strength

M. Shukla (✉) · J. Shah · T. Dave
Department of Civil Engineering, Institute of Infrastructure Technology Research and Management, Ahmedabad 380026, Gujarat, India
e-mail: maharshi.shukla.16mc@iitram.ac.in; maharshishukla1210@gmail.com

J. Shah
e-mail: jitenshah@iitram.ac.in

T. Dave
e-mail: trudeepdave@iitram.ac.in

D. Deb et al. (eds.), *Innovative Research in Transportation Infrastructure*, Lecture Notes in Intelligent Transportation and Infrastructure,
https://doi.org/10.1007/978-981-13-2032-3_12

1 Introduction

Infrastructure development comprises the sphere of activities creating the fundamental necessity includes sustainable transportation facilities, environmental solution, communication system, sewage and water supply facility and electric usage. Because of the intensive use of infrastructures, the transport sector plays a key role in economic development even in advanced economies and a common tool used for benchmarking. The present paper provides the deep insights in pavement failures and their sustainable solutions. Pavement failure is defined in terms of decreasing serviceability caused by the development of cracks and other distresses [25]. In order to increase the serviceability, it is necessary to understand the causes of failures and may be due to many reasons or combination of reasons [23]. Corrections in the pavement layers enhance the maintenance life and improve pavement performance as a whole. Literature illustrates that pavement deteriorates typically due to damage or unexpected stresses in subgrade soil beneath and hence, it should be strong enough and stable to bear the loads. Soil reinforcement is one of the techniques which help to improve basic engineering properties [19] of soil.

There are other materials also available to improve soil properties such as lime, fly ash, cement, copper slag, their combination, etc. The use of material has a specific limitation in order to improve engineering properties. However, very few materials that can improve the soil properties in all aspects wherein fibre reinforcement is one of them [12, 18, 21, 23]. Fibre inclusion can significantly increase soil tensile strength and soil tensile failure ductility [13, 23]. As the fibre content increases from 0 to 0.2%, the tensile strength increases by 65.7% [12, 20]. Many researchers have suggested that the fibre reinforcement will improve the soil strength significantly and also improve the performance of pavement layers [12, 18]. At present, fibre reinforcement is used extensively in problematic soil such as black cotton, sandy soil, silty sand etc. [1, 2, 7, 11], wherein, internal friction and the bond in between the material play an important role [3]. There are also other solutions to resolve the problems in pavement such as spreading and filling the aggregate, material, and premix to damaged part of the pavement [22, 24]. Looking at the complete behaviour of pavement, the ultimate solution is to remove and replace the overlays and subgrade soil [4]. However, the maintenance cost will surcharge further in road development. Reinforcement in an interlayer system has been improved overall performance to extend service life and thus to reduce maintenance costs of road pavements [4]. However, the mechanisms underlying the effectiveness and proper installation of these types of reinforcements system [8] are still not fully understood further their optimal locations in the pavement system are mainly based on experience.

This paper presents a study on the use of fibres as pavement subgrade soil reinforcement followed by pavement distresses/failures, matrix and properties of fibre-reinforced soil that allowed the soil to withstand. With this prospect, the paper provides a deep insight about causes of pavement failures and suitability of fibre for the given soil with explanation of one past incident of pavement failure.

Table 1 Functional distresses

Distresses	Figure	Causes	Solutions
Longitudinal cracking [22, 24]		Lacking internal friction in between the granular layers and subgrade, poor drainage, shoulder settlement	Stabilization of subgrade soil and prevent the entry of moisture into the subgrade
Corrugation (Ripples) [22, 24]		Excessive moisture in subgrade, lack of bond between layers, poor mix, lack of stability in the mix	Stabilization by additives, coarse sand with the binder, allow rolling and spread aggregate chips
Rutting (Pavement uplifting) [22, 24]		Insufficient compaction in subgrade and subgrade rutting	Apply compaction to subgrade with additives, filling the depressions with premix material

1.1 Pavement Failures

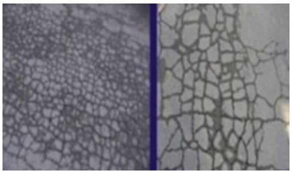
Pavement failure is broadly termed as decreasing serviceability caused by the development of surface distresses such as cracks, potholes and ruts [22, 24]. Before approaching the maintenance strategies, engineers must see the various aspects that cause pavement failures. It has been seen that only two major parameters such as pavement cracking and rutting are considered while maintenance. Pavement failure may be considered as structural, functional, or a combination of these [24].

1.1.1 Functional Failures

While pavement losses functionally that to fail in providing smooth and safe riding surface to the road users, it is considered as the functional failures. Table 1 shows the functional distresses' causes and solutions.

The main causes of these failures such as rutting are excessive moisture in subgrade and lack of proper compaction. The rutting is generated from subgrade and progressed upto surface course.

Table 2 Structural distresses

Distresses	Figure	Causes	Solutions
Shallow depression [22, 24]		Subgrade settlement, lacking compaction	Filling with the premix materials, stabilization
Alligator cracks [22, 24]		Lacking of compaction, Inadequate structural design, variation of moisture and loading	Unsound pavement will need rehabilitation, to be filled with a low viscosity binder or slurry seal
Potholes [22, 24]		The end result of alligator crack, Interconnected cracks create small chunks of pavement bowl shaped crack	Stabilization of subgrade, remove the affected material from the cut section and apply a coat of bituminous binder

1.1.2 Structural Failures

While pavement fails to carry the wheel loads and transfer it safely to the subgrade below, it is considered as the structural failure. Table 2 shows the structural distresses' causes and solutions.

The most important cause of structural failure is the settlement of subgrade. The settlement of subgrade is caused by inadequate moisture, uneven load, and improper mix design. The common failure in this type is alligator cracking.

The both of the failures occur with effective reasons such as insufficient compaction and stabilization. So, there are added the additives such as natural fibres and synthetic fibres as stabilizers to enhance the strength of subgrade soil.

1.2 Fibre Reinforcement

Fibre reinforcement in the soil can be observed in nature. In daily life, it may be noticed that the roots of vegetation act as a natural fibres, which holds and stabilizes the surrounded soil strata. The section presents the use of fibres and fibre-reinforced soils, focusing on types of fibres and their characteristics. Many researchers and specialized army crops have stabilized the soil with various fibre reinforcement such as synthetic fibre, coir, husk and jute [12, 18, 21]. Mostly, fibres are used in the sand and clay to allow heavy traffic load with more passes up to 90% and 60%,

Table 3 Different types of fibres and their suitability

Soil	Problems in soil	Types of fibres used	Properties of fibres
Sand [2, 7, 17]	Subgrade soil settlement, very less value of shear and tensile strength of soil, low ductility, low freeze-thaw resistance	Polypropylene fibre	Hydrophobic, 120–450 MPa tensile strength, 3–3.5 GPa Young modulus, noncorrosive, increases the value of soil CBR
Silty sand [3, 21]	Very low unconfined compressive strength, low ductility, high axial strain, low soil cohesion value	Glass fibre	High modulus of elasticity, 3000–4500 MPa tensile strength, 70–90 GPa Young modulus
River sand [21]	Low ductility and high axial strain	Polyvinyl alcohol fibre	Weather resistant, has good adhesive properties, 1078 MPa tensile strength
Clay [11, 12, 21]	Very low peak unconfined compressive strength in drained and undrained condition	Polyester fibre	Economical, 400–500 MPa tensile strength, resistant to chemical, alkalis, chlorides
Clay [4, 12]	Less CBR value, low toughness and secant modulus, less fracture energy	Polyethylene fibre	Very economical, 250–450 MPa tensile strength, 0.30–0.90 GPa Young modulus

respectively [18, 21]. Kanchi G. et al. [15] and Pal S. et al. [18] have found the stress-strain behaviour of soil and improved the CBR up to 250% by the inclusion of fibre. In contrast, the study observed increased in the value of maximum dry density up to certain range with increase in value of optimum moisture content due to the inclusion of fibre such as polypropylene fibre in subgrade soil [17]. There is effectively increased the pavement resistance to rutting than non-stabilized subgrade of pavement due to mixing the synthetic fibres in road construction [18].

Table 3 shows that various researchers have used different fibres to improve particular soil properties.

So, the addition of fibre into soil depends on problems of soil and properties of particular fibres. For further explanation, the case study is described in next clause.

2 Pavement Failure and Remedies: Case Study

As a case study, Izki road is shown in Fig. 1 which is situated in province of Ad-Dakhiliyah, Izki. It is around 125 km far away from the Muscat city, Oman. Izki

Fig. 1 Izki road, Muscat (Oman) and distress (Pothole) shown on the road [22]

road is around 35 km two-way road which had been constructed more than 10 years ago. This road has been suffered the distress as potholes which are generated the end result of alligator cracking. The road has been surveyed in different four sections and measured the dimensions of potholes and justified [22].

It has been reported the maximum depth (in mm) of potholes as 11.2, 60, 23.25, 40.5 at respective lengths (in mm) of 456, 810, 150, 470. The severity level is classified according to depth such as low (<25 mm), moderate (in between 25 and 50 mm), high (>50 mm) as per IS code. Usually, potholes are generated at having low thickness (<70 mm) pavement. There is only 55 mm thickness of the Izki road [22].

The key causes of the alligator cracks are insufficient pavement thickness [16]. This thickness depends on CBR value [14] of subgrade soil. So, it should be proposed that the subgrade stability (CBR value) can be enhanced by adding the polypropylene fibre (ppf) as stabilizer. This ppf also induces shear stress, ductility and lateral confinement in soil. It reduces vertical displacement in pavement. Ultimately, the alligator cracks and potholes will be reduced by inclusion of ppf in road structure. Simultaneously, it increases the tensile strength and freeze-thaw resistance. So, ppf is excellent solution for improving the subgrade soil as well as pavement [22].

3 Soil-Fibre Matrix

As per discussed above, the fibre should be added in the soil for sustainable improvement in pavement and subgrade soil. The particular section describes how the fibre is actually oriented in the soil with help of soil-fibre matrix which is the composition of soil and fibre reinforcement. This matrix is divided into two parts such as pure axial stress carrying area and pure shear stress carrying volume [5, 23].

Figure 2 shows the straight and perpendicular lines to the fibre axis in the illustration of a stressed–unstressed single-fibre configuration which is indicated the deformation pattern of the soil-fibre matrix [5, 23]. Figure 3 shows the soil-fibre composite.

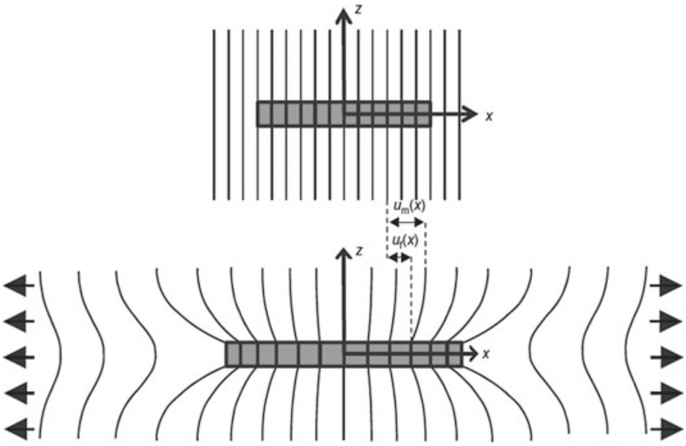
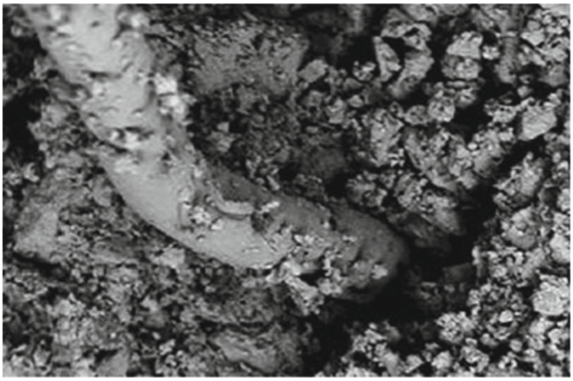


Fig. 2 Soil-fibre matrix stressed and unstressed configuration [5]

Fig. 3 Attached soil particles on fibre surface configuration [12]



3.1 Cylindrical Soil Volume Theory

The theory represents the soil and fibre as a cylindrical in shape. Cylindrical fibre which is loaded under tensile strain regime along the x-axis is embedded in a stressed confined cylindrical volume of soil. Equation (1) is used to define the volume and linear prediction of fibres over total composite volume of soil [5, 23].

$$\frac{\check{R}}{rf} = \frac{1}{2}(1 + \sqrt{\frac{lf}{\mu f}}) \tag{1}$$

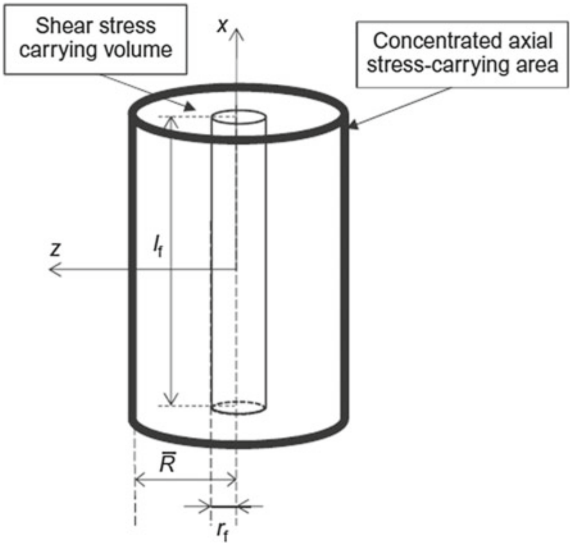


Fig. 4 Idealized soil-fibre composite model [5]

where,

r_f Radius of cylindrical fibre,
μ_f Volumetric fibre concentration,
l_f Length of cylindrical fibre,
R Radius of stressed confined cylindrical volume of soil,
$\hat{R}$ specific value

According to Eq. (1), there can be found the radius of influence for soil-fibre which represents as radius of stressed confined cylindrical volume of soil. That radius ensures how much soil mass is influenced by particular one fibre only. There can also be found out the volumetric fibre concentration with help of length and radius of fibre [5] (Fig. 4).

4 Properties Evaluation of Fibre Reinforced Soil

Tensile resistance [23] is induced due to shearing of soil along shear plane with help of adding the fibre in the soil for stabilization based on direct shear test concept [6]. The parameters lengths, interface friction, and confining pressure of fibre are sufficient to prevent shear and pull out failure [9] in soil-fibre matrix [5]. The skin friction along fibre is not increased by this effect of the composite. The shear strength Δs is increased with increasing fibre reinforcement [2, 3]. Equations (2) and (3) are used to find the shear strength with the help of mobilized tensile strength t_r [10, 12, 13, 20].

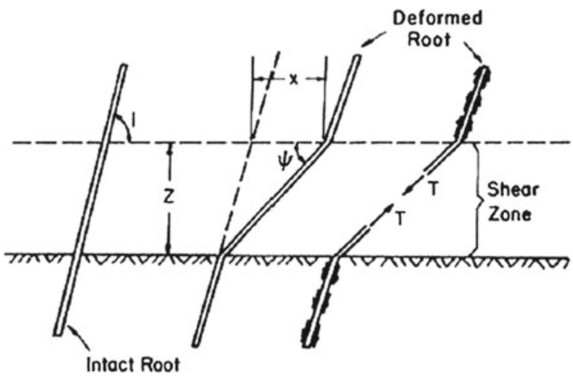


Fig. 5 Fibres are oriented at angle (i) to shear surface [10]

$$\Delta S_r = t_r(sin\,\theta + cos\,\theta\ tan\,\phi) \text{ For perpendicular oriented fibre} \quad (2)$$

$$\Delta S_r = t_r[sin(90 - \varphi) + cos(90 - \varphi)] \text{ At some arbitrary angle I,} \quad (3)$$

where

ΔS_R shear strength increase from fibre reinforcement,
t_R mobilized tensile strength of fibres per unit area of soil,
Ø angle of internal friction of sand,
θ angle of shear distortion,
i initial orientation angle of fibre with respect to shear surface,
x horizontal of shear displacement,
z thickness of shear zone,
k shear distortion ratio (k = x/z) and

$$\varphi = tan^{-1}[\frac{1}{k + \left(tan^{-1} i\right)^{-1}}]$$

Mobilized tensile strength [13, 23] per unit area is derived from tensile stress (**σ_R**) and area ratio. Equation (4) shows the induced tension in the composite of soil-fibre matrix [10, 20] (Fig. 5).

$$t_R = (\frac{A_R}{A})\sigma_R \quad (4)$$

A_R represents a cross-sectional area of all fibres crossing shear plane and A represents the total cross-sectional area of failure plane [10]. The linearly variation of tensile stress (σ_R) value is found by Eq. (5). This value is maximum at shear plane and reduced to zero at fibre ends. Total no. of randomly distributed fibre is found by Eq. (6) which is the contacting unit area of shear plane [2, 3, 20].

$$\sigma_R = (\frac{4E_R\tau_R^{1/2}}{D_R})\{z(sec\,\theta - 1)\}^{1/2} \quad (5)$$

where

E_R modulus or longitudinal stiffness of the fibre,
τ_R skin friction stress along the fibre,
D_R diameter of fibre,
z thickness of the shear zone,
v_f volumetric fibre content,
N_s no. of randomly distributed fibres per contacting the unit area of the shear plane

$$N_s = (2 \times v_f) / \left(\pi D_R^2\right) \quad (6)$$

After evaluation of reinforced soil properties, if angle of internal friction is found below the safe limit then it represents the lower value of the shear stress and strength. So, fibre should be added in the soil to enhance the strength properties. Those strength properties include the shear and tensile strength of fibre. The angle of internal friction increases due to fibre inclusion. Simultaneously, maximum dry density increases at certain moisture content and then it will be decreased. So, the optimum content of fibre is found to stabilize that particular soil with help of compaction.

5 Concluding Remarks

The study reflects insight into causes of pavement failures, which are remedied by fibre reinforcement techniques with a brief explanation of pavement failure case study. In order to design the pavement, it is prerequisite to understanding the soil properties and local solution to solve the problems related to subgrade soil. The study reveals that there are many kind of fibres available to enhance the pavement subgrade soil properties according to characteristics of soil and fibres. This study also concludes the properties of the soil-fibre matrix. The transportation infrastructure such as pavement and subgrade soil will be improved in terms of mobilized tensile and shear strength by fibre reinforcement due to the shearing action of soil with fibres.

References

1. Anagnostopoulos C, Tzetzis D, Berketis K (2014) Evaluation of the shear strength behaviour of polypropylene and carbon fibre reinforced cohesive soils. Res J Appl Sci Eng Technol 7:4327–4342
2. Attom M, Al-Tamimi A (2010) Effects of polypropylene fibers on the shear strength of sandy soil. Int J Geosci 01:44–50
3. Babu A, Snigdha VK, Suhaila KT, Swathy VR (2016) Influence of polypropylene fibre on shear strength parameters of sandy soil. Int J Eng Res 5

4. Deb K, Narnaware Y (2015) Strength and compressibility characteristics of fiber-reinforced subgrade and their effects on response of granular fill-subgrade system. Transp Dev Econ 1
5. Diambra A, Ibraim E (2015) Fibre-reinforced sand: interaction at the fibre and grain scale. Géotechnique 65:296–308
6. Diambra A, Ibraim E, Russell A, Muir Wood D (2012) Fibre reinforced sands: from experiments to modelling and beyond. Int J Numer Anal Meth Geomech 37:2427–2455
7. Eldesouky H, Morsy M, Mansour M (2016) Fiber-reinforced sand strength and dilation characteristics. Ain Shams Eng J 7:517–526
8. Freitag D, ASCE F (1986) Soil randomly reinforced with fibres. J Geotech Eng 112:823–826
9. Gao Z, Zhao J (2013) Evaluation on failure of fibre-reinforced sand. J Geotech Geoenviron Eng 139:95–106
10. Gray D, ASCE A, Ohashi H (1983) Mechanics of fiber reinforcement in sand. Int J Rock Mech Min Sci Geomech 20:131
11. Gupta D, Kumar A (2016) Strength characterization of cement stabilized and fiber reinforced clay-pond ash mixes. Int J Geosynth Ground Eng 2:32–36
12. Hejazi S, Sheikhzadeh M, Abtahi S, Zadhoush A (2012) A simple review of soil reinforcement by using natural and synthetic fibers. Constr Build Mater 30:100–116
13. Ilankeeran P, Mohite P, Kamle S (2012) Axial tensile testing of single fibres. Mod Mech Eng 2:151–156
14. IRC: 37-2012. Guidelines for the design of flexible pavements. Indian Roads Congress, New Delhi
15. Kanchi G, Neeraja V, Sivakumar Babu G (2015) Effect of anisotropy of fibers on the stress-strain response of fiber-reinforced soil. Int J Geomech 15:06014016
16. Khanna SK, Justo (2001) Highway engineering, 8th edn. Nem Chand & Bros Publications, Roorkee
17. Li H, Senetakis K (2018) Modulus reduction and damping increase of two sands reinforced with polypropylene fibers. J Mater Civ Eng 30:04017299
18. Pal S, Sonthwal V, Rattan J (2015) Review on stabilization of soil using polypropylene as waste fibre material. Int J Innov Res Sci Eng Technol 4:10453–10458
19. Punmia BC, Jain AK, Jain AK (2005) Soil mechanics and foundations, 16th ed. Laxmi Publications (P) Ltd
20. Ranjan G, Vasan R, Charan H (1996) Probabilistic analysis of randomly distributed fiber-reinforced soil. J Geotech Eng 122:419–426
21. Rivera-Gómez C, Galán-Marín C, Bradley F (2014) Analysis of the influence of the fiber type in polymer matrix/fiber bond using natural organic polymer stabilizer. Polymers 6:977–994
22. Reem Salim N, Rafeeq Ameen K, Alaa Moosa K (2017) Evaluation of flexible pavement failures—a case study on Izki Road. Int J Adv Eng Manag Sci 3:741–749
23. Tang C, Wang D, Cui Y, Shi B, Li J (2016) Tensile strength of fibre-reinforced soil. J Mater Civ Eng 28:040160311–0401603113
24. Woods W, Adcox A (2004) A general characterization of pavement system failures, with emphasis on a method for selecting a repair process. J Constr Educ 7:58–62
25. Yang B, Weng X, Liu J, Kou Y, Jiang L, Li H (2017) Strength characteristics of modified polypropylene fiber and cement-reinforced loess. J Cent South Univ 24:560–568

Effects of Material Characteristics on Flexible Pavement Rutting Phenomena in Gujarat

Jyoti Trivedi and Rakesh Kumar

Abstract As Mechanistic-Empirical (M-E) configuration keeps on progressing toward full usage by state offices, there is a need to survey the precision of the asphalt reaction models under unique movement. A constitutive model is proposed to predict the accumulation of permanent strains for bituminous surface (BS), subbase and subgrade soils. The deformation of the in situ traffic loading cycle is incorporated in the elastic theoretical framework based on the subgrade vertical compressive strain and horizontal tensile strain criterion. The model has been implemented on road stretch of Gujarat. Soil characteristics were assessed by developing the correlation using multilinear regression (MLR) and Artificial Neural Network (ANN) techniques with conventional volumetric and index properties. The in situ response based rut depth model was also developed to predict rutting taking consideration of volumetric, index properties and estimated vertical compressive strain, and horizontal tensile strain. The model was trained, tested and validated with 85%, 05%, and 10% data, respectively.

Keywords Rutting · Subgrade · Granular subbase (GSB) · MLR · ANN

1 Introduction

The impact of numerous layers of various materials qualities subjected to nonuniform movement loadings and shifting conditions is one of the conspicuous elements that control the execution of adaptable asphalt structures. In spite of having a current headway in Unthinking experimental estimations and experience, the measurement of the asphalt bothers in streets is not yet completely comprehended. Especially, subgrade soils, granular, and base layer material lack the required consideration in

J. Trivedi
Faculty of Technology, CEPT University, Ahmedabad, Gujarat, India

R. Kumar (✉)
Civil Engineering Department, SVNIT, Surat, Surat, Gujarat, India
e-mail: krakesh@ced.ac.in

D. Deb et al. (eds.), *Innovative Research in Transportation Infrastructure*,
Lecture Notes in Intelligent Transportation and Infrastructure,
https://doi.org/10.1007/978-981-13-2032-3_13

the portrayal of asphalt materials. Basic misshaping is a standout among the most genuine upsets in adaptable asphalts influencing its execution and administration life [1–3]. The material qualities and conduct of each layer significantly affect the rutting marvels [4–6]. The constitutive portrayal and demonstrating of the adaptable asphalt material attributes, and in addition the associations among its constituents, should be examined [7]. The reaction models are a basic essential for dependable assessment of asphalt basic condition regarding rutting and exhaustion by consolidating suitable exchange capacities [8, 9].

This paper introduces the investigation of in situ material attributes, development factors of the black-top layer, subgrade and granular subbase layers separated from customary quality and solidness parameters. The material quality properties and soil list properties of the Bituminous surface (BS), subbase and subgrade, are examined through trial site examination. Field examination on a 30 km since quite a while ago unified four paths national interstate utilizing 30 test pits performed of 3 distinct areas as given misery condition. The modulus of subbase and sub-review layers is acquired from lightweight deflectometer (LWD) testing on various layers, uncovered amid trial pits. The anticipated execution of rutting was contrasted, and real rutting saw in this adaptable asphalt. The in situ reaction-based groove profundity expectation demonstrate was produced with regards to the thickness, modulus of versatility, volumetric, record properties, and evaluated vertical compressive strain and flat pliable strain. Moreover, this paper likewise assessed the present asphalt outline subgrade rutting criteria of lasting twisting through contrasting and the genuine estimations of rutting through the 3 m straight edge. In view of genuine field information, a rutting forecast show was created utilizing MLR and ANN. The models were aligned and approved utilizing asphalt reaction, i.e., vertical resist the highest point of the subgrade and flat malleable endure the base of black-top layer. The objective of the study is:

1. To measure characteristics deflection using Benkelman beam deflection (BBD) and rutting measurement on real case pavement section using 3 m. Straight edge and portable LWD test to obtain back-calculated modulus for the pavement layers' subbase (wet mix macadam (WMM), GSB) and subgrade.
2. To develop vertical strain and tensile strain based rut prediction model using actual vehicular traffic loading, modulus of elasticity (E) and pavement thickness, material properties, bituminous surface characteristics deflection, asphalt/binder content, aggregate impact value (AIV), Flakiness Index and Elongation Index (FIEI), Volumetric Index properties of unbound granular layer viz; Liquid Limit (LL), Maximum Dry Density (MDD), Optimum Moisture Content (OMC), and Modulus of Elasticity (E) using multilinear regression (MLR) and artificial neural network (ANN) analysis.

2 Experimental Programme

Itemized trial examinations have been performed on the chosen 3 diverse street extends. Three diverse class of street extends were chosen having particular movement stacking and soil qualities as of Gujarat state. The whole field and lab examinations have been performed on the three chose asphalt area of every street extend, cumulating it to 33 test chainage focuses. In this manner, 33 diverse chainage point test area were picked experienced with lasting twisting. Field test office and information gathering exercises included versatile Lightweight Deflectometer (LWD) tests, rutting estimation, activity information accumulation, trial pit estimations for soil qualities, and volumetric list properties of subbase (unbound granular) and subgrade layers.

2.1 Rutting Measurement

The rutting estimation of the asphalt on wheel way was led. For the estimating field rutting, a 3 m straight edge and standard wedge were used, according to the rules in the IRC SP-16:2004. The focal point of the wheel way was chosen at 1.5 m from the edge of the street carriageway according to IRC: 81-1997 rules. The rutting estimations were made at the test focuses. The normal benefits of rutting in the moderate path of the street along the chainage focuses are specified in Fig. 1. The base normal rutting esteem was 4 mm seen at chainage point-6, the most extreme normal rutting profundity of 15 mm was seen at chainage point-10. The normal rutting profundity along the roadway extent is 10.1 mm.

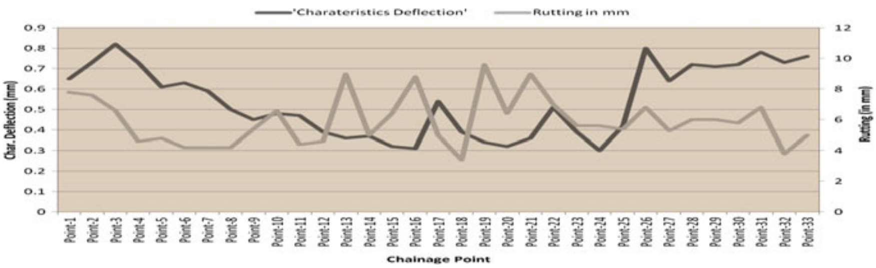


Fig. 1 Deflection and rutting measurement

2.2 Characteristics Deflection Measurement

Asphalt diversion is utilized to survey the auxiliary ampleness of the asphalt. For the auxiliary assessment of the asphalt structure, diversion estimation by Benkelman shaft gear according to the rules set down in the IRC: 81-1997 was finished. Attributes diversion estimated through BBD and rutting estimated through 3 m Straight edges as clarified in above area comes about into the reasonable effect of bituminous surface (BS) layer towards rutting as appeared in Fig. 1.

The total measured rutting to BS layer ranges increments to the observation of the characteristics deflection, this amount of similarity of surface rutting directly contributes to the variation of BS layer and construction material properties.

2.3 Investigation of Bituminous Surface (BS) Layer

The test pit site determination was fluctuated length because of varieties in asphalt trouble. The 33 soil tests were gathered from test pit. In view of research center outcomes, the soil was named as Sandy Soils (SM and SM-SC), Sand-Clay soils (CL, CL-ML, SC, and MI), and Clayey soils (CH and CI). In light of lab examination of the whole investigation extend utilizing trial pits, four sorts of soil were charted viz. CL (3.23%), SC (74.19%), SM (6.45%) and SMSC (16.13%). The outcomes demonstrate that review extend is having the soil of clayey sand (74.19%). Field examination of each layer was acquired by leading MDD (Maximum Dry Density)/OMC (Optimum Moisture content) as appeared in Fig. 2a, b.

The variety of LL, PL, and PI along the undertaking stretch was analyzed. The outcomes demonstrate that compaction for the greater part the investigation extend was under 97% compaction level, and subgrade CBR was 8% (MORTH, 2013). As far as possible was evaluated in the scope of 20–36% in the subgrade layer with max.MDD 2.05 gm/cc, max.OMC 11.1% and max.CBR as 13.1%. The idea of estimated rutting is relating with LL as given in Fig. 3. The modulus of elasticity of subgrade and subbase can be assessed from Lightweight Deflectometer (LWD). The quality properties, for example, modulus of versatility and CBR were additionally assessed for GSB and subgrade layer as given in Fig. 4.

3 Model Development

In this investigation, we have included two failure criteria of vertical compressive strain and horizontal tensile strain to portray the material properties of asphalt layers, subbase, and subgrade. In view of a surface deflection, bituminous surface (BS) material properties, soil subbase and subgrade properties, and asphalt content was utilized as contributions to the rutting improvement. Measured vertical strain and

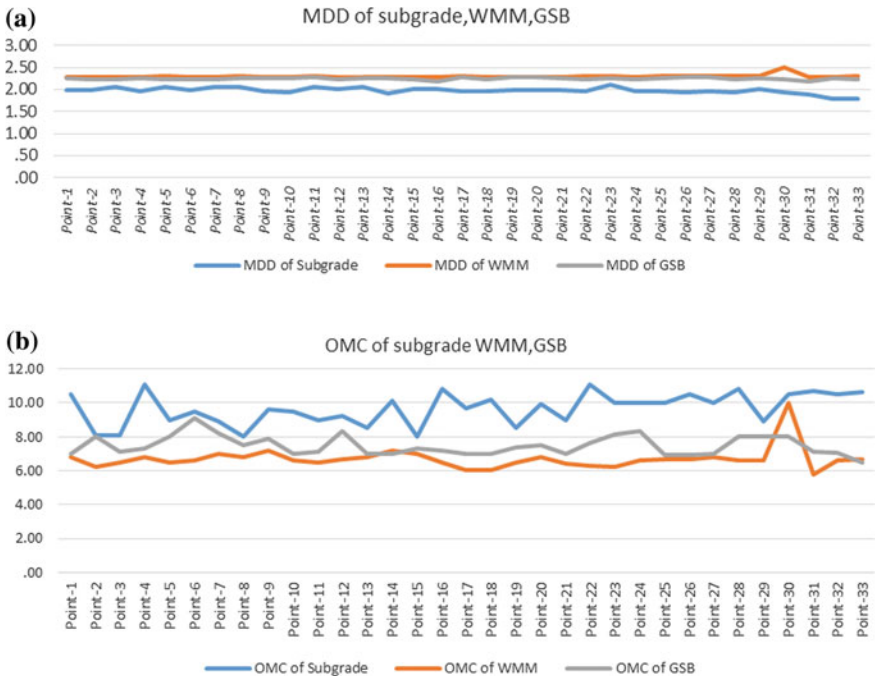


Fig. 2 **a** Maximum dry density, **b** OMC in GSB layer

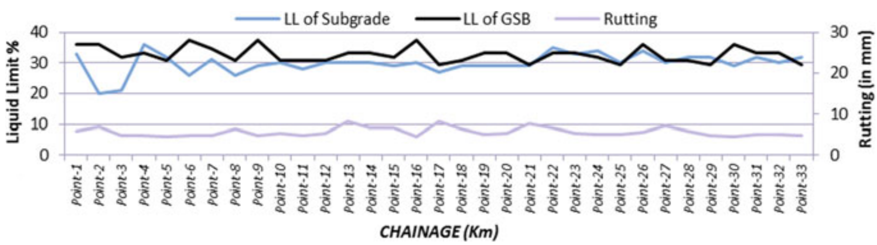


Fig. 3 Liquid limit and rutting

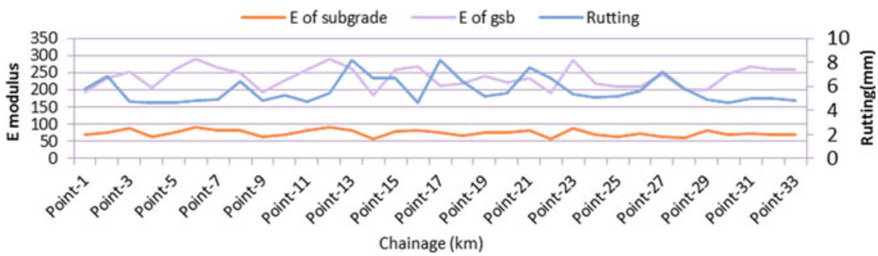


Fig. 4 Modulus of elasticity and measured is rutting

horizontal tensile strain response on the top of pavement layers is an important element of the rut model. Estimated vertical strain and horizontal strain reaction on the highest point of asphalt layers is an essential component of the rut deflection. KENPAVE, usually utilized multilayer linear elastic software, was utilized to anticipate vertical strain over the subgrade and horizontal strain on the base of bituminous layer because of vehicular movement. MLR and ANN strategies are connected for the reaction expectation show improvement and upgraded to the distinguished 18 number of variable combinations at each 33 informational collection point brings about 594 informational data. Out of that, 85% of it is utilized for preparing, 5% of it for testing, and 10% for approval. The architecture of the ANN model is decided by inputting the number of hidden layers and number of neurons that plays a vital role. The number of hidden layers is one, the algorithm is multilinear perceptron (MLP) and the output forms even models of mean square error (MSE) generated.

As expressed "Combination of variables" Model1 for Bituminous layers, its dependent variable factors are vertical compressive strain and independent variables E, Thickness, Asphalt content, AIV, FI, and EI. Horizontal tensile strain as dependent variable and for the independent variable, characteristic deflection, E, Thickness, Asphalt content, AIV, FI, and EI. Detailed calculation and results as MLP4-6-1:R2ANN-0.95, R2MLR-0.75, MSEANN-0.0005, and MSEMLR-0.4711 and MLP5-6-1:R2ANN-0.95, R2MLR-0.75, MSEANN-0.0005, and MSEMLR-0.471. Similarly, for Model2 Subbase layers, its dependent variables are vertical compressive strain and independent variables are E (modulus of elasticity), Thickness, WMM (LL), WMM (MDD), WMM (OMC), GSB (MDD), GSB (OMC). Horizontal strain as dependent variable and independent variables E, Thickness, WMM (LL), WMM (MDD), WMM (OMC), GSB (MDD), GSB (OMC)F formulated calculation and results as MLP5-5-1: R2ANN-0.84, R2MLR-0.745, MSEANN-0.0003, and MSEMLR-0.986, MLP5-8-1: R2ANN-0.89, R2MLR-0.791, MSEANN-0.0004, and MSEMLR-0.573 and for Model3 Subgrade layers, its dependent variable are vertical compressive strain and independent variables are Modulus of elasticity, LL, MDD, OMC. Similarly, horizontal strain as dependent variable and independent variables are modulus of elasticity, LL, MDD, OMC. Detailed calculation and results as MLP65-1: R2ANN-0.84, R2MLR-0.745, MSEANN-0.0003, and MSEMLR-0.986 and MLP5-9-1 R2ANN-0.89, R2MLR-0.791, MSEANN-0.0004, and MSEMLR-0.573.

The coefficient of determination (R^2) the extent of the aggregate variety in results clarified by the model given in Fig. 5. Investigation of Joined impact of parameters on rutting (MLR) parameters of various blends was identified with the reactions (vertical compressive strain and horizontal tensile strain) by MLR and ANN. Relations of all mixes are better, as R^2 is fine.

The critical strains obtained for the pavement were utilized to the pavement life in units of standard axle's repetitions to cause the failure of pavement due to rutting. IRC SP-37-2013 gives rutting model as calibrated studies at 80 and 90% reliability levels. The two equations are given below.

$$N = 4.1656 \times 10^{-08}\,[1/\varepsilon v]\,4.5337 \ldots 80\%\text{reliability} \quad (1)$$

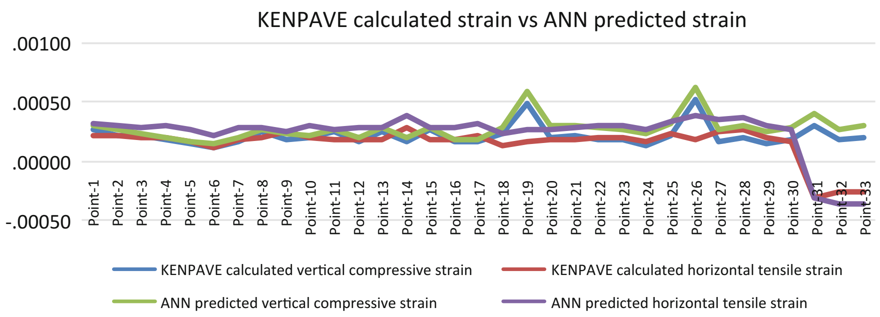


Fig. 5 Calculated strain versus predicted strain

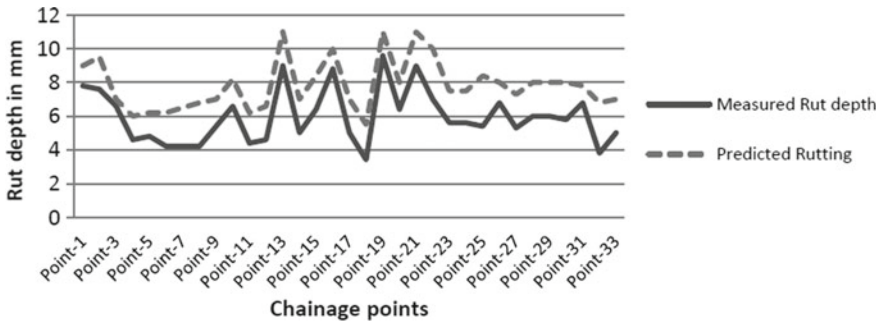


Fig. 6 Predicted rut depth versus measured rut depth

$$N = 1.41 \times 10^{-8}\,[1/\varepsilon v]\,4.5337\ldots 90\%\text{reliability} \qquad (2)$$

where N = Number of cumulative standard axles, and

ε_v = Vertical strain in the subgrade, using the above equation for 90% reliability and the pavement life in terms of msa is shown below in Fig. 6.

Some of the N values obtained in the analysis are very high; a probable cause is the limitation LWD equipment in predicting accurate modulus values for higher thicknesses of nongranular pavement layers and the layers having wide variations along the stretch. The overlaid thickness of bituminous layer also causes an error in the estimation of pavement life under rutting.

3.1 Response Based 2D Constitutive Modeling

Two-dimensional reaction-based constitutive model was created in light of the assessed or anticipated strains, i.e., vertical compressive strains and horizontal tensile strain. As the auxiliary twisting most usually known as lasting distortion or rutting incorporates a vertical compressive strain as well as horizontal tensile strain [5, 10].

Table 1 Rut prediction model coefficient values

Parameter	Coefficient	Standard error	p-value
β	0.533	1.04	0.00038
β0	−2.28	1.62	0.00016
α	1.34	1.46	0.00036
β1	6.87	3.5	0.00037
β2	6.40	5.5	0.00026

In this way, the principal type of the vertical strain based model has been received as appeared in Eq. 3, from the recorded speculations and further the base model is changed to 2D expression.

$$\text{Rut Depth} = \beta_0 \text{Ni}^{(\beta 1 \times \varepsilon v)} \tag{3}$$

where, Ni = Total number of cumulative axle passes at time i′, ε_v = Vertical base or subgrade strain calculated at time "i" from strain prediction models, β0, β1, = Regression constants for traffic and strain, respectively. The modified 2D constitutive model comprises of estimated or measured strains of an elastic half-space, i.e., vertical compressive strain and horizontal tensile strain accumulated, the number of load repetitions, and modulus ratio with rut depth as shown in Eq. 4. Multilinear regression analysis has been carried out to assess the correlation of the developed model between rut depth and response parameters along with the load repetitions. The outcomes acquired from the analysis give best-fit relationship estimation of 0.875. The results achieved from the ANOVA test, and the corresponding model coefficient values are shown in Table 1. Further, the model coefficients were analyzed to assess the reliability, and it is quite acceptable. The validation of the developed model with the test data set has been carried out, and the correlation between the measured and predicted rut depth is quite acceptable as shown in Fig. 6.

$$\text{Rut Depth} = \text{K} \times \text{K1} \times \beta 0 \text{Ni}^{(\beta 1 \times \varepsilon v)(\beta 2 \times \varepsilon t)} \tag{4}$$

$$\text{K} = (\text{E}_{\text{BS}} / \text{E}_{\text{GSB}})^{\alpha} \text{ and } \text{K}_1 = \left(\text{E}_{\text{GSB}} / \text{E}_{\text{subgrade}}\right)^{\beta}$$

where Ni = Total number of axle passes at time "i", εv = Vertical compressive strain calculated from strain prediction models, εh = horizontal tensile strain calculated from strain prediction models, β0, β1, and β2 = Regression constants for traffic and strain, K and K1 = Modulus ratio, α, β = Regression coefficient, respectively.

3.2 Investigation of Effect of Material Properties Parameter on Rutting: (MLR and ANN)

In situ field information examination of each of the three layers, viz., (bituminous layer, subbase, and subgrade):

a. Insufficiency in material properties and volumetric and soil record properties. As far as possible was assessed in the scope of 20–36% in the subgrade layer with max.MDD 2.05 gm/cc, max.OMC 11.1% and max.CBR as 13.1%. The LL answered to be in the scope of 20–24% in the WMM layer with the greatest MDD of 2.305 gm/cc with most extreme 7.2% ideal dampness content. The LL lies in the scope of 22–28% for GSB layer with max.MDD 2.29 gm/cc, OMC 9.1% and CBR 35%. It was watched that the material was utilized as a part of GSB layer contained exorbitant fines. The level of material going through 75 μm sifters changed from 14% to as high as 25%.
b. The results of the Benkelman beam deflection studies indicate the structural inadequacy and the need for a strengthening layer, after removal and reconstruction of failed portions in large patches. The total measured rutting to BS layer ranges increments to the observation of the characteristics deflection (0.65–0.85 mm), this amount of similarity of surface rutting (4–10 mm) directly contributes to the effect of BS layer and construction material properties towards structural inadequacy.
c. From the initial data analyzed, the rut depth calculation based on rutting model (IRC-37-2013) was calibrated to review existing traffic count using the pavement performance data collected during at 80 and 90% reliability levels for this case. Equations (3) and (4) as given for N = traffic axle count for a particular period, here the period is in the month of September-2013 for calibration of existing data. The results of calibration exceeded the allowable limit of vertical compressive strain (εv) on subgrade is 291×10^{-6}.
d. For this reason, consideration to review the current base model and validation for an in-service road are recommended.

4 Summary and Conclusions

This study investigates the function of strength parameters, material parameters and pavement responses in combination with subgrade and GSB layer characteristics. The accumulation of permanent deformation was addressed through sensitivity analysis carried out by considering the bituminous surface, soil and subbase material properties variables. The study results in three major significant outcomes:

The investigation brings about three noteworthy results:

(i) The effect of in situ field variable of all layers towards mechanistic response (vertical strain and horizontal strain). (ii) Modified the 2D response based rut formation model effect of in situ field variables. (iii) Development of modulus ratio of a bituminous surface, subbase, and subgrade layers.

From the outcomes acquired by MLR and ANN, the accompanying conclusions were drawn:

1. In situ field measured asphalt content; AIV and Flakiness Index are the important variables for asphalt layer rut formation in combination with layer characteristics deflection, thickness, and modulus of elasticity.
2. Soil index properties and material properties are significant variables in a combination of layer thickness and modulus of elasticity of subbase and subgrade layer towards mechanistic response for rut formation.
3. Multilinear regression (MLR) results significant co-relation for bituminous layer mechanistic response (vertical strain and horizontal strain) 0.75 and 0.74, respectively. Similarly for subbase and subgrade layer 0.74 & 0.79 and 0.83 & 0.88, respectively.
4. Artificial Neural Network (ANN) obtained values of relative good correlation observed which support the validity of R^2 values of a bituminous surface, subbase layer and subgrade towards vertical strain, and horizontal strain are 0.95, 0.85 & 0.84, 0.89, and 0.89, 0.88 respectively.
5. The results of measured rut depth and predicted rut depth based on ANOVA test validation R^2 is 0.875, and its variable coefficient are given in Table 1.

On the same basis, the methodological approach and the models developed in this paper need to be extended to other subgrade soil types and validated by different field test data. For practical application, this simplified prediction model was proposed for selected soil type and any of the available fields measured data. With further validation, sensitivity analysis, and field calibration, the new model proposed in this paper offers the greater promising potential for accurately predicting the permanent deformation behavior of subgrade and subbase soils.

References

1. Oscarsson E (2011) Modeling flow rutting in in-service asphalt pavements using the mechanistic-empirical pavement design guide. Road Mater Pavement Des 12:37–56
2. Leahy RB (1989) Permanent deformation characteristics of asphalt concrete. PhD dissertation, The University of Maryland, College Park, Maryland
3. Yeggoni M, Button JW, Dollinger DG (1994) Influence of coarse aggregate shape and surface texture on rutting of hot mix asphalt. Research report Texas Department of Transportation & Texas Transportation Institute
4. Selvaraj SI (2007) Development of flexible pavement rut prediction models from the cat test track structural study sections data. PhD dissertation, Auburn University, Aubum
5. Sunny Deol G, Singh K, Kumar R (2014) Prediction of 2D-structural deformation of flexible pavement using artificial neural networks. In: International conference on recent trends and challenges in civil engineering MNNIT Allahabad, India
6. Kim HB, Buch N, Park DY (2000) Mechanistic-empirical rut prediction model for in-service pavements. Transp Res Rec 1730:99–109, Paper no 00-0165

7. Huanan Yu et al (2014) Anisotropic nonlinear elasto-viscoplastic model for rutting of asphalt mixtures. J Eng Mech 140(2):242–249. https://doi.org/10.1061/(ASCE)EM.1943-7889.0000655
8. Tarefder RA, Zaman M, Hobson K (2003) A laboratory and statistical evaluation of factors affecting rutting. Int J Pavement Eng 4(1):59–68
9. Wang R, Zhou F, Chen DH, Zheng G, Scullion T, Walubita LF (2010) Characterization of rutting (permanent strain) development of A-2-4 and A-4 subgrade soils under the HVS loading. J Perform Constr Facil (ASCE) 24:382–389
10. Haora Z et al (2013) Mechanistic rutting prediction using a two-stage viscoelastic-viscoelastic damage constitutive model of asphalt mixtures. J Eng Mech 139(11):1577–1591. https://doi.org/10.1061/(asce)

Author Index

A
Anjali K. Khambete, 55
Ashish Bhaskar, 13

C
Chetan R. Patel, 111
Chintan Advani, 13

D
Deep Patel, 77
Dipankar Deb, 77

G
Gaurang Joshi, 1, 101
Guru Prakash Ramaguru, 33

J
Jashvi Mehta, 77
Jaykumar Soni, 45
Jiten Shah, 77, 121
Jyoti Trivedi, 133

K
Krupesh A. Chauhan, 55

M
Maharshi Shukla, 121

N
Nandan Dawda, 101
Narayana Raju, 1
Ninad Gore, 23
Nishant Pawar, 23

P
Partha Tripathy, 55
Patelia, P. R., 45
Pravin Jadhav, 65

R
Rahul Nath Choudhury, 65
Rajesh Gujar, 45
Rakesh Kumar, 133
Rathod, S. C., 89

S
Sachin Shah, 13
Sagar Deshmukh, 45
Samir J. Patel, 111
Shriniwas Arkatkar, 1, 13, 23, 101
Smit Thakkar, 13

T
Tejaskumar Thaker, 45
Trudeep Dave, 121

V
Varia, H. R., 89
Vasudevan, N., 101
Venkata Dilip Kumar Pasupuleti, 33

Y
Yashwant Dadi, 77

D. Deb et al. (eds.), *Innovative Research in Transportation Infrastructure*,
Lecture Notes in Intelligent Transportation and Infrastructure,
https://doi.org/10.1007/978-981-13-2032-3