Intelligent Transportation Systems

Intelligent Transportation Systems:

Concepts and Cases

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चरन्मार्गान्विजानाति

One who moves, understands the path

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PREFACE

Intelligent transportation systems (ITS) are sometimes referred to as smart transportation. In recent times, this is one of the most intriguing topics, and is equally discussed by academics, practitioners, and policy makers. Academia finds it interesting because the field is emerging and there is good scope for advanced technology and research. Practitioners find it interesting because there is a strong belief that the field has enough potential to enhance productivity and, thereby, improve profitability. Policy makers find it interesting because most ITS are based on emerging technologies and innovative models that can help achieve national goals and priorities, if well utilized.

However, it is worthwhile to realize that there is a huge gap between the technology-driven research, practice, and policy facets of ITS. Most of the available texts and literature on ITS focus on these facets in silos, neglecting the interdependencies of each other; understandably so, as each of these facets is held by stakeholders that may not have a comprehensive perspective and purview of ITS. An academic, or a research, organization works only on the prospects of advanced technologies, with little consideration of implementation challenges and policy directives. A corporation, or a practitioner, focuses more on productivity and commercial gains for the organization rather than the wholesome goals that the state may aim for. Governments, as stakeholders, are concerned about framing policies that address equity, sustainability, and national development; their reliance on the research and corporate world is high and, in turn, the policies framed by the governments impact what research and practice can deliver and contribute to the state goals.

Through various chapters in this text, it is argued that ITS are demonstrations of Industry 4.0 standards in the transportation service sector. Management philosophers have popularly termed the industrial revolution as four phases of milestone development and growth. The current stage is Industry 4.0, where systems productivity is enhanced through information and communications technology (ICT) and the internet of things (IoT). In that context, there are discussions on scope and possibilities through advanced technologies in the transportation sector.

ICT enables communication between three entities—vehicle, infrastructure, and systems—in any transportation domain. It helps in informed decision making for all the stakeholders. The socioeconomic development of a country is directly dependent on the transportation system. Typically, most discussions on ITS provide a systemic perspective that covers the following:

1. Advanced Traffic Management Systems (ATMS)
2. Advanced Traveler Information Systems (ATIS)
3. Advanced Vehicle Control Systems (AVCS)
4. Commercial Vehicle Operations (CVO)
5. Advanced Public Transportation Systems (APTS)
6. Advanced Rural Transportation Systems (ARTS)

This book focuses on the synergies of all three facets of ITS, based on the managerial and business perspectives of ITS. The coverage is comprehensive and relevant to all types of stakeholders of ITS.

1. Financial viability of the project
2. Social aspect of the project (technically safe and secure systems)
3. Policy making aspects

The essence of the text deals with the application of technology in a local context. The focus will be on the feasibility of these technologies in different cities. For instance, a particular technology can be applicable in Mumbai but not in Patna.

Challenges of ITS

ITS require people who are highly skilled in areas such as finance, engineering, securities, data science, etc. How people engage together makes it interesting. Another aspect to ponder is the need for a particular technology. Do we really need to have intelligent systems? Resoundingly, yes. Intelligent systems are safer and have fewer emissions. They also help in reducing congestion in the system.

One of the main areas of study will be that of congestion; in this textbook, congestion is analyzed from a supply–demand perspective. Why are cities congested? Demands for better mobility choice have consistently increased around the globe but resources have not kept up the pace with the growing demand. Reasons vary from poor urban planning, poor infrastructure, and lack of pace in developing infrastructure to meet the current and future demands. The bottom line is that the civil infrastructure is unable to meet and keep up with the pace in which mobility demands increase.

What can the government do to reduce congestion? By and large, the onus of providing good mobility solutions lies with the state authorities. Despite the governance and administrative constructs in different nations, challenges on the ground are real and large; however, urban congestion and reasonable mobility service in sparsely populated regions are common across the globe. Approaches to tackle the situation might be different and should be relevant to the context. A long term and sustainable solution lies with better urban planning designs, such as a hyper-local model. Not every city has been able to develop such urban designs, as city growth in many developed cities is organic and driven by various forces. Shared mobility systems, inducing behavior changes, and e-commerce are driving the urban mobility systems in completely different trajectories. State-level policies attempt to regulate such developments and enforce laws that help enhance trust and security in systems. State-level decisions happen at multiple levels: policy, strategic, tactical, operational, and real-time.

What kind of considerations go into decision making? The cost of congestion, time taken to build infrastructure, cost of building infrastructure, streamlined integration of existing infrastructure with newer developments (Greenfield Project vs Brownfield Project), safety and security of assets, and people are primary considerations in state decisions. There are other objectives, too, such as growth and planning of industries, and socioeconomic needs, that contribute to ITS development. Most decisions involve a long-term vision and national priorities dictated by governance structures. ITS are considered to address and resolve issues that arise in real time in a dynamic environment, which is very distinct from civil infrastructure-based transportation systems. Hence, ITS begin where civil infrastructure fails.

ITS: The Elephant in the Room

While transportation-related challenges are prevalent across the globe, solutions are poorly planned and implemented—the elephant is in the room. However, since ITS are multidisciplinary, the scope and possibilities of what ITS can offer to alleviate transportation challenges are understood independently rather than holistically. This is metaphorically paralleled with blind men trying to identify an elephant by touching and feeling the animal. Professionals, based on their own expertise, perceive and classify ITS under their own domains: i) civil engineers understand ITS as construction, ii) computer science graduates ascertain ITS as a softwarebased solution for transportation, iii) transportation engineers consider ITS as a vehicular technology, iv) legal professionals see ITS as a matter of the law, v) HR and OB professionals perceive ITS from a people–behavior perspective, vi) business management professionals look at the finance and management aspects of ITS, vii) operations research professionals handle ITS as model development, and viii) policy planners treat ITS as state intervention for transportation. None of these is complete and comprehensive, but only a partial and narrow view of the larger problem. This is one of the fundamental aspects of ITS. To develop meaningful solutions for real-world problems, it is necessary for decisionmakers from various backgrounds to work together to develop solutions that are contextually relevant and adoptable in a local ecosystem.

Are developed nations better off? Unfortunately, no. In fact, developed countries are less enterprising in experimenting with novel solutions for various reasons. Risk-awareness and stake of safety and security are more significant in developed countries. Hence, developing countries are usually the proponents of innovative solutions. The usability of a novel system cannot be evaluated unless it is deployed in a real-life setting. Developing countries are more amenable to experimentation and trials. Therefore, no country leads or lags in terms of real ITS that totally resolve all their local problems.

This textbook, *Intelligent Transport Systems: Concepts and Cases*, is organized into four modules; multiple chapters are included in each module, with each chapter focused on a specific theme with illustrated cases from across the globe. The first module is on ITS trends, challenges, and opportunities; an overview of ITS is presented, followed by the challenges in ITS development, the purpose of ITS deployment, and a final chapter on determinants of ITS. The second module covers the anatomy and framework of ITS development; the role of ICT, big data processing, storage, and analytics are discussed in this module. A framework for ITS development—comprising operations, technology, policy, business, and innovation—is also presented. Each topic is substantiated with brief real-life illustrations. The third module is on integrating requirements—planning, design, and development; here, most of the operational challenges, and scope for addressing these challenges using innovative technologies and models, are covered. The chapters in this module are ITS technology elements, building blocks, system design, capacity planning, operations planning, maintenance and control, signaling and priority, project management, fleet and commercial vehicle operations, safety, and security. The last module presents the business and policy perspectives of

ITS: strategic business planning, pricing and revenue management, sustainability of ITS operations, role of state and regulatory bodies, PPPs in ITS development, e-vehicles and their impacts, and emerging trends.

This book is an outcome of my personal academic experience in understanding and teaching the topic to various cohorts of students. I have known and learnt a lot from my audience; much more than what I, personally, was able to teach my students. Several academic projects done by my students, over the years, have enriched my knowledge with newer aspects. Priyanshu Raj, Lavanya Chintagunta, Harsh Gupta, and Arpit Kanv supported me with background research. Harshad Parmar, IIM Ahmedabad handles all my administrative tasks and I count on his support, as ever. Meenakshi read the first draft and helped me with the first round of proof reading and several suggestions to improve the language flow. Ms Lorna Pierce did the cumbersome task of a final professional editing and proofreading the full text; my gratitude to both of them. Adam Rummens was an excellent support from the publishing team, and it was a pleasure to interact with him. The Research and Publications division of my employer, the Indian Institute of Management Ahmedabad, provided some funding support for this work. I am immensely thankful to all.

I owe a lot to my family, my parents, two most beautiful daughters, husband, and my brother who have stood by me through thick and thin. They are very precious to me, and I am extremely grateful to have them in my life. My students are the constant source of my energy in my professional space. I am also thankful to them.

MODULE 1

TRENDS, CHALLENGES AND OPPORTUNITIES

CHAPTER 1.1

ITS: AN OVERVIEW AND CHALLENGES

Introduction

Efficiency and safety of transport systems in developed economies have long leveraged the potential of information and communication technology (ICT). Developing economies often lack a good quality transport infrastructure that can i) support the deployment of intelligent transportation systems (ITS), and ii) harness the full potential of advancements of ICT applications. Fast-paced deployment of ITS in developing countries is largely influenced by the socioeconomic and environmental safety requirements. Developed nations, like the United States, Japan, and regions like Europe, had created a well-established network of transport infrastructure by the 1990s and are, since, implementing ITS to further improve the network's efficiency and safety. Today, such countries have reached the real-world trial and implementation of advanced ITS applications. Interestingly, traffic congestion continues to plague these countries, mainly due to ever-growing mobility demands and the inability of the civil traffic infrastructure to cater to the increasing demands; despite the availability of technologically advanced transport systems solutions, rigid government policies and norms reduce the implementation pace. Developing countries stand at an advantage of procuring advanced traffic and ITS technologies from them, in addition to gaining a better clarity of the pros and cons of such advanced technologies. However, the fundamental challenge is to create design transformations of the systems to suit the contextual relevance and functional requirements that are locally unique. There are fundamental geographical, technological, practical, and cultural factors that make the exact replication of western ITS standards and system architectural practice difficult for developing nations, including India and China.

For instance,

- uncoordinated spatial and infrastructural development
- diversity in the types of vehicles and range of vehicular velocities (pedestrian, bicycle, LMVs, HMVs, animal carts, etc.)
- lack of lane discipline, mostly due to contrast in cultural practices
- high population density
- insufficient legislations, weak enforcement of rules and regulations

Table 1.1.1 represents an overview of a study that presents the number of countries that are grouped region-wise and the percentage implementation of ITS applications in those countries, based on the International Monetary Fund report of 2018.

Developing countries (regional groups)	Number of countries	Percentage of ITS applications
Middle East (including Egypt)	15	35 %
Emerging and developing Asia	19	27 %
Developing countries in Europe	10	19 %
Latin America	17	12 %
North Africa (excluding Egypt)	6	8 %
Sub-Saharan Africa	48	7.5 %

Table 1.1.1: Countries and ITS Implementation
Source: El Mokaddem, Jawab and Saad (2019)

Types of Challenges

ITS implementation in developing nations is very complex. Some challenges are consistent while others are unique to a country or region. The characteristics and prospects of ITS services and applications are distinct from those of conventional transport applications. These challenges are often based on the prerequisites for the deployment of the subsystem. Some challenges are technical in nature, due to the inherent characteristics of the ITS subsystem; some are contextual to a region and others may be application specific. For instance, whole ITS systems usually have high budget requirements while certain subsystems, like automatic vehicle identification (AVI) and automatic vehicle location (AVL), are not only capital intensive but also require public endorsement. Furthermore, it is also essential that each subsystem complements the other. A good example would be the use of CCTV. Despite the lack of legal regulations and discipline, CCTV-based video capturing can be deployed for data collection for motorized traffic on a road. In developing countries, there is a lot of unorganized traffic penetration, which is cumbersome to track and regulate. In other words, ITS development challenges are technical, managerial, financial, legal, social, and political; this makes ITS studies engaging and meaningful for researchers and practitioners to use to develop pragmatic systems and solutions. Technical barriers can be classified as inadequate knowledge about i) artificial intelligence (AI) operations, ii) capabilities of big data storage, analysis, and techniques, and iii) the absence of standards and protocols that support interoperability to complement effective and streamlined transport network operations. Non-technical barriers relate to the sociopolitical and legal aspects, such as poor enforcement of rules and regulations, and weak governance mechanisms.

The overall challenges of ITS in developing nations can be broadly classified into the following categories:

1. Lack of Legal Structures, Regulatory, and Governance Mechanisms

One of the most fundamental requirements and characteristics of ITS is data collection, access, and analysis. Additionally, data collection and processing are required to be real-time and secure for all stakeholders. It is imperative to establish data regulation policy and governance structures that ensure transparency in user data collection and sharing. Most developing countries lack a regional-level framework, such as the General Data Protection Regulation (GDPR) in the European Union, or a state-level framework, like the City of Los Angeles Department of Transportation's (LADOT's) Mobility Data Specification (MDS), to create a favorable environment for ITS deployment.

2. Lack of Institutional Will

Public transport authorities play a crucial role in the deployment and maintenance of ITS. There is a need to create a synergy between the public and private sectors, which, in turn, requires the restructuring of the institutional framework and ensures the overall capacity building for the operation and management of ITS. Setting up of a unified transport authority at a state level and developing a national ITS data repository can help mitigate implementation delays and eliminate the multiplicity of decision-making agencies at various levels.

3. Inadequate Infrastructure and High Implementation Cost

ITS are considered technology-driven systems that can enhance transport network efficiency through informed decision making by various stakeholders for the optimal utilization of the existing infrastructure. Developing nations have a weakly coordinated spatial and infrastructural development, resulting in poor traffic services. Apart from transport network infrastructure, ICT infrastructure, like data storage units, enhanced wireless networks, etc., should also be well established to ensure efficient operations. Huge funds might be required to design, develop, deploy, and operate ITS.

4. ITS Technology Readiness and Maturity

It is very crucial to understand that regional context impacts the specifications of the deployed ITS. Any outsourced technology/component needs to be calibrated and customized to match the local setting. Homogeneity of the deployed components is also essential to avoid issues related to system nonconformity and interoperability with the existing systems. As ITS include multiple stakeholders and technologies from various sectors, like the automobile industry, transport agency, equipment manufacturers, etc., the interpretation of ITS differs for each stakeholder; interfacing among the many ITS subsystems can be a huge challenge.

5. User Behavior and Transport Professionals' Awareness

User acceptance plays a crucial role to ensure proper trust and collaboration. It is essential to ensure knowledge sharing, with respect to new ITS technologies and initiatives, among different stakeholders. Most of the drivers in the public transport sector or logistics sector are not matured; there is a huge gap in education, training, and skill development for operating ITS equipment onboard and on transport practices. It is also essential for transport sector professionals to remain aware of regional characteristics—like the challenges faced due to the presence of informal transportation—before implementing best practices from other countries.

Indian Context and the Current State of ITS in India

The growth rate is one of the highest in the world, when compared to other cities in the developing world. The high rate of urbanization results in high daily demands for citizen mobility for their occupational requirements, which results in a high number of private vehicles in urban areas throughout the country, owing to a subpar public transport system. With the increase in per capita GDP, there has been a significant rise in the income levels of people, which results in high vehicular traffic and demand for better transport infrastructure. Apart from all these, the high amount of rural to urban migration also plays a prominent role in vehicular demand increase and, thus, the transportation infrastructure. Indian urban areas are not equipped enough to sustain the escalating number of vehicles and, as a result, many cities face heavy traffic congestion. This has become a universal problem that needs to be addressed by policy makers and urban authorities.

As per the Government of India data, the transportation sector is a major contributor to the GDP. Currently, its share is around 6.7 %, which is expected to reach around 12 % in 2026 (Rawal 2015). It would be one of the biggest employment-providing sectors. As per the World Bank data, currently, around 32 % of the population resides in urban areas, which is expected to grow to 40 % by 2030. There will also be a contribution of around 75 % of the GDP by the urban population. Over the past few decades, India has experienced an enormous growth in vehicular traffic, as the number of registered vehicles has surged from 0.3 million, in 1951, to 142 million, in 2011, with a CAGR of 9.9 %, between 2001 and 2011 (Rawal 2015). Monetary damages suffered due to congestion and poor roads are as high as $6 billion a year in India (World Bank).

The main reason behind traffic congestion in India is the fact that road capacity and other transport infrastructure have not kept pace with increasing demands and vehicular traffic. Traffic-related challenges in a developing country, such as India, are mainly due to i) failure of civil infrastructure development, proportionate with growing demands, and ii) lack of regulation.

Successful application of ITS can help achieve an efficient, effective, satisfactory, and sustainable multi-modal transport system that will integrate vehicles and management systems through well-established technologies. The purpose behind the deployment of ITS projects in India is to i) provide multiple choices for mobility, and ii) analyze and integrate new emerging technologies to achieve sustainable, reliable, affordable, and efficient transportation that provides public safety and conserves time and energy.

The Indian government has invested about €1.6 million (≈ $1.6 million) to implement ITS, which resulted in improved traffic regulations, a reduction of road accidents and congestion by 52 %, and an increase in new road infrastructure, by 26 %, and road upgrades, by 17 %. (Sengupta 2014). At present, there are no fully developed ITS applications with traffic management centers in India. However, a few small-scale ITS applications have been implemented in India in some metropolitan cities like Bengaluru, Pune, New Delhi, and Chennai. Most of these projects are pilot projects, curated for future large-scale implementation of ITS projects. These are stand-alone projects, which focus on limited functions of ITS, like traffic signal management, public transportation management, organized parking management, and highway toll collection. The ITS program in India mainly focuses on stand-alone deployments of area-wide signal control, advanced public transportation, parking information, etc.

Some of the existing applications of ITS are given below:

1. Advanced Traffic Management System (ATMS)

The first trial of an ATMS in India was introduced in the city of Chennai, Tamil Nadu, in 2009; this involved a trial run of the fully automated traffic regulatory management system (TRMS), involving the usage of surveillance cameras. Automatic number plate reader (ANPR) cameras were installed, while pan tilt zoom (PTZ) cameras were deployed in ten out of twelve busy junctions identified. Traffic police also planned to install forty CCTV cameras at various junctions.

2. Advanced Public Transportation System (APTS)

One application implemented in the APTS areas is the GPS vehicle tracking system in public transport buses (Bengaluru, Chennai, and Indore) to monitor vehicle routing and frequency so that passengers' waiting time for buses is reduced and there is less uncertainty and frustration. Display boards with high quality LEDs in wide-view angle are provided at bus stops so that passengers can read the information easily. It displays the number and destination of the approaching bus, expected time of arrival, and messages of public interest.

3. Automated Traffic Control (ATC)

ATC has been set up in many cities in India, including Delhi, Pune, Mumbai, and Chennai. The ATC project of Mumbai focused on synchronizing major junctions with financial aid from the World Bank. Similarly, the Chennai traffic police set up the city's first ATC system at twenty-six major traffic signals around the new secretariat complex. The system monitors and regulates traffic without any manual intervention and helps police regulate VIP routes.

4. Automatic Traffic Information Service (ATIS)

The main objective of implementing ATIS is to inform road users of latest traffic updates and better management of traffic through SMS, the internet, and radio. A few cities, like Bengaluru (through the internet and SMS), Hyderabad (through the internet and SMS), Chennai (through FM radios) and Delhi (through the traffic people), have initiated technology-enabled traffic information systems.

5. Bus Rapid Transport System (BRTS)

In India, the cities that have been selected for implementing BRTS include Ahmedabad, Bhopal, Rajkot, Pune, Jaipur, Indore, Vijayawada, and Vishakhapatnam. Pune was the first to experiment with a BRTS but the Ahmedabad BRTS is the earliest and most successful rapid transport system in terms of public adoption. In 2009, the Ahmedabad BRTS became India's first fully featured BRT service with median stations, central control, level boarding, signal priority, vehicle tracking, and automatic fare collection.

6. Electronic Toll Collection (ETC)

The ETC is designed to detect if a vehicle is registered in a toll payment program. It alerts enforcers to toll payment violations and debits the exact fee from the user account. The technologies used in ETC are automatic vehicle identification (AVI), automatic vehicle classification (AVC), video enforcement system (VES), and vehicle positioning system (VPS). ETC systems are deployed in the cities of Kharagpur (NH 6 Toll Road), Ahmedabad-Mumbai Highway (RFID-based), Chandigarh (pilot project on Chandigarh), Parwanoo (NH 5), Delhi (Delhi–Gurgaon Expressway), and Chennai (IT Corridor).

7. Advanced Parking Management System (APMS)

The first parking management system was set up by the New Delhi Municipal Council (NDMC) at Palika Parking, in Connaught Place, having a capacity of 1,050 cars and 500 two wheelers, with electronic parking guidance and VMS smart card. This system permits vehicle users to be guided by a wide range of sensors, lights, signboards, and directional displays to the closest vacant space existing in the parking lot and to identify the vehicle's location at the time of exit. Also, automated multi-level parking in Sarojini Nagar Market was established.

8. B-TRAC Bengaluru

B-TRAC refers to the Bangalore Traffic Improvement Project, 2010. The five-year project began in 2010. The project was initiated by Bengaluru traffic police in the central area of Bengaluru city. The objective was to reduce traffic congestion by 30 %, reduce accidents by 30 %, achieve a significant reduction in pollution, achieve substantial compliance with traffic laws, and to set up an effective trauma care system.

The development and deployment of ITS is a strenuous task in all parts of the world. On the technology side, they have accurate and comprehensive real-time traffic data as their input. Various traffic detectors are commonly used all over the world, including sensors based on radar, magnetic, infrared, inductive, laser and video, AVI, VPS, and AVL. Even though these are proven and are widely accepted data collection technologies for traffic conditions, it is possible that they might not work for Indian traffic conditions due to various reasons such as inconsistency of vehicle types and the absence of lane discipline. It should be noted that for any data collection technique to be adopted in India, it must consider the heterogeneity of the users, the large number of pedestrians, the absence of lane-based traffic, and the synchronicity of Indian roads, which consists of two-, three-, four-, and multiple-wheel vehicles. Sometimes, even stray animals on the streets are to be considered.

Issues and Challenges in ITS Development in India

The rapid growth of the Indian economy has resulted in an enormous increase in the use of personal vehicles. In 2007–08, alone, 9.6 million motorized vehicles were sold in India and, during the same period, the cumulative growth of the passenger vehicles segment in India was 12.7 % (Venajakshi, Ramadurai and Anand 2010). A World Bank study states that almost 600 million people will inhabit Indian cities, while only about twenty cities, with an overall population of about half a million, are expected to have an organized public transport system. It is expected that India will surpass China as the fastest growing car market within the next few years. The economy-induced automobile growth is coupled with extensive rural-to-urban migration, making the situation more critical and leading to a greater demand for transport infrastructure. In 2001, India had thirty-five cities with a population of more than one million, which has been increasing continuously, indicating a need for urgent attention towards the improvement and management of the transportation system through the application of ITS in Indian cities. Several small-scale ITS projects have already been introduced in various cities in India and a few are underway, but most of these are single-city pilot projects focused on isolated deployments. To date, there is no fully developed comprehensive ITS application in India. It shows that much more needs to be done towards the adoption and implementation of ITS projects in India. As per the study conducted by the World Bank, the deployment of ITS in the developing world (including India) faces some significant complications that must be addressed if ITS are to be widely applied. However, the lack of adequate research as well as concern for cost effectiveness are still global challenges (Krishnan, Winnie and Diehl 2015). The following are the core reasons behind the lack of ITS development in India:

1. Interoperability: In multi-agency projects, the various client agencies may not have any mandate to share data, and, even if exchanged, it may not conform to standardized formats.
2. Data analysis: Even when data systems are integrated and standardized, the capacity of agencies in developing countries, like India, is often challenged by the task of analyzing raw data, which yields useful results.
3. Documenting effectiveness: The relationship between ICT and transport benefits has not received enough systematic research.

Some of the main issues facing the deployment of ITS in developing countries, like India, are an underdeveloped road network, explosive urbanization and growth, lack of resources for maintenance and operation, severe budget restrictions, less demand for automation, lack of interest among government decision makers, and lack of users' awareness; a list is presented in **table 1.1.2**. There are some inherent challenges and threats present in the Indian transportation system that need to be addressed before making any further way for implementing ITS in urban areas (Grant Thornton 2016).

Inadequate and inefficient public transport infrastructure	**Transport emissions and air quality**	**Inadequately implemented ITS**
Inadequate and insufficient public transport. Traffic and road congestion.	Emission of greenhouse gases. India is still following BS IV as opposed to EURO 6, implemented in European countries, which is equivalent to BS VI.	Inadequate setups for electronic toll collection and traffic monitoring. Very few ITS and multi-level parking systems.

Table 1.1.2: Inherent Challenges Present in the Indian Transportation System
Source: Authors' compilation

ITS have a very wide range of applications but in the Indian context the challenges of traffic sensing applications emerge as the priority. The ITS technique of traffic sensing can be broadly classified into two categories:

1. **Fixed sensor-based techniques**

This technique uses various sensors that are mounted on the roadside infrastructure. These sensors are often referred to as roadside units (RSUs). The two main techniques under this are:

Dual-loop detector-based congestion detection

In this method, a pair of inductive loop detectors are used, which re-identify the vehicles based on their length. It measures the time taken by the reidentified vehicle to travel between two detectors, which, in turn, gives an estimate of the congestion present on the road section. This technique requires a large number of detectors to be installed along the road, resulting in extensive capital investment. Furthermore, the algorithm of these systems is often developed with the assumption that consecutive vehicles maintain a lane-based approach for a long distance, which becomes an unrealistic assumption in the Indian context, where over taking and random halting of public vehicles is a common scenario.

Image sensor-based congestion detection

This method uses image-processing techniques, based on the feeds from CCTV deployed, to measure the amount of congestion. The level of congestion is identified by the time duration taken for an image to change. With constant advancement in technologies, various deep learning algorithms are being implemented in this method to improve its effectiveness. Yet, there are challenges in terms of placement and distribution of cameras to capture the disorderly traffic on the Indian roads.

2. Probe vehicle-based techniques

Probe vehicles refers to vehicles that are installed with various sensors, like GPS, accelerometer, gyroscope, etc., to measure traffic conditions, road situations, etc. It usually employs two methods: a predictive approach and a localization approach.

Techniques	**Installation cost**	**Lane system assumption**	**Freeway traffic assumption**	**Low variation in vehicle speed assumption**
Dual-loop detector-based congestion detection	High	Yes	No	No
Image sensor-based congestion detection	High	Yes	No	No
Travel time prediction for freeways	Low	No	Yes	Yes
Cellphone-based travel time prediction	Low	Yes	Partial	Yes
Kalman filtering technique (KFT)-based bus arrival time prediction	Low	Yes	No	Yes

Table 1.1.3: Reasons for the Inapplicability of Various ITS Techniques in the Indian Context
Source: Sen *et al*. (2009)

Table 1.1.3 is a tabulation for the reasons for the inapplicability of various ITS techniques in the Indian context. The traffic condition in India is highly uncertain, chaotic, and faces heavy congestion. The deployment of conventional ITS techniques, prevalent in developed nations, requires