Use of geospatial technologies in transport infrastructure

A white paper from the Association of Geospatial Industries
Rajesh Krishnan
Yogita Shukla

Use of geospatial technologies in transport infrastructure

A white paper from the Association of Geospatial Industries
Executive Summary

This is a white paper from the Association of Geospatial Industries (AGI) that examines the scope for the application of geospatial, positioning and location measurement technologies in India’s transport sector. The term Geospatial Technology refers to a wide range of techniques and processes ranging from the acquisition, measurements, processing, analysis and dissemination of geospatial data to its usage and maintenance. Technologies, methods and systems such as surveying (including hydrographic surveying), Global Navigation Satellite System (GNSS), remote sensing, aerial photography, LiDAR, photogrammetry, GIS, cartography and construction automation using machine control solutions fall under the umbrella of geospatial technologies. These technologies can be applied to save time, reduce costs, improve safety, quality, governance and environment during planning, design, construction, operation and maintenance of transport infrastructure in highway, railway, aviation and maritime and inland navigation sectors. There are a number of real-world examples illustrating how the above benefits can be achieved by means of applying geospatial technology in transport infrastructure projects. With a huge focus on improving the transport infrastructure in India over the next decade with documented plans by the government for investing Rs. 17,48,685 Crores over the next five years, there is a clear scope for the geospatial industry to play a constructive role in this nation building exercise.
It gives me immense pleasure to present this white paper on the **Use of geospatial technologies in transport infrastructure** from the Association of Geospatial Industries (AGI).

Transport Infrastructure is one of the major drivers for the growth and economic development of any country. This document talks about the role of Geospatial technologies in fostering the sustainable development of transport infrastructure in India. Over the years India has witnessed a progressive growth; sustaining this growth requires a robust and world class transport infrastructure that will empower the 1.2 billion population of our nation and connect the remotest of the villages. This needs not just state-of-the-art construction technologies but application of Geospatial technologies that can help save time, reduce cost by optimising resources at every stage of infrastructure development as well as maintenance during its entire life cycle.

Geospatial technologies contribute towards saving time, reducing project costs, improving safety and quality as well as protecting the environment during the different phases of infrastructure development. Once the geospatial information is available, it becomes very valuable in the maintenance of the large infrastructure investments that have been made. This white paper also includes the technology benefits through case studies for each phase from planning, design and construction to operation and maintenance in highway, railway, aviation, maritime and inland navigation sectors. **With an investment of about a trillion dollar in the infrastructure sector for the twelfth five year plan period, we at AGI feel that it is essential for the programmes to leverage critical Geospatial technologies and solutions to contribute to nation building.**

This paper is an AGI effort to reach out to both the transport sector and geospatial industry to join forces and work together with the government in building a sustainable transport infrastructure across India. The transport sector can look forward
to gaining a deeper insight as to how these technologies can be applied in the sector and more importantly the key benefits that can be gained by its application. For the geospatial industry, this white paper aims to provide potential application areas and case studies of technology applications in the transport sector in India.

K. K. Singh
President of the AGI
Contents

Executive Summary i
Preface iii
Contents v
List of Figures ix
List of Tables xi

1 Introduction 1
  1.1 Objective of the white paper  ........................................... 1
  1.2 Guide for the audience ................................................... 2
    1.2.1 Policy makers and bureaucrats ...................................... 2
    1.2.2 Transport sector professionals ...................................... 2
    1.2.3 Geospatial technology professionals ................................. 2

2 Introduction to geospatial technologies 3
  2.1 Data acquisition ............................................................ 4
    2.1.1 Survey technologies .................................................. 4
    2.1.2 Global Navigation Satellite System (GNSS) ...................... 4
    2.1.3 Automated GNSS Survey techniques ................................. 7
    2.1.4 Hydrographic surveying .............................................. 8
    2.1.5 Remote sensing ........................................................ 9
    2.1.6 Aerial photography ................................................... 10
    2.1.7 LiDAR and other terrestrial scanning technologies ............. 14
### Table of Contents

#### 2.1.8 Summary

#### 2.2 Data processing and analysis

2.2.1 Photogrammetry

2.2.2 GIS

---

### 3 Transport and infrastructure market in India

3.1 Indian transport and infrastructure market

3.1.1 Roadways

3.1.2 Railways

3.1.3 Aviation

3.1.4 Maritime and inland navigation

3.1.5 Summary

3.2 A few ongoing and upcoming Indian government initiatives in the transport sector with geospatial technology scope

3.2.1 Road sector

3.2.2 Rail sector

3.2.3 Aviation sector

3.2.4 Maritime and inland navigation

---

### 4 Application of geospatial technologies in transport

4.1 Transport planning

4.1.1 Transport planning for roads, rail and aviation

4.1.2 Transport planning for the maritime sector

4.2 Design and construction

4.2.1 Engineering design

4.2.2 Construction

4.3 Operation and maintenance

4.3.1 Roadway and railway sectors

4.3.2 Aviation

4.3.3 Maritime and inland navigation

4.3.4 Transport infrastructure security

4.4 Generic opportunities for geospatial technologies in transport

4.4.1 Roadways and railways

4.4.2 Aviation
### 4.4.3 Maritime and inland navigation

### 4.5 Case studies for the application of geospatial technology in the transport sector

<table>
<thead>
<tr>
<th>Subsection</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5.1 Road sector</td>
<td>51</td>
</tr>
<tr>
<td>4.5.2 Railways</td>
<td>54</td>
</tr>
<tr>
<td>4.5.3 Aviation</td>
<td>55</td>
</tr>
<tr>
<td>4.5.4 Maritime and inland navigation</td>
<td>56</td>
</tr>
</tbody>
</table>

### 5 Conclusion

- Bibliography 61
- Appendix 65
  - A Breakdown of estimated transport infrastructure investment 65
  - B Remote sensing satellites and available data 67
  - C OGC initiatives in the transport sector 71
List of Figures

2.1 Beacon stations installed during Phase One of the Indian Beacon DGPS Network .............................................. 7
2.2 A schematic depiction of vehicle mounted data collection ............ 8
2.3 Major components of an analogue aerial photography camera .......... 12
2.4 Schematic of a digital aerial photography camera ...................... 13
2.5 Linear Array Camera System ........................................ 13
2.6 Panorama Camera ....................................................... 14
2.7 Typical data layers used in a GIS system .............................. 18
2.8 Schematic Depiction of Enterprise GIS ................................. 22

3.1 Relative share of estimated infrastructure investment in different transport sectors ....................................... 28

4.1 Illustrative screen shot of a GIS based warehouse location system (Source Hancock (2008)) ................................. 35
4.2 Life-cycle of transport infrastructure construction projects ........... 38
4.3 An early concept diagram of construction automation using machine control solutions (Source: Society of Civil Engineers, Construction Robotics Commission, Prof. Shigeyuki Obayashi, 1985) ................ 40
4.4 Augmented reality display of marine construction automation equipment (Source: Hirabayashi et al. (2006)) ................... 42
4.5 Illustrative example of data required for transport-pollution models in the roadway sector(Source: Wang et al. (2008a)) ............. 45
# List of Tables

<table>
<thead>
<tr>
<th>Table No.</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Summary of data acquisition methods and their output</td>
<td>16</td>
</tr>
<tr>
<td>3.1</td>
<td>Categorised estimated investment in transport infrastructure in the</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>next five years</td>
<td></td>
</tr>
<tr>
<td>4.1</td>
<td>Applications of geospatial technology in roadway and railway sectors</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>during planning and design phases</td>
<td></td>
</tr>
<tr>
<td>4.2</td>
<td>Applications of geospatial technology in the aviation sector</td>
<td>49</td>
</tr>
<tr>
<td>4.3</td>
<td>Applications of geospatial technology in maritime and inland navigation sector</td>
<td>50</td>
</tr>
<tr>
<td>A.1</td>
<td>Estimated infrastructure investment in the roadway sector over the</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>next five years</td>
<td></td>
</tr>
<tr>
<td>A.2</td>
<td>Estimated infrastructure investment in the railway sector over the</td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>next five years</td>
<td></td>
</tr>
<tr>
<td>A.3</td>
<td>Estimated infrastructure investment in the aviation sector over the</td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>next five years</td>
<td></td>
</tr>
<tr>
<td>A.4</td>
<td>Estimated infrastructure investment in the maritime sector over the</td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>next five years</td>
<td></td>
</tr>
<tr>
<td>B.1</td>
<td>List of commercial remote sensing satellites</td>
<td>68</td>
</tr>
<tr>
<td>B.2</td>
<td>List of multi-purpose Indian remote sensing satellites</td>
<td>69</td>
</tr>
<tr>
<td>B.3</td>
<td>List of Indian remote sensing satellites: IRS Series</td>
<td>70</td>
</tr>
</tbody>
</table>
This white paper from the Association of Geospatial Industries (AGI) examines the scope for the application of geospatial technology including, positioning and location measurement in India’s transport sector. The paper provides an overview of these technologies, followed by the scope for the application of these technologies in the transport infrastructure sector, including the size of the potential market opportunity. The highway, railway, aviation and maritime sectors are included within the umbrella of transport infrastructure in this paper. The application of geospatial technologies in these sectors are categorised into planning & design, construction and operation & maintenance, with specific examples and case studies. The paper also contains a reference list that will help users to identify materials for further reading and better their understanding of this topic.

1.1 Objective of the white paper

This paper is intended for audience in both the geospatial industry and the transport sector. It is hoped that transport industry personnel will gain an understanding about the capabilities offered by geospatial technologies, and insight into how these technologies can be gainfully applied in the sector. On the other hand, people in the geospatial industry can use this white paper to understand the potential scope for the application of their technology in the transport sector. The white paper provides a number of case studies illustrating the application of geospatial technologies in the transport sector and associated benefits. These should help decision makers in the transport sector identify situations where they can use geospatial technologies to: (a) save time, (b) cut costs, (c) improve quality, (d) increase safety, (e) enhance governance and (f) help benefit the environment.

---

1This document is optimised for online reading. Many of the references and external links are hyper-linked, and these are accessible with the click of the mouse when reading online.
1.2 Guide for the audience

1.2.1 Policy makers and bureaucrats

Policy makers and bureaucrats can gain an understanding of the breadth of geospatial technologies available and what they can offer in Chapter 2. This understanding can be further enhanced by example applications of geospatial technology in the transport infrastructure area, both from generic themes in Section 4.4 and specific case studies in Section 4.5, given in Chapter 4. Summary points given in Chapter 5 will also be helpful for policy makers. We hope that policy makers and bureaucrats will gain an appreciation of the benefits of using geospatial technology to improve quality and reduce costs of our nation’s infrastructure building programme, and be able to mandate the use of appropriate technology for upcoming infrastructure projects for overall gain.

1.2.2 Transport sector professionals

Transport sector professionals can gain an understanding of what geospatial technology can offer in Chapter 2. Information about the choice of available technology will help transport professionals to understand the benefits and make technology investment decisions. An overview of common applications of geospatial technology in transport given in Section 4.4 is intended to help further this understanding, and practical examples provided in case studies in Section 4.5 will help further this understanding. Decision makers in transport sector who are pressed for time can directly go to the case studies in Section 4.5 to see practical examples of the benefits gained by using these technologies and the corresponding Return on Investment (ROI).

1.2.3 Geospatial technology professionals

Leaders in geospatial technology companies will gain an understanding of the size of the potential market as well as specific opportunities of their technology in the transport sector in Chapter 3. Examples and case studies given in Sections 4.4 and 4.5 will help sales people in geospatial companies to understand the transport context and help position their solutions to solve problems that are relevant to the transport industry. Information in Chapter 5 should provide practical advice to geospatial technology professionals to address the opportunities for their solutions in the transport sector.
Chapter 2

Introduction to geospatial technologies

The term Geospatial Technology refers to a wide range of techniques and processes ranging from the acquisition of geospatial data, position measurement, post processing of geospatial data, spatial analysis, creation and use of databases to manage geospatial data obtained from different sources, data maintenance and finally its usage. A number of scientific methods, software and hardware are required for each of the above functions that fall under the agies of geospatial technologies. Geospatial technologies can be broadly divided into three categories: technology for data acquisition, technology for data assimilation, processing & analysis and technologies that enable the use of geospatial technologies in different application contexts.

Geospatial data measurement technologies range from traditional surveying to GNSS to advanced surveying tools such as total stations including robotic total stations that can be controlled remotely, laser levels, 3D laser surveying, various sensors such as gyroscopes, accelerometers and inertial measurement units, remote sensing and aerial photography. Data acquired through these techniques are spatial in nature. These datasets need to be post processed and combined with non-spatial data for different usage contexts. For example, orthophotos are created by correcting for geometric distortions in aerial photography images for using in mapping systems such as the Open Street Map. The geospatial data, once corrected and referenced with other data sources, can be used in a number of application contexts; e.g. construction automation and tunnel construction. The rest of this chapter provides an overview of different geospatial technologies categorised into data acquisition and data processing & analysis.
2.1 Data acquisition

2.1.1 Survey technologies

Surveying is the art as well as the science of measuring the surface of the earth and its features. It is used for determining the three-dimensional position of objects on the earth’s surface based on the measurement of distances and angles between them. These measurements are then used to portray them in an understandable form such as maps or drawings.

Surveying techniques vary depending on whether they take into consideration the true shape of the earth (geodetic) or treat the earth as a flat surface (plane). Surveys are also categorised into horizontal and vertical based on positioning features on the ground (horizontal surveys) or determining the elevation or heights of features (vertical surveys) or a combination of both. Transportation sector use surveying and mapping techniques extensively in different stages from planning to construction. Cadastral surveys are carried out while planning and constructing highways, railways, airports and seaports wherein a detailed plan or layout of the assets to be constructed is also done.

Surveying can be carried out using a range of tools, ranging from traditional tools such as compass and chain, transit and tape or transit and stadia as well as modern tools such as theodolite, total station and Global Navigation Satellite Systems (GNSS). The advent of new tools and technology with more precision and accuracy has reduced the use of traditional survey tools and methods. Most surveying work is done using total stations and GNSS now-a-days.

Total station is a surveying instrument used for land surveying and mapping. It is a multi-purpose electronic instrument with a built-in electronic distance measurement (EDM) capability. It is capable of measuring horizontal distances, slope distances, angles, vertical height differences, three-dimensional coordinates and a number of other positional features. While some of the total station models feature internal electronic data storage to record the measured data, others are equipped to write these measurements into an external data storage device. Some of the total stations also come with a GNSS interface which combines the advantages of these two technologies; information about GNSS assisted surveying is given in the next sub-section 2.1.2.

Surveying plays a very important role in the planning and building of highways, railways, airports and seaports. Accurate measurement of the landscape is crucial to establishing the location and alignment of transport infrastructure, and indeed that of all man-made structures.

2.1.2 Global Navigation Satellite System (GNSS)

GNSS is a generic term for satellite based positioning systems that provide the geographic location of a receiver device anywhere in the world. GNSS systems consist of a constellation of satellites whose positions are known in advance. Receiver devices measure the distance (range) between visible satellites and self and determines its current location using the principle of trilateration.
Each satellite in the system transmits coded signals at precise intervals which are converted by the receiver into position, velocity, and time estimates. With this information, any receiver on or near the earth’s surface is able to calculate the distance (from the transmission time delay) between the satellite and the receiver. A receiver determines its position using signal data from three or more satellites.

Two GNSS systems are currently operational: the NAVSTAR Global Positioning System (GPS) of United States and the Russian Federation’s Global Orbiting Navigation Satellite System (GLONASS). Two more GNSS systems are currently under development: Europe’s Galileo and China’s COMPASS (global version of their regional Beidou). The Global Positioning System (GPS) consists of a network of 24 operational satellites (as in June, 2009 there are 31 satellites in orbit) placed into orbit by the U.S. Department of Defence. GPS was originally intended only for US military applications, which was subsequently made available for civilian use. It works in any weather conditions, anywhere in the world, 24 hours a day. There are no subscription fees or setup charges to use GPS.

The Russian owned GLONASS system is an alternative to the US owned GPS system and it works using similar data transmission and positioning methods. It is managed by the Russian Space Forces and operated by the Coordination Scientific Information Centre (KNITs) of the Ministry of Defence of the Russian Federation for the Federation. GLONASS has a constellation of 21 satellites to provide location information to the user on earth surface.

The positional accuracy obtained using the GNSS technology depends upon the type of instrument used and the data processing techniques. Consumer grade GPS devices generally provide 15m nominal position accuracy. A number of factors contribute to the error such as inaccuracies in the GPS receiver clock, atmospheric distortion of GPS signals and multi-path error. The accuracy of GPS based locations can be further improved by using dual-frequency GPS receivers, ground based augmentation systems and space based augmentation systems.

### 2.1.2.1 Dual frequency GPS receiver

GPS satellites transmit signals in two different frequencies. By comparing the time delay between these two signals, it is possible to estimate atmospheric distortion and correct for it. In Dual-frequency RTK (Real Time Kinematic) GPS configurations, a fixed-location reference receiver (commonly referred to as a base station) is deployed to provide real-time corrections for atmospheric influences. In a construction site scenario, the base station receiver is typically located to ensure the base-to-rover receiver distance does not exceed 20km. In this arrangement, accuracies of around 1cm in position and 2cm in elevation are reliably achievable. This has immediate benefit for precise real-time surveying and real-time machine control applications, further enhancing savings through more precisely set-out and constructed works (materials, time and labour optimisation).

---

1Satellite signals get reflected by surfaces such as buildings before reaching the GPS receiver.
2.1.2.2 Ground based augmentation

Ground Based Augmentation Systems (GBAS) are known as Differential Global Positioning Systems (DGPS). DGPS consist of a network of ground-based reference points at known locations, and broadcast the difference between known reference locations and the position calculated using the GNSS system. These corrections are transmitted locally using ground based transmitters of short range.

In India, the Director General of Lighthouses and Lightships (DGLL) prepared a specification for an advanced DGPS network using radio beacons for direction finding application. The specified network would meet all international standards, and would provide excellent accuracy and operational availability even under adverse conditions. The Indian Beacon DGPS Network started off with 10 stations shown in Figure[2.1] in Phase One, and it currently has 22 stations in India. The reference receivers and integrity monitors meet the latest RSIM and RTCM message standards, are extremely rugged, and are designed for continuous unattended operation. The frequencies allocated are in the range of 283.5 - 325.0 KHz. Depending on the radiated power and environmental conditions, the beacon signals have a range from 10 - 200 NM. Beacon systems have a number of advantages for broadcast of DGPS corrections. They are in place and maintained, have broad existing coverage, have the necessary frequency allocation, are relatively inexpensive to purchase and operate, and have sufficient power to provide an adequate range for coastal navigation.

The corrections typically transmitted using the beacon are GPS L1 only corrections which can give an accuracy of 50 cm to 1 metre depending on the base line length. The Beacon corrections can be used with of the GPS receivers with an assisted beacon module. Typically the receivers can be used for a range of 300 kms towards the sea and 120 km towards the land. The application areas for this system include inland waterways hydrographic surveys, sub-metre GIS survey in available areas and port surveys.

The Inland Waterway Authority of India (IWAI) are also setting up a series of permanent reference points in close proximity to inland waterways to provide safe navigation, in consultation with DGLL. The proposed system is expected to assist navigation along the National Waterway network. More commonly, base stations at known locations are set up by surveying and civil engineering contractors using construction automation technology to provide differential correction in the vicinity of work sites.

2.1.2.3 Space based augmentation

Space based, or satellite based augmentation systems (SBAS) also have multiple ground stations at known locations situated at accurately surveyed points. Correction data calculated using these points are sent to a constellation of satellites and are broadcast back to end users.

The Indian Government is in the process of implementing an SBAS system called GAGAN. The system is implemented by the Airports Authority of India with the help of Indian Space Research Organisation. GAGAN is expected to be compatible
with major SBAS systems outside India, such as the European EGNOS, the American WAAS and the Japanese MSAS. GAGAN is expected to be operational by 2014 and will be able to provide positional accuracy of 3m in the Indian airspace. The system is mainly intended for use by the aviation industry.

2.1.3 Automated GNSS Survey techniques

Automated GNSS survey techniques have evolved as a new direction in GIS data collection. Most commonly used automated survey tools are Mobile GIS technology and Vehicle Mounted Imagery Collection. These techniques are fast gaining acceptance for application areas like asset management inventory, engineering survey and property assessment, asset condition assessment, mapping and GIS requirements.

2.1.3.1 Mobile GNSS technology

With recent technological advances in mobile computing, wireless communication, GNSS and software design, web based solution integrating geospatial technologies with mobile applications are being used to streamline and reduce the costs of data collection and updation. Mobile GIS converges technologies like GNSS, rugged
2.1. Data acquisition

Introduction to geospatial technologies

handheld computers and GIS software. This allows direct access to enterprise database whenever and wherever it is required. Updating data through mobile text messages received from field officers and incorporating the data along with location coordinates enables timely updating of the data sent by field officers. Also the data can be reflected on GIS maps which enable generating regular summarised and specialised reports for the analysers and administrative functionaries.

2.1.3.2 Vehicle mounted imagery collection

The vehicle-mounted imagery collection technique (see Figure[2.2]) uses a video camera and GNSS for the rapid field data capture of an area. This is further supported by processing software for data extraction and a GIS software for finishing the data processing. It provides a complete end-to-end solution for the GIS data capture and digitisation of Road/Highway/Railway alignments, assets and defects, field boundary measurement, agriculture surveys and vehicle tracking.

![Vehicle Mounted Data Collection](image)

**Figure 2.2:** A schematic depiction of vehicle mounted data collection

2.1.4 Hydrographic surveying

Hydrography has been defined by the International Hydrographic Organization (IHO) as the branch of applied science which deals with the measurement and description of the physical features of the navigable portion of the earth’s surface (seas) and adjoining coastal areas, with special reference to their use for the purpose of navigation.

Hydrographic Surveying is used to measure water depth, nature of the floor material (sand, mud or rock) and configuration of the water bodies. Equipment used for hydrographic surveys can be broadly classified into three: equipment to measure the depth, equipment to establish the position and equipment to measure the water level (e.g. automatic tide gauges). Data obtained from hydrographic surveys is processed to remove errors and are cleaned to prepare the output.

The hydrographic survey results are used to produce Bathymetric Charts, which visually represents points of equal depth using contour lines. Bathymetric charts are the submerged equivalents of above water topographic maps providing an accurate description of the submerged terrain. The contour lines on a bathymetric chart are spaced at 50, 100, 200 or 400 meters depending on the water depth. Hydrographic surveys can be broadly classified as Reconnaissance or Class 3 surveys, Project Condition or Design or Class 2 surveys and Contract Payment or Class 1 surveys. The accuracy level of the output will depend on the class of survey carried out:
Introduction to geospatial technologies

2.1. Data acquisition

Class 3 has the lowest accuracy, Class 2 has medium accuracy and Class 1 is the highest accuracy survey standard. The accuracy difference between these classes can be attributed to field procedures used for the survey. Techniques used for hydrographic surveying vary depending on the size of the area to be surveyed.

Hydrographic surveys are used to compile the nautical charts for navigating waterways across the globe. A nautical chart is a map that includes depth measurements and other critical information for safe navigation and ecological protection. The symbols on the nautical charts tell the captain of the ships or recreational boaters whether the area is too shallow or very much dangerous to operate the vessels or if they are going near sensitive marine sites. Hydrographic surveying is important not only for navigation, but also for anchoring, dredging, infrastructure construction, cable and pipeline routing and protection of the marine habitat.

Recent hydrographic survey datasets by most of the maritime nations are collected and processed digitally and built on a spatially enabled relational database. These can now be represented in a variety of units, formats and geographic projections. Moreover the database can also execute spatial operations on the data. Even the nautical charts are available in digital formats. The digital nautical charts are known as electronic nautical charts (ENC). Built on IHO’s S-57 standard ENC is a vector database of chart features to support navigation in real-time, provide collision and grounding avoidance requirements of the mariner, and provide a real-time tide and ocean current display which is essential for navigation of large vessels. The vector base maps from ENC can be used in geographic information systems (GIS) for coastal management or other purposes.

2.1.5 Remote sensing

Remote sensing is the art and science of obtaining information about any object using tools that are not in direct contact with the object. In this technique, an object is observed or monitored without being in physical contact; in other words, the information is obtained remotely. The most common example of remote sensing in our day-to-day life is our eyesight.

Remote sensing techniques are of two types: passive and active. This categorisation is based on whether the remote sensor relies on an external source of energy to obtain the information or the energy source is inbuilt within the sensor. Passive remote sensing uses energy source from external sources. Human eye and optical sensors are classic examples of passive remote sensing as they rely on an external light source. Most of the remote sensing carried out today use passive sensing, since it is easier and cheaper compared to active remote sensing. Passive remote sensors are mounted either on satellites or on aircrafts and are operated only when sunlight illuminates the area under observation.

Active remote sensing involves focusing an energy source on the object on which the observations are made. One of the widely known forms of active remote sensing is RADAR, where a single instrument emits radio waves and senses the reflected energy coming back from the target. Since the speed of radio waves and the time delay between emission and return are known, the distance between the source and the target can be determined. Light Detection and Ranging (LiDAR) is the optical
analogue of radar. A concentrated light beam from LiDAR equipment is emitted onto the target and the energy reflected back to the LiDAR receiver is measured. More details on LiDAR are given in sub-section 2.1.7.

Remote sensing using satellites as the sensor platform is referred to as satellite imaging; the term remote sensing is commonly used in this context. Today, there are many satellites in space that provide remote sensing data (satellite images) at different spatial resolutions. Data from satellites such as IKONOS, Quick bird, CARTOSAT, GEOEYE, WORLDVIEW offer a high spatial resolution ranging from 50 cm to 1 m\(^2\). Datasets from satellites such as SPOTVEGETATION, NOAA-AVHRR, OrbView 2 have a spatial resolution of 1-4 km. Satellites such as Landsat and IRS provide data with a spatial resolution of 25-35 metres and satellites such as MODIS and IRS-WIFS provide data at a medium resolution ranging between 150-250 metres. A list of commonly known remote sensing satellites is given in Appendix B.

Temporal resolution\(^3\) of data from different satellites also varies; satellites provide data on daily, weekly, fortnightly or monthly basis. Remote sensing data from satellites also vary in terms of spectral bands\(^4\). Remote sensing data available in black and white is known as panchromatic data. Multi spectral data\(^5\) from different satellites provide data in several spectral bands ranging from visible and infra-red regions to far infrared regions of light energy. Details regarding the data available from multiple satellites are also given in Appendix B.

### 2.1.6 Aerial photography

**Aerial Photography** is a remote sensing technique where photographs of earth surface are taken from an elevated position or where the sensor is mounted on an aircraft, helicopters, balloons, kites, etc. Aerial photography can also be carried out using radio-controlled model aircraft for low altitude aerial photography. The aircraft are equipped with accurate location sensors and follow a preplanned flight path at a planned altitude and speed, and photographs are taken at regular time intervals determined based on the above parameters. Different types of photographs are produced using aerial photography.

- **Oblique photographs:** Photographs taken at an angle are called oblique photographs. Oblique photographs are used to created 3D models of cities and other locations. A combination of rigid vertical and oblique cameras are mounted on an aircraft for simultaneous image capture. These images capture the fronts and sides of buildings and locations on the ground, and can be stitched together to create composite aerial maps that seamlessly span many kilometres of terrain. Each pixel in the composite aerial map is georeferenced and can be used to create rich GIS applications.

---

\(^2\)Spatial resolution is defined as the minimum distance between two objects that can be distinguished using satellite data

\(^3\)The frequency at which a satellite re-visits a given location in its orbit

\(^4\)The electromagnetic frequency spectrum captured by the satellite image

\(^5\)Multispectral image captures data at specific frequencies across the electromagnetic spectrum. Multi-spectral images captured by remote sensing satellites and are used for visualising and analysing vegetation coverage, water coverage, soil moisture content etc.
• **Vertical photographs**: Vertical photographs are taken straight down (nadir view) and are used mainly in photogrammetry and image interpretation.

Aerial photographs are used for preparation of topographic maps, cadastral surveys and civil engineering projects. In India, aerial photography is permitted subject to Ministry of Defence (MoD) clearance.

### 2.1.6.1 Camera technology used for aerial photography

Cameras with different levels of precision for aerial mapping are available in the market today. They are photographic instruments with finely adjusted precision and meticulously polished lens. These cameras systems are available in both analogue and digital formats. The cameras are mounted on the floor of the aircraft with their centre over a hole at the bottom of the aircraft. The camera is able to rotate horizontally and can be tilted in two directions by several degrees to compensate for inconsistencies in the flight attitude.

Analogue cameras used for aerial photography have a detachable magazine that fits on top of the camera cone and contains two reels of film. There is a frame of unexposed film that lies along the underside of the focal plane. A lens cone separates the lens assembly from the focal plane. The camera shutters are made as a series of thin metal plates which overlap with one another, as shown in Figure.[2.3].

As the aircraft proceeds along the flight path, the camera also moves forward. Since the film is not moving within the camera during exposure, the movement of the camera platform during the exposure period can cause blurring of the image. Camera mounting systems that reduce this blurring effect and the blurring caused due to the vibrations of the aircraft are typically used in aerial image platforms. Camera calibration reports are generated periodically by precision aerial mapping cameras and submitted for approval to assure that the cameras are working consistently in the expected manner.

Digital camera systems are very much similar to the analogue camera systems in that they also collect images in black and white, natural colour and colour infrared imagery. However, the distinguishing features between analogue and digital camera systems are the charge coupled device (CCD) and the digital image storage device. Unlike analogue cameras which use film, the digital camera systems record an image on a CCD as a matrix of pixels, as illustrated in Figure[2.4]. The benefits with digital images are that they can be incorporated as a softcopy into a computer soon after data collection and intermediate steps like film processing and printing are not required before data manipulation and analysis.

The CCD used in aerial photography digital cameras vary in storage capacity and resolution, thereby affecting the clarity of the digital image. One can improve upon the clarity and resolution of an image by capturing it at lower altitudes. However this increases the number of image files for a specific project ground area and require higher image storage capacity. Recent advances in CCD development, computer

---

6 Seven copies of the application form need to be submitted to the Director General of Civil Aviation in order to obtain the required clearance

7 Inclination of the three principal axes of an aeroplane in flight to the relative wind
2.1. Data acquisition

Introduction to geospatial technologies

Figure 2.3: Major components of an analogue aerial photography camera

Processing and data storage capacities have started making digital camera systems competitive with analogue systems for several projects.

Digital aerial cameras can be classified broadly into four categories: linear and area-array solutions, oblique camera systems and panorama cameras, based on the technology. Array based cameras are further classified into small, medium and large format cameras. Typical applications for small-format cameras are corridor mapping, updating site maps, engineering projects and as image-acquisition device operating alongside airborne LiDAR scanners. Large format cameras address metric accuracy requirements for bulk topographic and cadastral mapping of larger areas. Linear array cameras, as illustrated in Figure[2.5], are also used for accurate mapping and remote sensing applications, as the sensors in these cameras collect RGB\(^8\) and NIR\(^9\) imagery simultaneously to acquire and process imagery over large areas in limited time.

\(^8\)Red, Green and Blue
\(^9\)Near-Inra Red
Pictometry has popularised the use of oblique imagery of urban areas. In addition to vertical, oblique images are also taken, enabled by a sensor system configured with five cameras, one directed nadir, the others viewing forward, backward, left and right. The shape of the ground covered is captured simultaneously by the five cameras. Depending on the along-track and across-track overlap, each point on the ground may be visible in dozens of images, provided there is no occlusion. The five cameras are mounted rigidly together and their geometric configuration is calibrated to enable accurate measurements in both the vertical and oblique images. The main advantage of oblique images over vertical is better and more intuitive interpretation, making photogrammetry accessible to non-professionals.
2.1. Data acquisition

Introduction to geospatial technologies

images show parts of buildings and other structures invisible in vertical images, making them useful for 3D cadastral applications, determining property taxes and providing building permits. Geo-referenced oblique images are also useful for highly automatic creation of 3D city models in combination with airborne LiDAR and planar topographic maps containing building outlines.

Panorama camera is an oblique camera that deviates from the above design. It has been developed so as to reduce flying and processing costs; see Figure[2.6] for an illustration. The latter is achieved by automation of all processes, from flight planning to triangulation, from DEM generation to ortho image creation.

![Panorama Camera](image)

Figure 2.6: Panorama Camera

2.1.7 LiDAR and other terrestrial scanning technologies

Light Detection and Ranging, more commonly referred as LiDAR, is a technology that utilises lasers to determine the distance to an object or surface. LiDAR sensors record the time difference between the emission of the laser beam and the arrival of the reflected laser signal from a given object. LiDAR has applications in a number of fields such as geomatics, archaeology, geography, geology, geomorphology, seismology, forestry, remote sensing, atmospheric physics and the transport sector. LiDAR mapping can be either airborne or terrestrial.

In airborne LiDAR, a pulsed laser ranging system is mounted on an aircraft which is equipped with a precise kinematic GPS receiver and an Inertial Navigation System (INS). The laser beam is emitted by a diode that produces a light source at a very specific frequency. This laser beam is sent towards the earth where it is reflected off a feature back towards the aircraft. A receiver mounted on the aircraft then captures the return pulse. The distance to the feature is measured by the time
the signal takes to travel from the aircraft to the object and back to the aircraft since the speed of light is known. Airborne LiDAR is also referred to as Airborne Laser Terrain Mapping (ALTM) since it is able to capture parameters that provide required information to create a Digital Terrain Model (DTM). Murakamimi et al. (1999) examined the accuracy of LiDAR measurements and showed that it has the vertical accuracy of 10-20 centimetres and the horizontal accuracy of approximately 1 metre. Like aerial photography, air borne laser mapping is also subject to MoD clearance in India.

Terrestrial or ground-based LiDAR is a modern technology with applications in diverse fields from forests to geology to infrastructure and utilities. It is also referred to as 3D laser scanning and employs a laser and rotating mirror(s) to rapidly scan and image surface features such as rock slopes and outcrops, trees, buildings, bridges and other natural and man-made objects. It is used for creating three dimensional topographical maps and surveys of geographical regions, industrial plants and buildings. Ground-based or terrestrial LiDAR use tripod-based measurements unlike airborne LiDAR measurements which are made from aeroplanes or helicopters.

The output from ground-based LiDAR is available as a point cloud consisting of millions of laser distance measurements which represents the three-dimensional scanned scene. These point clouds are then processed to extract as-built information. High-resolution digital images of the scanned scene are also taken, which can be draped onto the point cloud using texture-mapping techniques to provide a 3D colour DTM of the scanned scene. The DTM provides additional information which would otherwise be difficult to observe in the point cloud.

Ground-based LiDAR has applications in a number of areas, and detailed three dimensional output from ground-based LiDAR can be used as input into 3D discontinuum models\textsuperscript{10}. In the transport sector, it can be used for preparing as-built drawings of the terrain as well as existing assets. Laser scanning technology has become an essential tool for capturing and maintaining accurate asset information. Although the process of creating 3D asset models from legacy information can be time consuming and expensive, once prepared it helps in maintaining optimal workflow for the management and maintenance of these assets. This eventually reduces the total effort by 70% over past practices as mentioned by several studies.

LiDAR is used in the transport sector for Adaptive Cruise Control (ACC) systems in automobiles. A LiDAR device mounted on the front of a vehicle is used to measure the distance to the vehicle ahead. If the measured distance falls below a threshold, the ACC system reduces the speed of the vehicle; otherwise, the vehicle proceeds at a pre-set speed specified by the user.

\textsuperscript{10}Discontinuum modelling refers to 3D simulation techniques in geo-mechanics where the discontinuity and to some extent interactive coupling of slope and hydraulic response is taken into consideration for design analysis of slopes (generally rock slopes). It is an iterative process that allows the improvement of the numerical model as well as the measurement system to provide a decision making capability at different stages of design and construction of various civil engineering structures.
2.2. Data processing and analysis

<table>
<thead>
<tr>
<th>Technology</th>
<th>Output</th>
<th>Example uses in transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surveying</td>
<td>Maps</td>
<td>Preparation of site drawings, designs, transport network maps</td>
</tr>
<tr>
<td>Hydrographic surveying</td>
<td>Bathymetric charts</td>
<td>Navigation aid for ships and boats</td>
</tr>
<tr>
<td>GNSS</td>
<td>Location measurements</td>
<td>Navigation in road, aviation and maritime sectors</td>
</tr>
<tr>
<td>Remote sensing</td>
<td>Topographic maps, digital elevation models</td>
<td>Monitor land-use patterns, construction automation, air traffic control</td>
</tr>
<tr>
<td>Aerial photography</td>
<td>Oblique photographs, vertical photographs</td>
<td>3D models of cities</td>
</tr>
<tr>
<td>LiDAR and terrestrial scanning</td>
<td>Digital terrain model</td>
<td>Construction automation</td>
</tr>
</tbody>
</table>

Table 2.1: Summary of data acquisition methods and their output

2.1.8 Summary

A summary of the output from the above data acquisition methods and their relevance in the context of transport infrastructure is summarised in Table 2.1.

2.2 Data processing and analysis

2.2.1 Photogrammetry

The American Society for Photogrammetry and Remote Sensing (ASPRS) defines photogrammetry as the art, science, and technology of obtaining reliable information about physical objects and the environment through the processes of recording, measuring, and interpreting photographic images and patterns of electromagnetic radiant energy and other phenomena. Photogrammetry is used for taking measurements from photographs or image data. Photogrammetry is used in different fields, such as topographic mapping, cadastral surveys, architecture, engineering, manufacturing, quality control, police investigation and geology. It is also used by archaeologists to quickly produce plans of large or complex sites. Stereo-photogrammetry is an advanced technique in photogrammetry used to estimate three dimensional measurement of objects.

Photogrammetry measures 2D and 3D objects from photogrammes. Photogrammes are photographs or images created using video or Charge Coupled Device (CCD) cameras\(^\text{11}\) or radiation sensors that are stored electronically on a tape or disk. This

\(^{11}\)A charge coupled device (CCD) camera is an equipment which is designed to convert optical
2.2. Data processing and analysis

 technique is applied to obtain coordinates of the required object-points, topographical and thematic maps and rectified photographs (orthophotos).

Post-processing of aerial photography output falls within the scope of photogrammetry. A number of different assets are created by processing the output of aerial photography.

- **Orthophotos:** Orthophoto is the simulation of a photograph taken from an infinite distance. Orthophotos are geometrically corrected aerial photographs to compensate for camera tilt, lens distortion and topographical relief. Orthophotos can be used to measure true distances between objects. Orthophotos are used in GIS systems to digitise features on a map, and some GIS software can process orthophotos automatically to create GIS features. Commonly used map platforms such as Google Maps and Open Street Map use orthophoto images.

- **Digital elevation model:** Digital elevation model (DEM) is a 3D representation of the terrain’s surface. There are two types of DEM: digital terrain model (DTM) represents bare ground without buildings or plants and digital surface model (DSM) represents earth’s surface including all objects in it. Sometimes, the term DEM is used for data representing only the height information without any further definition of the surface. DEM is used for a number of applications including city modelling and visualisation, flight simulation, 3D flight planning and transport infrastructure design. DTM is used for determining the optimal alignment of the right-of-way for highways and railway lines (see section 4.2.1.1). DTM can also be created using LiDAR data, and software tools for automated and assisted classification of LiDAR data are available.

- **Stereo feature extraction:** Stereo feature extraction is used for creating 3D urban models. Buildings can be *manually extruded* from ortho photos by specifying the height of buildings manually; this operation can be done using a number of commercially available software. If a DEM is available, a large number of buildings can be extruded simultaneously, saving time. The texture (images of building surfaces) can then be draped onto the extruded features. Feature attributes of buildings, such as name, description etc. have to be entered in manually after feature extrusion. Output of the 3D model are often stored in proprietary formats of geospatial platforms used, or can be used in an open format called CityGML. The ability to create rich 3D urban images is a recent technological development and the application areas for the usage of 3D urban images is still evolving.

2.2.2 GIS

Geographic Information System, commonly known through its acronym GIS, is a computer-based system where the features present on the earth’s surface are represented, visualised and analysed based upon their attributes and location. A
2.2. Data processing and analysis

geographic information system is designed to capture, store, manipulate, analyse, manage and present all types of geographically referenced data. Commonly used data types (usually referred to as layers) used in a GIS system are illustrated in Figure [2.7]. While the fields of map making and geographic analysis are not new, what GIS does is combine them on a common software platform and make these tasks easier and faster in comparison to the traditional methods. GIS has been proven to be invaluable tool for solving many real-world problems and decision making in a wide range of fields such as resource planning to modelling global atmospheric circulation and disaster management.

![Figure 2.7: Typical data layers used in a GIS system](image)

2.2.2.1 Data creation

Data stored in a GIS system is in digital format. Nowadays geo-referenced maps are available either in vector format (e.g. .dxf, .shp, .tab etc.) or raster format (e.g. .jpg, png, .tif etc.) for different co-ordinate system projections (e.g. WGS84, RSO, Cassini). Layers are typically available for diverse layers giving information about streets, road networks, buildings, railway lines, waterways, utilities, points-of-interest, addresses, administrative boundaries, post codes, land use and much more as per the requirements of different applications. Alternatively, if the GIS ready data are not available one can create this digital data by scanning printed maps and specifying the coordinates of known points. This process is called digitisation. The purpose of the digitisation process is to prepare a digital spatial dataset that could be further modified and integrated with additional feature data to perform geospatial analysis and reporting.

GIS data can also be created through surveying (sub-section 2.1.1) or remote sensing (sub-section 2.1.5). GIS software tools are capable of reading data from survey equipment like total stations and dual-frequency GPS receivers (RTK), including advanced features such as automated workflow between field and office. The tools also allow the user to standardise feature naming and publishing standards, and store valuable attribute information collected during surveys. Thus, these tools
allow the user to maintain, manage and post-process GIS, GNSS and surveying data from multiple devices, and bring efficiency in data acquisition, management and use.

In India, GIS ready vector datasets for different topographic features and other relevant information are available from multiple national mapping agencies, and are made available to an end user on demand. However, there is no single portal to obtain all digital vector datasets in India. Government of India has set up the National Spatial Data Infrastructure (NSDI) as a geospatial data repository, and is recently working on establishing a national GIS platform under National GIS Organisation (INGO) to cater to end users who require GIS ready datasets and GIS based applications. There are also no standards in India for surveying methods and conventions unlike other countries; for example, the Departments of Transport in the United States of America have published surveying standards to ensure consistency in captured survey data. India can also benefit from such standardisation, and industry organisations like the AGI have a crucial role to play in this area.

2.2.2.2 Data storage

GIS stores the underlying spatial data using different types of data models - the vector model and the raster model. In the vector model, spatial information about features and objects is encoded and stored as points, lines and polygons which are nothing but a collection of x and y coordinates. A point feature is described by a single x and y coordinate while linear features are stored as a collection of point coordinates. Polygonal features, such as administrative boundaries are stored as a closed loop of coordinates which contain an area. The vector model is extremely useful in describing discrete features, but it has certain limitations in describing continuously varying features such as topography and terrain type. Raster model was designed for modeling of continuous features (ESRI, 2008). The most commonly used examples of raster data are satellite imageries and aerial photographs which are used as background maps in most of the web based GIS systems. For example Google map and Bing maps can be consumed as web service in majority of the transportation related applications. Both the vector and raster models have their advantages and disadvantages, and modern GIS software packages are able to handle both these data models.

2.2.2.3 Analysis and visualisation

After creating spatial data on a GIS system, additional attribute data may be created and associated with the spatial features. Once required attribute data are entered into GIS, the system can be used for spatial analysis. Common GIS products have a Graphical User Interface (GUI) that will allow the end user to query the underlying data based on spatial or attribute criteria; for example, it is possible to identify all traffic sensors installed within a 5km from a toll plaza using a spatial query. The user is also able to carry out transformations or other calculations on the data to perform the required analysis. The user will be able to view the results on the analysis on a map, a graph or in a tabular format. The user
2.2. Data processing and analysis

has the ability to store different types of attribute data as different layers within a GIS system and turn different layers on or off to create a required map based view of underlying data.

GIS systems also allow users to write software scripts and programs to analyse data. Hence, the analysis in GIS systems is not just limited to simple algebra and arithmetic calculations, but users can also create complex mathematical models and generate visual outputs for the same. Users can also build statistical models to capture interactions among different attributes of spatial objects and use this information to generate what-if scenarios and predict future outcomes. Geospatial analysis and complex spatial modelling are being increasingly being used in a number of fields.

GIS databases can also function within the context of web-based systems or other server based software applications. Such systems may have a web-based user interface, and these systems can also be used to run geospatial analyses in an autonomous mode when integrated with real-time data feeds. For example, one can integrate rainfall data harvested from the web into a GIS system and create alerts when the cumulative rainfall quantity falls below a given threshold in a district.

2.2.2.4 Integration of GIS with legacy IT systems

The trend of computerisation gathered momentum in the 90’s in India. This has led to the proliferation of IT systems among government departments and private companies. While the IT eco-system may have grown organically over time to fulfil specific business and functional requirements, this has often lead to duplication of data and functionality across systems and requiring organisations to spend extra effort to keep the data across various systems synchronised. Open systems that can be integrated with existing IT systems try to avoid this pitfall. In an open IT architecture, each system fulfils its intended function while accessing data from and supplying data to external systems. Modern GIS systems are, in general, open and can play a key role in enhancing the value of data in existing IT systems by adding spatial intelligence. Government agencies can use GIS platform to bring together information about existing infrastructure and assets for integrated decision making (Vanier, 2004). Operational information about transport networks can also be shared with interested parties when open data standards are adopted. The Geospatial One-Stop initiative launched by the US Federal Government is a good example of this; details about this initiative can be found in Appendix C.

Integration of GIS with legacy IT systems and adding spatial intelligence to data go a long way in introducing transparency in governance. Hence, the use of GIS featured prominently in the Eleventh Five Year Plan. The recommended application of GIS in the Eleventh Five Year plan covered a number of areas ranging from agriculture to forestry to land records. A number of representative examples of the use of GIS outlined in the plan are given below.

- Modernisation and management of land records and titles
- Creating of an online registry of farmers and their land status
2.2. Data processing and analysis

- Use of satellite imagery and GIS for ground water mapping and water management
- Preparation of forest inventories, including the use of satellite imagery processing and GIS
- Use of smart metering technology and GIS for real-time monitoring of the electricity network with an aim of reducing Aggregate Technical and Commercial (AT&C) losses
- Transformation of various maps into uniform GIS format and their publication and dissemination
- GIS was identified as a niche area for the country for IT and IT-enabled services

Full benefits for the above can only be achieved when the aforementioned GIS platforms are integrated with existing IT systems used to administer and manage the domains. We feel that such focus on GIS will continue into the Twelfth Five Year plan, taking advantage of the momentum generated during the previous plan period.

2.2.2.5 Enterprise GIS

As the integration of IT transformed GIS use in fundamental ways in various sectors of planning and management, Enterprise GIS is a natural progression in the development of geo-spatial technologies. Enterprise GIS is a platform for delivering organisation-wide geospatial capabilities while improving access to geographic information and extending geospatial capabilities even to non traditional users of GIS. A schematic depiction of Enterprise GIS is shown in Figure[2.8].

Enterprise GIS integrates various organisational databases, processes, enterprise systems (such as ERP, billing systems etc.) and users intrinsically to provide a common platform for data collection, storage and access, harmonising the workflow of respective departments and disseminate information for the benefit of citizens at large. It allows easy access to data and GIS functionalities for desktop computer, web and mobile users.

Through innovative fusion of business and spatial information, Enterprise GIS is used to provide new insights that strengthen strategic and operational decision-making and deliver great impact to a diverse range of governmental, utility, communications, economic development, transport and defence agencies. Enterprise GIS enables users to extract insights through a spatial view of business and operational data. These insights strengthen strategic and operational decision-making and generate a significant impact on operational performance.
2.2. Data processing and analysis

Figure 2.8: Schematic Depiction of Enterprise GIS
Transport sector in India is quite diverse catering to the varied requirements of about 1.2 billion people (Chandramouli, 2011). The growth rate of population in the last decade is 17.64%. Better transport infrastructure is required to meet the mobility demands of a growing population that is getting increasingly prosperous. The Government of India has proposed an investment of about a trillion US dollar for the infrastructure sector in the 12th Five Year Plan which has proposed an ambitious, time bound development plan of new roads, railway tracks, ports and airports and upgradation of existing infrastructure. Business Monitor International have indicated in their report that the transport infrastructure sector is expected to grow annually at 23% CAGR to USD 114.9 billion between 2008-09 and 2014-15. Similarly, the GDP share of the sector was expected to increase from 10% to 11% in 2011-12 (Rangarajan et al., 2010).

The government’s approach to infrastructure development has shifted from traditional government managed projects to increased private sector involvement through Public Private Partnerships (PPP). PPP projects are now commonplace for transport infrastructure projects in highway, aviation and maritime sectors. The government acts as the regulator and oversees the implementation of these projects of national importance through the PPP scheme. Although this arrangement would require users to pay for the use of transport infrastructure, it is expected to infuse a traditionally conservative industry with new tools, technologies and mindsets, attract private capital and accelerate the pace of infrastructure building.

This presents an opportunity for the geospatial industry to bring innovative tools during planning, design, construction and operation & maintenance stages of infrastructure projects to increase efficiency and reduce costs. This chapter is aimed at readers from the geospatial industry and presents the size and overview of the transport infrastructure sector, subdivided into roadways, railways, aviation and maritime sectors. This will enable the readers to estimate the size of the market and consequently the size of business opportunities for the geospatial sector. The chapter continues to provide a list of initiatives and activities in the transport sector.
3.1 Indian transport and infrastructure market

The transport sector is traditionally subdivided into roadways, railways, aviation and maritime sectors. The scope of the maritime sector includes seaport and navigable inland waterways. A market size overview of each of these transport areas are given below.

3.1.1 Roadways

India has the second largest road network in the world totalling 4.2 million km but most of it is of not so good quality and half the network is not paved (Planning Commission, 2011a). The National Highway (NH) network accounts for only 1.7% of the total road length, but carries over 40% of the traffic. With a target growth rate of about 9%, a total NH road network of about 85,000 km is considered reasonable by the Government of India for the 12th Five Year Plan period (Working Group on Central Roads Sector, 2011). This means that there is a target to upgrade 32,750 km of NH network to four or more lanes during the Five Year Plan requiring an investment of Rs. 3,23,774 Crores. In addition, there are plans to upgrade 11,220 km of the NH network to two lane standard; the quantum of budgetary allocation for this upgrade is not clear yet. Moreover, Rs. 6,30,550 Crores has been allocated for the state highways development programme.

There are special road building programmes envisioned for Arunachal Pradesh and Left Wing Extremism (LWE) affected areas in the 12th plan. A total of 7016 km of road network is expected to be constructed in Arunachal Pradesh during the 12th plan period involving an estimated investment of Rs. 37,674 Crores. Under the LWE special programme, 4426 km of roads worth Rs. 5,376 Crores are expected to be complete by March 2015. Under a special Tribal Sub-Plan (TSP), 2,235 km of roads are expected to be built with a budgetary allocation of Rs. 2,976 Crores. In addition, Phase-II programme of LWE is pending approval worth Rs. 10,700 Crores for building a further 8014 km of roads. Lastly, there are plans to build 600 km of roads in Andhra Pradesh-Jharkhand-Orissa corridor worth Rs. 1,100 Crores (Working Group on Central Roads Sector, 2011).

A National Expressway Authority of India has been proposed with a master plan to build a network of 18,637 km of expressways with new alignments. The network is expected to facilitate the movement of people and goods in high traffic density corridors through access controlled motorways with closed loop tolling. A target of 500 km of the proposed network may be fixed for the 12th 5-year plan, with an estimated capital requirement of Rs. 4,140 Crores. The programme is expected to be implemented jointly by Central and State governments and the private sector.

In addition, there are a number of special programmes for roads under the 12th
3.1. Indian transport and infrastructure market

5-year plan. A special package for the Delhi-Mumbai Industrial Corridor (DMIC) involves developing 812 km of roads to 4-lane standard, requiring a funding of Rs. 14,425 Crores. Rs. 700 Crores is proposed for a special road development package for Jammu & Kashmir. Road development work for connectivity to minor ports is estimated at Rs. 5,000 Crores during the 12th 5-year plan, while a connectivity programme to airports is estimated at Rs. 1,800 Crores. Development of NH segments under the Border Roads Organisation (BRO) plan is worth a further Rs. 3,000 Crores. In addition, the Rural Roads programme requires a funding of Rs. 2,00,000 Crores during the 12th 5-year plan (Planning Commission, 2011b). It is expected that a lot of with work will be carried out by state, district and even panchayat level administrations.

The 12th 5-year plan proposes the use of advanced technology in a number of areas. There is a specific thrust on R&D and acquiring state-of-the-art technologies under the expressway programme. The government target of building 20 km of NH per day under the 12th plan will require the use of advanced construction automation technologies. The government also plans to improve the ride quality of about 5000 km of roads during the 12th 5-year plan, with a budgetary allocation of Rs. 3,750 Crores; this is another clear opportunity for construction automation technologies, which includes geospatial technologies. Progressive use of technologies is recommended under the 12th plan to enable real-time monitoring of projects and making timely corrective actions when required; GIS can play a crucial role in assimilating disparate sources of data corresponding to ongoing projects and providing real-time reports to key decision makers. The report also recommends an institutionalised database for the road sector that can be used for planning, prioritising development and maintenance. In addition, electronic maintenance of Right Of Way (ROW) data is recommended. These present an opportunity for traditional GIS technologies. In summary, the investment planned under the roadway sector during the 12th 5-year plan is approximately Rs. 12,30,515 Crores, with ample opportunities for the application of geospatial technologies.

3.1.2 Railways

Indian Railways (IR) traverse the length and breadth of the country, with a total route length of more than 64000km. There are more than 7000 stations distributed over its network. IR’s rolling stock assets include more than 8000 locomotives, 45,000 passenger coaches and 2,20,000 wagons. Fixed assets comprise the 64,000 km permanent way, more than 1,50,000 bridges, 25,000 km of overhead electrical equipment, signal and telecoms equipment, and numerous buildings distributed across the rail network. To maintain this equipment, workshops, sheds, and depots are located in more than 1000 locations. Railway land runs into thousands of square kilometres across the country. IR carry over 30 million passengers and 2.8 million tons of freight daily. With approximately 1.36 million employees, it is the second largest employer in the world.

IR need to adapt to the needs of a country that is experiencing rapid economic

1Technology investment budget for construction costs typically vary between 1-3% of the total project budget. Technology investment tends to be higher for toll road project where the value of time is high.
growth. As a part of the required modernisation programme, the government has planned a number of major infrastructure upgradation initiatives during the 12th 5-year plan. Construction of new lines, upgradation of existing lines such as gauge conversion, track doubling and electrification, port connectivity initiatives and suburban rail initiatives are on the cards. Total infrastructure investments on rail network alone is Rs. 2,67,623 Crores (Ministry of Railways, 2011).

Technology, including geospatial technology, has a role to play in this modernisation programme. One of the key capability gaps identified in the 12th 5-year plan working group report (Ministry of Railways, 2011) is asset maintenance - specifically predictive maintenance of tracks and signalling. A reliable GIS platform (Section 2.2.2) and associated data form the basic foundation of any asset management and maintenance tracking system. Innovations in asset maintenance, such as predictive asset maintenance as opposed to schedule based asset maintenance, are built on top of the basic GIS layer. Latest developments from the field of asset maintenance need to be combined with state-of-the-art GIS technology in order to provide suitable solutions to the rail sector for asset management and maintenance. State-of-the-art in surveying and construction automation (Section 4.2.2) can be applied to accelerate the process of track building and improve quality.

3.1.3 Aviation

During the 12th Five Year Plan period the capacities of both the aircraft and the airports will be increased through modernization and up gradation of passenger facilities, speedy cargo clearance, strengthening the security and safety measures. The 12th Five Year Plan also focuses on safe and trustworthy air services, improved air connectivity to NE Region and other remote areas, create suitable infrastructure for rapid growth of helicopter operations, introduce sea-plane operations and generate employment. For faster, inclusive and sustainable growth during the 12th Five Year Plan a total outlay of Rs. 67,500 Crores is proposed for airport infrastructure projects and Rs. 4,400 Crores is proposed for investment in air navigation services (Planning Commission, 2011c).

Since IT and ITES is now integral to the faster growth of Civil Aviation sector it has been planned for an average raise of 35% over the entire 12th Five Year Plan. IT and ITES requires continuous upgradation after installation and a maintenance fund has also been designated for regular upgradation of the IT and ITES data, skills, training, capacity building and related hardware and software that would be required from time to time.

3.1.4 Maritime and inland navigation

India is the 20th largest maritime country in the world. It’s strategic location of a long coastline that flanks important global shipping routes, makes it a major maritime nation. The maritime sector in India comprises of ports, shipping, shipbuilding and ship repair as well as inland water transport systems. About 95% of the country’s trade by volume and 70% by value is moved through maritime transport. With India’s current share in global merchandise trade at around 0.80%, a
sound maritime infrastructure plays an important role in the pace, structure and pattern of our economic development.

Department of Shipping (DOS), under the Ministry of Shipping, Road Transport & Highways, is the nodal organisation entrusted with the responsibility of formulating and implementing policies and programmes on these sectors. Vision of Department of Shipping is to take Indian maritime sector to commanding heights in order to serve India’s trade and security interests in an efficient and economical manner. It has been taking several measures for upgrading and modernising the maritime infrastructure in the country so as to meet the international standards. One such important step has been the formulated of the National Maritime Development Programme (NMDP) comprising a total of 387 projects which cover the entire gamut of activities in ports, merchant shipping and inland water transport. The objective of the programme is to facilitate focused and accelerated investment in specific infrastructure including port infrastructure, tonnage acquisition and institutional capacity building. It envisages a total investment of Rs. 1,00,339 Crores out of which Rs. 55,804 Crores is for major ports and the rest for shipping and inland water transport sectors.

Port development is the priority area for 12th 5-year plan (Ministry of Shipping, 2011). The total outlay proposed for the development of major ports for 12th Plan period is Rs. 22,757 Crores, excluding the private sector investment. The investment from the private sector for major ports during the 12th plan period is anticipated to be Rs. 51,037 Crores.

Maritime states in India have drawn highly ambitious programmes to create additional capacity of the non-major ports during 12th Plan. To implement this they have identified projects for development of several non-major ports at an estimated cost of Rs. 1,06,832 Crores to create an additional capacity of 1039 million tonnes. It has been envisaged that private sector will fund about Rs. 1,04,808 Crores (98.1%) of the total development budget for these ports through PPP or BOT or BOOT basis. The remaining amount of Rs. 2,025 Crores is to be contributed by the respective State Governments through Internal Resources / Gross budgetary Support/ Internal Extra Budgetary Resources.

3.1.5 Summary

The estimated investment in transport infrastructure over the next five years exceeds Rs. 17,48,685 Crores. Figure[3.1] illustrates the relative size of estimated investments in different transport sub-sectors, and Table[3.1] provides the corresponding figures. To summarise, more than 50% of the estimated investment is going to be in the road sector, followed by rail and maritime sectors, and the aviation sector is expected to see the smallest quantum of investment. A more detailed breakdown of these numbers is given in Appendix A.
3.2. A few ongoing and upcoming Indian government initiatives in the transport sector with geospatial technology scope

![Transport Infrastructure Spend Breakdown](image)

**Figure 3.1:** Relative share of estimated infrastructure investment in different transport sectors

<table>
<thead>
<tr>
<th>Sector</th>
<th>Investment Amount (Rs. in Crores)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roadways</td>
<td>12,30,515</td>
</tr>
<tr>
<td>Railways</td>
<td>2,67,623</td>
</tr>
<tr>
<td>Airports</td>
<td>71,900</td>
</tr>
<tr>
<td>Maritime</td>
<td>1,78,647</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>17,48,685</strong></td>
</tr>
</tbody>
</table>

**Table 3.1:** Categorised estimated investment in transport infrastructure in the next five years

3.2 A few ongoing and upcoming Indian government initiatives in the transport sector with geospatial technology scope

This section outlines a number of initiatives and opportunities in the transport sector that are of relevance to geospatial professionals interested in applying their technology in transport. The list below does not contain those initiatives declared under the 12th 5-year plan outlines in section 3.1, for the sake of avoiding repetition.

3.2.1 Road sector

- The NHAI are going to launch a project called *GIS based satellite imagery project for planning monitoring and management of National Highways*. It
3.2. A few ongoing and upcoming Indian government initiatives in the transport sector with geospatial technology scope

is proposed that the project will initially cover 1200 km in pilot mode, and extended further based on the outcome of the pilot. The budget for this is Rs. 1.3 Crores per year and the project is expected to run for 3 years.

- The NHAI are going to upgrade two of their GIS based information management systems: the Computerised Project Information System and the Road Information System. An Expression of Interest call for this work was published and vendors have already been short-listed for this work.

- Road Management Systems (RMS) are being implemented by state government. For example, the RMS initiative is already underway in Tamil Nadu, and the total value of the project is approximately Rs. 14 Crores. RMS is essentially a GIS system customised to hold data needed for highway planning, operation and maintenance. Similar initiatives are expected to get underway in other states for efficient management of state highway networks.

- India leads the world in terms of road accident fatalities. Consequently, road safety is now a priority for the government and there is emphasis on analysing accidents scientifically. GIS based accident information systems are needed to capture accident related data in a consistent manner and to carry out the required analyses. These systems also have customised interfaces that allow the user to carry out basic analysis, and functionality to export data into statistical software for more complex accident data modelling. Some states such as Kerala have already implemented similar systems. Road safety is also a focus area for the 12th Five Year Plan. Among the list of recommendations made by the sub-group on this topic (Ministry of Road Transport and Highways, 2011), it is recommended that the response time for incidents be reduced from 30 minutes to 10 minutes. In order to facilitate this, the location of emergency medical care centres should be mapped across the country and integrated with real-time location and availability information of ambulances and information about the road network. If deployed in the right manner, geospatial technologies can assist in saving lives and reducing the impact of injuries among road accident victims.

3.2.2 Rail sector

- IR are planning to prepare a GIS map of the entire rail network and map its various assets in the system and create a web-based GIS interface. The type of assets include civil engineering assets (e.g. bridges, tunnels etc.), track related assets (e.g. level crossings, sidings etc.), land assets (e.g. stations, workshops, railway colonies etc.), signalling and telecommunication assets (e.g. optical fibre network, signals etc.), movable and fixed location mechanical and electrical engineering assets (e.g. coach production units, bull dozers etc.), movable and fixed safety assets (e.g. cranes, railway, civil & private hospitals, fire service brigades) and their associated information such as location/address and phone numbers. This is an ambitious GIS initiative that will help modernise the operation of IR.
3.2. A few ongoing and upcoming Indian government initiatives in the transport sector with geospatial technology scope

3.2.3 Aviation sector

- **NOCAS** is a No Objection Certificate (NOC) Application System. This system has been deployed by the Airports Authority of India (AAI) to provide NOC to construction in the vicinity of the airports. Since there is prescribed limit for height of any building construction within certain area near airports, this application helps in identifying the exact location of the building to be constructed and provides factual details to help the decision making process regarding the NOC application.

- **GLAMS** is GIS based Land Asset Management System for management of AAI assets. In this application, all the assets of AAI have been mapped on a GIS platform. AAI is planning to enhance GLAMS to include overall maintenance and management of its assets.

- **GIS based applications for cartography** provide the details of land parcels of AAI. There are plans within AAI to upgrade this system.

- AAI are working on a GIS based application for Planning Air Operations Control Centre. Tender for this project has already been floated and AAI are currently finalising the vendors. The system is going to be implemented in 10 airports under the authority of AAI including Chennai, Kolkata, Ahmadabad, Pune and Jaipur.

3.2.4 Maritime and inland navigation

- **Safe navigation on national waterways**: In order to ensure safe navigation on inland waterways, Inland Waterways Authority of India (IWAI) are planning to introduce Differential Global Positioning System (DGPS). This is a ground based augmentation system to increase the accuracy of GPS based navigation to obtain +/- 1m accuracy. This is complemented by navigation charts and desktop based navigation software to be used by vessels. This software is expected to be used in seasonally meandering alluvial rivers such as the Ganga and Brahmaputra. Private vessel operators are being encouraged by the IWAI to use this navigation system for safety.

- **Web-based asset management system**: The Ministry of Shipping has mandated implementation and use of a web-based land asset tracking system for all the ports owned by the ministry in order to minimise the loss of revenue due to poor management of its land assets.
Humans are a mobile species. Homo sapiens evolved in Africa around 200,000 years ago and have occupied every conceivable corner of the earth since then. Modern human society is highly globalised and the interdependency and trade between different nations and regions is essential to the survival of modern society as we know it. The transport sector fulfils the need for the mobility of people and goods in our highly interconnected world.

The transport sector can be broadly categorised into two. Civil engineering focused activities focus on the planning, design, construction, operation and maintenance of the fixed infrastructure of transport systems. Mechanical engineering focused activities provide mobile transport infrastructure, viz. the vehicles such as automobiles, trains, aeroplanes and ships. This chapter focuses on the application of geospatial technologies in the context of fixed transport infrastructure.

There are common themes that run across the planning, design, construction, operation and maintenance phases of transport infrastructure projects across multiple transport modes such as roadways, railways, aviation and shipping. Hence, next sections in this chapter will present the overall context within which these activities are carried out across sectors. It is hoped that the knowledge provided in this section will enable geospatial professionals to engage more fruitfully with the transport industry. Similarly, policy makers and bureaucrats will gain a practical understanding of activities carried out in transport infrastructure projects and how geospatial technologies play a major supporting role in these activities. Transport professionals can see examples where geospatial technologies have been successfully applied to transport projects in the past and the benefits realised by using these technologies.
4.1 Transport planning

Transport planning is but one aspect of urban planning. Cities have existed in history since the time of Mohenjodaro-Harappan civilisation as a hub of economic activity. Cities have to provide a number of facilities to its population such as safety, a sound economic environment, housing, health, water supply, energy supply, sanitation and transport. All these factors come together to make a city liveable and attractive. Urban planning focuses on the design and regulation of the use of space with a focus on its physical form, economic functions and social impacts of the urban environment and the location of different activities within the urban space (Shrey et al., 2011). Transport planning is but one of the aspects of urban planning.

The provision of fixed transport infrastructure starts with transport planning. Transport planning involves itself with the evaluation, assessment, siting and design of transport facilities to fulfil current and future travel demand in an urban area or a region. Effective transport planning should focus on providing the required mobility for people and goods using a multi-modal transport system, and transport planning usually cuts across multiple travel modes such as roads, rail, public transport, cycling and walking. Transport planning is closely linked with land use planning and urban planning, as the demand for mobility depends on the population density and the nature of economic activities undertaken by the population. An overview of the transport planning activity that typically takes into account multiple travel modes, such as roads and rail, is given below.

4.1.1 Transport planning for roads, rail and aviation

A major component of traffic on the road, rail and aviation network is due to the demand for mobility of individual people. Transport planning is traditionally carried out using a four-step model\(^1\) that is used to forecast and estimate traffic demand of passengers. While the approach is applicable to road, rail and aviation sectors, it is an integrated activity that takes into account all available transport modes in a given city, region or even country.

The first step in the planning process is the forecasting of trip generation. In order to do this, the area of interest is divided into geographic zones. Trip generation forecasts the number of trips originating (trip generation) and terminating (trip attractors) in each given zone. Trip generation is typically modelled as a function of social and economic attributes of households in a given zone. Non-residential land uses are treated as trip attractors; e.g. commercial or industrial areas attract workers who commute from their homes. Population data, socio-economic data and land-use data are needed in a GIS format in order to carry out the trip generation step.

Trip distribution is the next stage in four-step transport planning. Trip generation focuses on estimating the demand between each pair of zones using data from the trip generation step. Gravity models are commonly used for this purpose, which

\(^1\)More recent methods for transport planning exist, such as activity based modelling approach. However, the transport industry still predominantly uses the four-step modelling process.
work on the principle of proximity. It is assumed that the interaction between two zones decreases as the distance between them increases, while it is positively correlated with the amount of activity in each zone. The output of the trip generation step is called an Origin-Destination (OD) matrix that captures the travel demand between zones. OD matrices that capture the variability of travel demand across time-of-the-day are called dynamic OD matrices.

Once the travel demand is estimated, the transport planner tries to estimate the share of different transport modes to satisfy that demand through mode choice analysis. A given city or region will typically have a number of transport sub-systems and a person will have the choice of a number of travel modes such as walking, cycling, para-transit (shared autos), two-wheelers, cars, buses, Bus Rapid Transit (BRT), metro or rail. The mode choice of a typical traveller will depend on a number of factors such as the travel time, travel cost and psychological factors (e.g. the typical upper middle-class in India have an aversion to public transport). The geographic layout of the transport network and associated travel costs (time and cost) in GIS format forms a key input into this transport planning step. The output of mode choice analysis will provide the proportion of trips between each origin and destination zone using a particular mode of transport.

The last step in transport planning is traffic assignment to determine the level of traffic in each segment of the transport system. For example, in the case of the road network, traffic assignment will provide an estimate of traffic volume on each road link. Traffic assignment leads to the user equilibrium solution for the transport system as opposed to system equilibrium. In order to estimate the user equilibrium state, it is assumed that each road user has perfect information and acts rationally and selfishly to choose a route that provides the least travel time for him/her; taking an alternative route will lead to increased travel time.

The above transport planning process forms the scientific basis for transport infrastructure projects. Planners, economists and transport planners forecast population growth, changes in land use pattern and changes to the nature of economic activities undertaken by the population over a future time horizon and estimate transport demand. Analysis of a number of transport infrastructure improvement scenarios are then undertaken based on socio-economic and environmental policy objectives and economic criteria to fulfil the forecasted mobility demand. Roadway and other transport infrastructure projects are commissioned based on the above analysis.

Transport planning is a GIS centric activity as all the data sets needed for transport planning are geospatial in nature. Some transport planning software such as TransCAD are GIS systems with integrated transport modelling functionality. Others such as VISUM, CUBE and SATURN (to quote a few examples) have the functionality to import road network and zoning data in traditional GIS formats.

The following data are needed as input into transport planning models (Beimborn, 2006). Please also refer to section 4.1 for details.

- **Land use data:** Current and predicted future land use data categorised by

2System equilibrium, as opposed to user equilibrium is the state where the sum total of travel times for all road users is minimised. Such a state cannot be achieved in a transport system of individuals seeking to maximise individual travel times unless external interventions such as traffic restrictions and traffic control are introduced.
geographical zones used in the planning model

- **Population data:** Current population from Census data and future prediction after taking into account population growth and migration patterns
- **Economic data:** Employment levels, type of current and future industry sectors
- **Land utilisation data:** Information about where people live, work, shop, go to school etc. Future evolution of these is linked with planning rules and local government policies.

- **Travel demand forecasting:** Data in the previous step are used to estimate trip generation rates per zone, trip distribution to estimate travel demand between each pairs of zones (Origin-Destination (OD) matrix), the percentage of trips undertaken by different transport modes such as cars, public transport or rail (mode choice/modal split) and estimation of traffic flow or passenger numbers on each segment of the transport network (traffic assignment). Road network data from external vendors or Open Street Map data could be used for this purpose.

### 4.1.2 Transport planning for the maritime sector

Most of the maritime activity is due to the movement of goods across the globe. A considerable percentage of long distance road and rail travel demand also arises due to freight movement. Freight modelling tools need to be used in order to estimate the demand on the transport system due to freight movement and take this factor into consideration in optimally designing the transport system.

Freight modelling is a complex activity. In our globalised era, a huge number of commodities are traded and transported across the world. Factors such as GDP of regions and countries and trade imbalances due to the nature of economic activity undertaken in different regions generate demand for the movement of commodities. Freight mobility demand is also a function of local production costs, inventory costs and transportation costs, and is influenced by the supply-chain and logistics policies of manufacturers in a region.

While freight modelling is an activity that requires understanding of a number of disciplines such as economics, logistics and supply-chain, geospatial technologies also have a role to play in this sector. There are demand modelling tools analogous to the four-step model for estimating freight demand. These models require geospatial and land use data as inputs. At a smaller scale, individual business entities who deal with raw materials and commodities have to deal with the classic warehouse location problem; in other words, they need to determine the optimal location of warehouses to minimise overall costs of sourcing the required raw materials and ensuring reliability of supply. Geospatial data with respect to available transport networks, travel times, costs and land value data form the basis for such systems, and GIS software is typically used to compile the required information. An example screen shot of GIS based warehouse location system is given in Figure[4.1].
4.2 Design and construction

4.2.1 Engineering design

4.2.1.1 Engineering design for road and rail sector

Once the need for a new transport link, such as a highway or a railway line, is established through the transport planning process, one of the key subsequent activities is the right-of-way alignment design. This involves the specification of the geometry of the road or the railway line that connects two locations. The geometry is determined by factors such as location of interest that the transport link must pass through (e.g. towns and villages), cognizance of restricted areas (e.g. religious places, historical monuments) and land acquisition factors. Once such constraints have been taken into account, the objective of the highway engineer is to design an alignment that minimises construction costs.

Right-of-way alignment design is currently a manual process, where the engineer identifies a number of potential alternate alignments based in intuition and experience. This is an error prone process since the most optimal alignment may not be identified by the engineer. The current practice is also time-consuming; for example, creating three alternate alignments for a 100 km road/rail section requires roughly 30-36 person days of engineers.

Automated alignment identification software tools (AAIST) are available in the GIS market to inject efficiency into this process. Such tools typically combine an
4.2. Design and construction

optimisation engine with a GIS platform, and work as follows. The base data in the GIS platform consists of the geology of the area of interest and topology (elevation). This is supplemented by information about external constraints that the right-of-way alignment must be subject to. Users can typically specify other constraints such as specific points through which the right-of-way must pass through. The AAIST then identifies the route that minimises the construction cost, typically by minimising the quantity of cutting and filling materials such as earthwork, and other materials such as asphalt, ballast, sub-ballast, subgrade and pavement layers.

Other factors that contribute to cost, such as cost of constructing bridges, land value etc., can also be included in the optimisation framework. The use of AAIST at the highway and railway planning stage is expected to reduce construction costs as much as 15-18%; the savings can be higher in mountainous terrain. AAIST not only identifies the specified number of least cost right-of-way alignments, but also reduces the effort required to generate alternate alignments. For example, creating alternate alignment options for a 100km right-of-way section requires only about 2 person days using AAIST, while the manual method requires about 35 person days.

AAIST functionality could also be extended to problems unique to the Indian context. Recent studies by the PMI have concluded that 41% cost over runs and 81% of time over runs are due to land acquisition problems in transport infrastructure projects. AAIST tools could take land acquisition factors into consideration when determining optimal alignment. The land acquisition impact of transport projects thus determined can also be published on the web to benefit the public and bring transparency for all parties concerned.

The government should mandate the use of AAIST during feasibility study phase of new highway (e.g. bye-pass roads) and new railway line projects in order to identify alignments that result in the least construction cost. AAIST is also of particular value to the rural road building programme, and should be used by state departments and their contractors designing new rural roads. However, it should also be noted that AAIST is of limited value to highway and railway projects that upgrade existing infrastructure.

4.2.1.2 Engineering design for aviation sector

Geospatial technologies can be used in airport design and other fixed infrastructure facilities in the aviation sector. GIS can be used to aid the site design of such facilities, including the preparation of site-plan and management of engineering design documents. However, geospatial technologies can play a key role in the efficient design of the airport itself.

The alignment of the runway is a key decision in the design of airports, as the siting of all other facilities such as terminal buildings, cargo hold areas, maintenance facilities, access and parking facilities for passengers depend on the runway alignment. GIS can be combined with optimisation technologies to determine the optimal alignment of the runway, as opposed to the current trial and error method (Jia et al., 2004).
4.2. Design and construction

4.2.1.3 Engineering design for maritime sector

With rapid advancement of globalisation and associated increase in global trade, the quantity of materials transported by ships has been increasing steadily over the years. This requires upgradation of existing ports and construction of new ports, where geospatial technologies add value. Design of the port area consists of a number of distinct activities such as entrance channel design, design of anchorage ground, design of watercraft turning around area and harbour basin, land area design, breakwater design etc. Locating the above facilities and their design depends on the prior state of the harbour area. Elevation, hydrological and meteorological data stored in a GIS are typically used for this purpose.

A number of engineering rules go into harbour design. For example, the angle between the approach channel of ships and wind, water flow and waves should not exceed 20° for navigational ease; the diameter of the watercraft turning around area should be at least twice the maximum design length of ships calling at the port; the width of water at the harbour basin should be at least 1.5 times the maximum design length of ships to facilitate pulling in and out of anchorage location; the areas where ships manoeuvre should have adequate under-keel clearance. The data required for the above are collated and linked together on a GIS during port design. The siting and associated dredging requirements for these port facilities are carried out with ease using a user-friendly GIS (Wang et al., 2008b).

4.2.2 Construction

4.2.2.1 Construction of roadways, railways and aviation

A massive highway construction programme is underway in India, along with expansion of the rail network. Judicious use of geospatial technologies during planning and construction phases has the potential to reduce the construction costs, and this presents a massive opportunity for the geospatial and transport sector professionals to work collaboratively. Figure[4.2] gives an illustration of the overall life-cycle of infrastructure construction projects. There are three main categories of geospatial technologies available for use in transport infrastructure construction projects in the road and rail sector.

Once the optimal right-of-way alignment has been identified with the help of GIS, the contractor in charge of a construction project carries out detailed engineering design. This is followed by the construction phase where the detailed design is implemented on the ground. The use of positioning and location measurement technologies, which are complementary to core GIS, can be used to further reduce construction costs. These are survey equipment such as total stations, Mapping and Geographic Information Systems (MGIS) equipment and construction technology equipment. When constructing highways, railway lines, airports and seaports, it is essential to stick to the exact engineering design within tolerance specified in job specifications. For highway and railway construction, it is also important to accurately locate existing gas, electricity & telecommunication lines and other nearby infrastructure. Lack of accuracy can easily cause disruption to these facilities and can lead to service outage and add a significant amount of time and cost to the
4.2. Design and construction

Figure 4.2: Life-cycle of transport infrastructure construction projects

project. MGIS technology can provide accuracies of up to 10cm, which reduces the possibility of damage to existing infrastructure and effectively lowers the expected cost of these projects. MGIS products can also help to accurately measure the length and width of highways and railway embankments in order to keep the materials used to a minimum.

The use of survey products help to accurately pinpoint specific locations and landmarks essential to the specific infrastructure. This is useful for all the four transport infrastructure sectors - highways, ports, airports and rails when identifying reference points and important architectural specifications. Using remote controlled survey equipment, required workforce is reduced by as much as 50% as operators would not need an assistant to control equipment in opposite ends. Survey equipment is also useful when it is necessary to determine the terrestrial or three-dimensional position of points and the distances and angles between them, which is a common requirement in infrastructure construction.

Implementation of detailed design during the construction phase is still largely not automated. Technicians manually operate construction machinery to implement the specified design, aided by a supervisor and a team of surveyors to check the quality of the output. Detailed design drawings are still paper based in many instances. However, forward looking engineering firms have been using software tools to capture the design output and a 3-D rendition of the design is often created in software format. Machine control solution for construction automation aided by positioning and measurement technologies can bring efficiency into the construction process in these instances.
Construction automation using machine control solutions enables automatic implementation of 3-D design output in the field with no operational input from a human, which works as follows. To start off, the design output needs to be georeferenced either to a local coordinate system or to a global coordinate system and uploaded to the construction machinery. In cases where a global coordinate system is used, the location of construction equipment is determined with the help of high accuracy GNSS devices such as differential GPS (section 2.1.2.2). Total Stations equipped with high accuracy GNSS (RTK equipped) are available in the market to enable this. Such systems improve efficiency by reducing the time needed for set-up, totally eliminating the need for carefully setting up control reference points.

In case of local coordinates, reference points must be established though surveying and a system for local positioning of the construction machinery must be established with the help of devices such as total stations; location measurement is achieved using Total Stations in these instances (Hahn, 2012). The machine operator drives the vehicle through required areas with the help of a visual display. The main operation of the machine (e.g. movement of the blades, compacting of the soil, pouring of concrete etc.) is automated by matching up the uploaded design with the given location of the machine and controlling the hydraulics in order to achieve the designed output. This is achieved by combining the 3D design drawing and position measurement technologies and integrating it with the CAN bus interface of the construction equipment. While the concept of construction automation using machine control solutions has been around for more than two decades (see Figure[4.3]), the technology is mature enough today to bring real advantages to infrastructure construction.

The advantages of construction automation using machine control solutions are many. It’s important to understand that the key to building long-lasting transport infrastructure of high quality is to get the foundations right the first time. Attempting to fix mistakes made earlier in foundation and subgrade layers during later stages of construction simply does not work, and can actually increase materials costs. Using machine control to deliver optimal smoothness (grading) and layer thickness saves contractors time and money when constructing the upper layers. Moreover, foundation and subgrade materials (typically graded rock or cement-stabilised material) are significantly cheaper than hot-mixed asphalt or pavement quality concrete. Homogeneous layer thicknesses, and consistent compaction, ensures traffic loads are distributed evenly. This allows paved surfaces to last longer, with significantly less maintenance required, so whole-life-costs of the infrastructure can be reduced. Machines which can be equipped with 3D machine control include fine-grade trimmers, bulldozers, excavators, motor graders, compactors and all paving machines.

Machine control solution reduces the error between design and implementation. For example, a typical highway surface level has an error of +/-20mm compared to the design. Construction automation using machine control solutions can reduce the error to +/-3mm. This not only reduces material wastage, but also results in a smoother ride for vehicles on highways. Construction quality and reduced error tolerance are also important for high-speed railway tracks and airport runways. The construction work can be carried out faster since the number of passes of the construction equipment over a given location to achieve the desired design is re-
4.2. Design and construction

Figure 4.3: An early concept diagram of construction automation using machine control solutions (Source: Society of Civil Engineers, Construction Robotics Commission, Prof. Shigeyuki Obayashi, 1985)

ducted drastically from around 10-12 to about 4-5 passes. Reduction in the number of passes reduces completion time, fuel and labour costs and the maintenance cost of the construction equipment, while increasing the longevity of the machinery. Construction automation using machine control can also improve safety at con-
4.2. Design and construction

Construction sites (Adams, 2012). Construction automation technologies using machine control solutions can be applied in highway, railway, aviation and maritime construction projects. They are particularly beneficial in runway construction projects in aviation where quality and design tolerance are of utmost importance.

Machine control solutions can also improve efficiency and quality of tunnel construction in roadway and railway sectors. Tunnel profiling systems can provide automatic profile measurement for geometric information and compare against the design profile, thus bringing speed and accuracy in quality checks during tunnel construction. The point-clouds measured by such equipment can also be used to create colour-coded elevation maps enabling detailed visual analysis. Colour-coded elevation deviation map is an especially useful tool to quickly spot depressions and other imperfections on the surface that can cause drainage problems. The scanning technologies improve safety since the measurements can be carried out from a distance, with the added advantage of not disrupting ongoing construction equipment and activities.

Various estimates based on pilot studies in India show that approximately Rs. 7.5 to 75 Lakhs can be saved per kilometre for a four lane divided highway by using construction automation technology using machine control solutions. The actual savings figure will vary depending on the nature of terrain, construction equipment used and the level of sophistication of construction automation technology and machine control solutions used. Similar levels of cost savings can also be expected for railway projects. The technology also helps engineering firms to do more work using lesser number of machines thereby reducing their capital expenditure. Lastly, saving time translates directly into revenues for highway projects with tolling. A project finished three months early means that the contractor can start collecting the toll revenue three months early, which can turn into considerable savings for the contractor.

The time is ripe for the introduction of construction automation technologies using machine control solutions in India. While the transport infrastructure construction is booming in India, the construction costs are going up. Typical project costs have increased by 8.4% in 2010-2011, while cement costs have gone up by 34% in 2011 alone. Diesel costs have increased by 250% since 2002 and labour costs have gone up by 25% during the same period\(^3\). Construction automation using machine control solutions can save time, materials cost and fuel costs for the contractor and result in superior quality for the constructed infrastructure resulting in reduced maintenance costs. Construction automation using machine control solution helps finish transport infrastructure construction projects faster, which is essential for a country like India which is rapidly expanding its transport infrastructure. We recommend that the government mandates the use of construction automation technology using machine control solutions for all infrastructure projects, including those in the transport sector, to help accelerate the infrastructure building in India.

---

\(^3\)The Cost Crunch, www.constructionupdate.com, May 2011
4.3. Operation and maintenance

4.2.2.2 Construction in the maritime sector

Machine control solution for construction automation, aided by geospatial technologies, can increase efficiency of underwater construction activities during port construction. For example, remote operated underwater construction machines are used in port construction, where the construction machine underwater is remotely controlled by an operator above the water level. The remote operator cannot rely on cameras mounted on the construction equipment if the water is murky. Hence, geospatial technologies in combination with haptic technology are used to operate the machines (Hirabayashi et al., 2006). This technology used a 3-D terrain model of the surface under the water to create an augmented reality display of where the machine is (see Figure[4.4]), in conjunction with haptic feedback on machines control levers. Other common activities such as cutting underwater and dredging (Noland, 2010) can also be automated using machine control solutions (Tang et al., 2009). Adams (2010) provides an overview of various machine control based construction automation activities for the maritime sector.

4.3 Operation and maintenance

4.3.1 Roadway and railway sectors

The operation and maintenance of the transport infrastructure can again be categorised into two areas: operation of the infrastructure from a traffic management perspective and maintenance of the infrastructure. The use of technology for the
4.3. Operation and maintenance

Former typically falls under the umbrella of Intelligent Transport Systems (ITS). A common ITS application incorporating geospatial technologies are situation awareness tools for road network managers in traffic control rooms, where real-time traffic data are integrated into a GIS based visualisation platform. Though geospatial technology can provide assistance in this area beyond the example given, this is considered outside the scope of this white paper. Geospatial technologies are also relevant when it comes to asset management related to transport infrastructure (US Department of Transportation, 1999), which is within the scope of this paper.

Asset monitoring and management practices in roadway and railway sectors are comparable, though the operational details of maintenance processes vary. The condition of transport infrastructure assets such as the pavement, railway track related assets such as points and crossings, signalling hardware, bridges, culverts etc. need to be monitored at the required intervals and repairs or maintenance procedures need to be applied as and when required. The maintenance process is complex involving a large number of components spread across large geographic areas in many cases. GIS based asset management systems are used to manage this activity efficiently. The location of assets is first entered into asset management systems, either automatically from other electronic information sources or manually. Location information about assets can be stored using a standard co-ordinate frame such as the WGS-84 or a Linear Referencing Model (LRM). Operation and maintenance related information such as photographs, inspection logs, repair notes etc. are then cross-referenced against location data in such systems. This information can be then visualised on a map by managers and location based information combined with maintenance schedule related information can be used to carry out maintenance activities optimally. The use of technology enhancements on projects in the infrastructure segment will improve productivity, increase accuracy, reduce rework, improve safety and minimise lifetime cost of transport assets.

Other geospatial technologies that can help in asset monitoring are the street mapping technology and the profilograph. Street mapping combines 3D laser scanning of highways, pavements, surrounding buildings and vegetation with a high precision navigation system. The output of street mapping or the profilograph can be used to identify areas that are in need of repair such as pot-holes and ruts. These technologies allow condition monitoring of the road surface at speed and thus reduce maintenance costs.

Another area where geospatial technologies can help in the operation of the road network is environmental impact assessment. Vehicles emit pollutants and excite particulate matter (dust) on the road surface (Ishaque, 2006). Long term exposure to these pollutants has harmful health effects. Traffic microsimulation software
4.3. Operation and maintenance

combined with pollution dispersion models are used to determine the location and concentration of pollutants due to vehicular traffic, typically in urban settings. Remedial actions such as implementing traffic restrictions to change traffic flow patterns or changing traffic signal control settings relocate queuing can be taken if it is deemed that pollution levels in an area is unacceptably high. Road network data in GIS format and digital elevation models are required in order to implement transport-pollution models. An illustrative example of data required for pollution modelling in the roadway sector is shown in Figure[4.5].

Geospatial technologies can play a key role in traffic operations by improving safety and managing accidents and other emergencies efficiently. GIS based accident information systems with embedded statistical analyses can help pin-point accident hot-spots (Erdogan et al., 2008) and take remedial measures to improve safety at these points. Similarly, having a GIS with up-to-date location information about the road network, hospitals and medical facilities, accident relief medical equipment and civil administration locations such as police stations, district administration and disaster management authorities can help expedite the arrival of rescue teams and streamline their operations. Such functionalities are already envisioned by various government authorities, e.g. Indian Railways for subsequent phases of their Long Range Decision Support System (LRDSS) (Mathur, 2012).

4.3.2 Aviation

GIS is widely used for asset tracking and inventory management in the transport sector and beyond (Arvanitis et al., 2000). GIS and GNSS are particularly used in airport pavement management systems. This has been the case with US airports for over a decade, and airports in developing countries like China have also started using geospatial technologies for pavement management recently (Chen et al., 2012).

The pavement area in an airport is typically divided into branches, which are subdivided into sections having uniform design, construction history, traffic and condition. Lastly, sections are divided into survey units for inspection and evaluation. A number of pavement characteristics such as distress condition, traffic data, roughness and friction are collected for each survey unit. Airports consist of large open areas, and identifying a survey unit manually for inspection and problem rectification is a time consuming process. GIS and GPS assisted pavement management systems reduce the time needed for carrying out pavement surveys, thereby minimising the impact of airfield inspection on flight operations (Chen et al., 2012).

Geospatial technologies can also be used for a wide range of operational requirements such as monitoring the traffic entering and leaving the airport to identify congested spots, managing maintenance requirements, analysing footprints for retail spaces inside the airport, mapping noise pollution and managing land parcels and other real-estate. A good overview of the use of GIS in an operational context at an airport is given in Airport-Technology.com (2009).
4.3.3 Maritime and inland navigation

Sea port operation is highly complex. Port operators have to optimally manage the available space, while taking into account the schedule of ships on the one side and cargo trains and lorries on the other side. A GIS based information management system can help streamline this process and improve port operations efficiency. For example, a recent study demonstrated that using GIS in port operations can improve performance by 15% on average and up to 60% in some cases (Prasad and Gavirneni, 2010) without expanding the physical area of the port.
4.3. Operation and maintenance

4.3.4 Transport infrastructure security

GIS forms a key component in the plan to ensure infrastructure security; for example, GIS forms an important component of the US government’s approach to homeland security (Cox-Drake, 2005). Planning for infrastructure protection involves many steps, such as threat detection, target hardening, threat deterrence, consequence planning, response and recovery. The basis for all these steps is sound vulnerability assessment, and GIS can play a key role in this vital step. One needs to have a detailed understanding of the infrastructure itself and built environment, the geological structure and the demographics of the region or site for carrying out the vulnerability assessment. Geospatial collateral such as maps, multi-spectral satellite images and geo-referenced videos, photos and sound clips aid this process.

The analysis involves identifying infrastructure elements and resources that are critical to the system. For example, bridges form vulnerable points in transport networks. A more complex example involves carrying out network analysis to identify critical links in a transport network. This is followed by identifying geographic areas within which activities can affect the critical link, and interdependency analysis of the critical link with other network elements. GIS tools are essential for carrying out the above tasks in vulnerability analysis (Cox-Drake, 2005).
4.4 Generic opportunities for geospatial technologies in transport

This section lists generic application areas where geospatial technologies can be applied in the transport sector. As opposed to specific opportunities related to planned and upcoming projects, a list of application scope areas for geospatial technologies in transport is presented. It is reasonable to assume that the application areas listed below will form a part of the scope of upcoming projects that is of interest to the geospatial industry.

4.4.1 Roadways and railways

The nature of application scope for the geospatial technology in the road and rail sector is similar. Table[4.1] summarises the list of opportunities in these sectors.
4.4. Generic opportunities for geospatial technologies in transport

Table 4.1: Applications of geospatial technology in roadway and railway sectors during planning and design phases

<table>
<thead>
<tr>
<th>Application context</th>
<th>Phase</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>GIS can be integrated with most transport planning tools to save time and to increase quality</td>
<td>Planning</td>
<td>Time</td>
</tr>
<tr>
<td>3D design output can be used as input to construction automation using machine control solutions to save time and money and to increase quality</td>
<td>Construction</td>
<td>Time, money, quality and governance</td>
</tr>
<tr>
<td>Remote sensing data, combined with a GIS, can be used to carry out environmental impact studies of transport infrastructure projects</td>
<td>Planning</td>
<td>Governance, environment</td>
</tr>
<tr>
<td>Location measurement technology, such as LiDAR and GNSS, can be used to carry out land surveys more accurately using less time</td>
<td>Construction</td>
<td>Time, cost, quality</td>
</tr>
<tr>
<td>Combining remote sensing data with optimisation tools to determine the optimal alignment of the right-of-way</td>
<td>Design</td>
<td>Time, cost</td>
</tr>
<tr>
<td>GIS can be used to streamline the land acquisition process and right of way planning for highway and railway projects</td>
<td>Planning</td>
<td>Time, governance</td>
</tr>
<tr>
<td>GIS based construction project monitoring systems can be used to efficiently monitor highway and railway construction projects</td>
<td>Construction</td>
<td>Time, cost, governance</td>
</tr>
<tr>
<td>GIS forms the basis of highway and railway infrastructure asset management systems</td>
<td>O&amp;M</td>
<td>Time, cost, governance</td>
</tr>
<tr>
<td>GIS forms the basis for accident information and analysis systems</td>
<td>O&amp;M</td>
<td>Time, safety, governance</td>
</tr>
<tr>
<td>GIS is an integral component of Advanced Traffic Management Systems that will help traffic managers visualise the state of the road or rail network in real time</td>
<td>O&amp;M</td>
<td>Time, safety, environment</td>
</tr>
<tr>
<td>GIS and digital terrain models (DTM) are essential for carrying out noise and pollution studies related to transport</td>
<td>O&amp;M</td>
<td>Environment</td>
</tr>
</tbody>
</table>
4.4. Generic opportunities for geospatial technologies in transport

4.4.2 Aviation

Table [4.2] summarises generic opportunities in the aviation sector.

**Table 4.2: Applications of geospatial technology in the aviation sector**

<table>
<thead>
<tr>
<th>Application context</th>
<th>Phase</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>GIS aids in airport planning aspects such as site selection, design of components,</td>
<td>Planning &amp;</td>
<td>Time, cost, quality</td>
</tr>
<tr>
<td>runway, taxiway design and drainage</td>
<td>design</td>
<td>design</td>
</tr>
<tr>
<td>Construction automation using machine control solutions is essential for</td>
<td>Construction</td>
<td>Time, cost, quality,</td>
</tr>
<tr>
<td>airport construction in general and runway construction in particular</td>
<td></td>
<td>safety</td>
</tr>
<tr>
<td>GIS can be integrated with aeronautical applications at a single internet portal</td>
<td>O&amp;M</td>
<td>Governance, safety,</td>
</tr>
<tr>
<td>for submission as well as delivery of airport and related aeronautical data</td>
<td></td>
<td>environment</td>
</tr>
<tr>
<td>GIS based systems can be used for managing land development around airports,</td>
<td>Time,</td>
<td>governance</td>
</tr>
<tr>
<td>including approval for new constructions in the vicinity of airports (e.g. NOCAS</td>
<td>governance</td>
<td></td>
</tr>
<tr>
<td>system by the Airports Authority of India)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### 4.4.3 Maritime and inland navigation

Table [4.3] summarises opportunities in the maritime and inland navigation sector.

**Table 4.3:** Applications of geospatial technology in maritime and inland navigation sector

<table>
<thead>
<tr>
<th>Application context</th>
<th>Phase</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integration of data from LiDAR and hydrographic surveys help assist in aspects related to dredging, preparation of the models of coastal features and virtual representations of near-shore structures</td>
<td>Planning, O&amp;M</td>
<td>Time, quality, safety</td>
</tr>
<tr>
<td>Automatic classification of coastal and marine infrastructure using a combination of LiDAR and photo imaging assists in port construction and management</td>
<td>Planning &amp; construction</td>
<td>Time</td>
</tr>
<tr>
<td>The LiDAR reflectivity signatures let automatic identification and georeferencing of coastal signage, buoys and other objects</td>
<td>O&amp;M</td>
<td>Time, quality, safety</td>
</tr>
<tr>
<td>GIS based modelling in combination with hydrographic surveys are used for the preparation of navigational maps in inland waterways and near harbours</td>
<td>O&amp;M</td>
<td>Quality, safety</td>
</tr>
</tbody>
</table>
4.5 Case studies for the application of geospatial technology in the transport sector

4.5.1 Road sector

4.5.1.1 Planning

Re-engineering design of NH-40, Meghalaya, India

- **What was the application?** Design, visualise and refine right-of-way alignment by considering multiple alignment alternatives, and arrive at an alignment that avoids deep valleys and hillocks while retaining existing two-lane bridges in good condition.

- **Where did geospatial technologies fit in?** AAIST was used to optimise the right-of-way alignment.

- **What benefits did geospatial technologies bring?**
  - **Time:** Reduced design time by 40%

Construction of Six-Lane Elevated Highway at Badarpur, Delhi & Haryana, India

- **What was the application?** Alignment design of new six-lane elevated highway on the Delhi-Agra section of NH-2. The new alignment had to be designed in such a way that it would minimise impact on urban settlements and construction activities for the Delhi Metro Rail project.

- **Where did geospatial technologies fit in?** AAIST was used to optimise the right-of-way alignment.

- **What benefits did geospatial technologies bring?**
  - **Time:** Reduced design schedule by 35 days
  - **Money:** Reduced 20% of design costs

4.5.1.2 Design and construction

Road construction evaluation study using construction automation using machine control solutions - Malaga, Spain

- **What was the application?** Two identical 80m roads were built, one using traditional equipment and one using construction automation technology using machine control solutions. The road construction included cuts and fills, curves, elevation changes and super elevation. The objective of this exercise was to evaluate the efficiency improvement achieved using construction automation technology with machine control solution.
4.5. Case studies for the application of geospatial technology in the transport sector

- **Where did geospatial technologies fit in?** High accuracy location measurement systems are integrated with construction machines in order to automate construction. The work carried out consisted of stakeout alignment, excavating & grading of sub-grade, import & spreading of base course material, fine grading of base course and compaction. The positioning technologies used included a GPS base station and a GPS rover.

- **What benefits did geospatial technologies bring?**
  - **Time:** Reduced construction time by approximately 50%
  - **Fuel:** Reduced fuel consumption by 43%
  - **Quality:** Increased the number of measurement points within the required tolerance level by more than 50%

### 4.5.1.3 Operation and maintenance

**NHAI Road Information System**

- **What was the application?** National Highways Authority of India (NHAI) has developed Road Information System (RIS) for Golden Quadrilateral (GQ) for the length of 5,846 km. RIS comprises of computerised time series database on National Highways attributes like traffic analysis, pavement condition, road inventory, asset condition on the Geographical Information System (GIS) interface along with economic modelling with HDM IV software.

- **Where did geospatial technologies fit in?** GIS is an important component of the RIS. The GIS module is a user-friendly front-end for linking to any sub-system and will extract information for highway management in the form of standard viewing operations, standard thematic operations, standard edit operations and thematic map queries.

  **What benefits did geospatial technologies bring?**
  - **Time:** Reduce time needed for managing information related to assets
  - **Quality:** Keep information accurate and up-to-date easily

**GIS enterprise solution for Roads and Transport Authority (RTA), Dubai, UAE**

- **What was the application?** A GIS based enterprise solution was developed for catering Decision Support System with GIS using for Advanced Web GIS tools and functionalities for Map Navigation, Layer Management, cascading maps, enabling better citizen centric services for travel planning, analyzing transport options and connectivity, query parking availability and places of interest, etc. It provided tools to check and monitor work progress of various projects facilitating near real time monitoring and easy maintenance and management of assets.
4.5. Case studies for the application of geospatial technology in the transport sector

- **Where did geospatial technologies fit in?** Geospatial technology allowed seamless integration and compilation of disparate data sources both spatial and non-spatial and facilitated complete analysis of a large amount of information in a single window platform.

**What benefits did geospatial technologies bring?**

- **Time:** The time needed for performing various point to point route and travel time analysis, monitoring project progress and status monitoring was reduced

- **Quality:** The solution allowed access to updated, reliable information for reducing traffic congestion

**Enterprise asset management system for Bahrain**

- **What was the application?** Bahrain Ministry of Works (MOW) was in need of an Enterprise Asset Management System, with GIS as core to the system. The requirement was to accommodate existing content, and facilitate importing Computer Aided Design and Drafting (CADD) content on a regular basis. The GIS based asset management system allowed spatial extract, load and transfer process, reducing enterprise wide data interoperability challenges for data translation and transformation.

- **Where did geospatial technologies fit in?** Geospatial technologies provided seamless integration of asset register, document management, project management and complete digital workflow on asset requirements in spatial context. Combining GIS with asset management provided a pervasive foundation for a scalable and robust solution for asset planning, maintenance and customer service management.

**What benefits did geospatial technologies bring?**

- **Time:** Enabled effective maintenance and management of infrastructure assets. Provided data conversion tools to upload standardised asset data and reduce duplication of data.

- **Cost:** Capital and recurrent cost of infrastructure assets were lowered by providing a tool to analyse and schedule a more realistic preventive and predictive maintenance of assets

**Capital Project Request Management System (CAPRMS) for Qatar**

- **What was the application?** The solution enabled Qatar’s public works agency Ashghal to coordinate infrastructure capital project budget applications by numerous government agencies. The implemented solution was a web-based system to handle massive collaboration effort.

- **Where did geospatial technologies fit in?** Geospatial solutions were used for integrating GIS with CAPRMS standalone systems, customised business workflows for Ashghal, Qatar. The geo-spatial solution allowed managing capital projects throughout their life-cycle: from initiation and budget approvals,
4.5. Case studies for the application of geospatial technology in the transport sector

to monitoring their execution. The multilingual aspect of the sub solution enhanced the usability and brought in better understanding and participation of various external stakeholders by representing the information in regional language.

**What benefits did geospatial technologies bring?**
- **Cost:** Geospatial technology brought visibility to where these projects were planned, and where potential cost savings could be realised.

### 4.5.2 Railways

#### 4.5.2.1 Planning

**Long Range Decision Support System (LRDSS) - Indian Railways**

- **What was the application?** *Long Range Decision Support System (LRDSS)* was initiated by Indian Railways in 1994 to evaluate the diverse impact of the interdisciplinary investments on Indian Railways. The system was aimed to develop highly scientific database system to prepare investment plans for the railways while addressing the long term financial viability of these plans. Its aim was to act as an objective tool for effective planning and prioritisation of capacity enhancement based on various traffic projections that were predicted for the coming two decades.

- **Where did geospatial technologies fit in?** LRDSS is built upon state-of-the-art GIS technology, with a suite of simulation and optimisation tools built on top of it. Decision makers can construct and test *what-if* scenarios using the system. The combination of geospatial systems with simulation and modelling tools is a common practice in the transport sector.

- **What benefits did geospatial technologies bring?**
  - **Time:** Carry out analysis faster, as compared to using traditional sources
  - **Money:** Carry out more complex analysis arriving at more efficient design solutions

#### 4.5.2.2 Design and construction

**Chennai Metro Rail Project**

- **What was the application?** Design of right-of-way alignment through a dense urban environment, with sufficient clearances above and below ground.

- **Where did geospatial technologies fit in?** AAIST was used to optimise the right-of-way alignment.

- **What benefits did geospatial technologies bring?**
  - **Money:** Reduced alignment length by 100m, saving $5m USD
4.5. Case studies for the application of geospatial technology in the transport sector

4.5.2.3 Operation and maintenance

Railway Asset Management System in Turkey

What was the application? The Turkish State Railways transferred its network data into GIS environment about more than a decade ago. This was done to provide best quality decision support systems (DSS). Turkish railways have been able to successfully transfer highly complex data related to its network on GIS platform. The track section data that was available in different databases along with the asset management data was transferred into GIS platform to provide detailed analysis of track conditions and accordingly devise work planning schedules for different assets. The information captured on the GIS database on facilities conditions and their performances helped the managers to develop work plan schedule. It also enabled these asset managers to prepare short as well as long-range strategies for their Asset Management System (AMS). Since GIS provides the location of any event or asset as well as their relationship or proximity to another event or asset it plays critical role in decision making on various aspects of the event or asset right from design to construction, or maintenance. GIS based AMS have helped the Turkish Railways in analysing the actual track assets in real time and providing consequent requisite decision support concerning the assets (Guler et al., 2004). Railway asset management systems are commonly used across the world. These are GIS based systems to map all railway related assets and store data related to operation and maintenance of those assets. The new GIS based system planned by Indian Railways (see section 3.2.2) is an example of this.

Where do geospatial technologies fit in? Railway asset management systems are essentially GIS applications customised to support the operation and maintenance of railway systems.

What benefits do geospatial technologies bring?

- **Time**: Reduce time needed for managing information related to assets
- **Quality**: Keep information accurate and up-to-date easily

4.5.3 Aviation

4.5.3.1 Planning

Environmental Permit Support for Sea-Tac airport, Seattle, USA

- **What was the application?** The Port of Seattle’s master-plan called for the construction of a third runway over a newly built embankment over existing water bodies. The authorities had to obtain water-quality permits during the planning stages before the work could be carried out.

- **Where did geospatial technologies fit in?** The authorities had to address the issue of contaminant migration via subsurface utility lines in order to obtain required permits. GIS was used to map and visualise subsurface utility lines, in addition to presenting complex information related to ground water and geological conditions.
4.5. Case studies for the application of geospatial technology in the transport sector

- **What benefits did geospatial technologies bring?** The GIS based analysis helped the port authorities to obtain requisite permissions.

4.5.3.2 Design and construction

**Phase I modernisation programme at O’Hare Airport, Chicago, USA**

- **What was the application?** As a part of the modernisation programme, 14.7 million cubic yards (11.24m cubic metres) of earthwork had to be undertaken at a cost of 150 million USD. The movement of the earthwork has to be optimised to minimise costs.

- **Where did geospatial technologies fit in?** GIS software was used to carry out earthwork analysis to compute cut-and-fill volumes.

- **What benefits did geospatial technologies bring?** The analysis using GIS technologies helped save 1.5 million USD per every million cubic yard of earthwork, or approximately 22 million USD in total.

4.5.3.3 Operation and maintenance

**Airport information system for Ataturk airport, Istambul, Turkey**

- **What was the application?** A GIS based application (Kavzoglu et al., 2006) was created from scratch by importing available design drawings to help manage airport operation.

- **Where did geospatial technologies fit in?** GIS was an integral component of the airport information system.

- **What benefits did geospatial technologies bring?**
  - **Time:** Airport staff can use a single system as opposed to numerous disparate systems
  - **Quality:** Cross referencing between multiple datasets in a single GIS platform can result in increased planning efficiency and service improvement

4.5.4 Maritime and inland navigation

4.5.4.1 Planning

**Marine Spatial Data Infrastructure, Japan**

- **What was the application?** A pilot Marine Data Spatial Infrastructure (MSDI) system was developed in Japan to integrate, and provide marine-related information now dispersed among agencies, with a view to organising
4.5. Case studies for the application of geospatial technology in the transport sector

such information efficiently and rationally in a user-friendly manner, as well as to contributing to the development of marine industry, promotion of basic research and streamlining of marine surveys (Muto et al., 2010).

- **Where did geospatial technologies fit in?** GIS is an integral part of Spatial Data Infrastructure projects, and the prototype Japanese MSDI is developed as a web-based GIS system.

- **What benefits did geospatial technologies bring?**
  - **Time:** MSDI will act as a one-stop-service for all marine related information to users.
  - **Safety:** Most updated information can be made available to all users ensuring safety of marine activities. Information such as bathymetry charts, shipping routes, location of environmentally sensitive areas, sedimentological maps, active faults, boat accident maps etc. are included within MSDI to facilitate this.

4.5.4.2 Design and construction

**Breakwater/Dike construction using machine control solutions, Qatar**

- **What was the application?** Use of machine control solutions to profile the outer dike of the new Ras Laffan LNG terminal and dike profile creation for other offshore projects such as The Pearl, Qatar and the New Doha International Airport where 60% of the land is reclaimed from the Arabian Gulf.

- **Where did geospatial technologies fit in?** Construction automation using machine control solution for dredging work. RTK GPS was used as the location measurement technology, and other sensors such as angle sensors were used on crawler excavator machines.

- **What benefits did geospatial technologies bring?**
  - **Time:** Improved productivity
  - **Quality:** Seamless integration between design and construction

4.5.4.3 Operation and maintenance

**Vessel Traffic Management System (VTMS), Ministry of Shipping, India**

- **What was the application?** All ships are mandated to be installed with an Automatic Identification System (AIS) by the International Maritime Organisation (IMO). Vessel Traffic Management System (VTMS) identifies vessels fitted with AIS as soon as they are within the range of VTMS radars (20-30 nautical miles) and tracks them in real-time. VTMS systems are installed in many ports in India including Ennore, Kochi, Paradeep, Tutricon and Vishakhapatnam.
4.5. Case studies for the application of geospatial technology in the transport sector

- **Where did geospatial technologies fit in?** Geospatial and position measurement technologies such as RADAR, GPS and GIS are used in a VTMS system.

- **What benefits did geospatial technologies bring?** Reduces congestion and minimises collisions and accidents in harbour areas.
Conclusion

This white paper summarised the areas where geospatial technologies can be applied in the transport sector. In addition, the paper presented an overview of the transport infrastructure market in India, specific opportunities for the application of geospatial technologies in India over the next five years as well as case studies where geospatial technologies have been successfully applied in the past. It is hoped that this paper is useful for professionals from the geospatial industry and the transport industry alike.

There is a huge focus in India on building and upgrading the nation’s infrastructure, including the transport infrastructure, over the next decade. The central government has earmarked Rs. 17,48,685 Crores during the 12th Five Year Plan in the transport infrastructure sector. It has been shown in this white paper that geospatial technologies can be applied to save time, reduce costs, improve safety, quality, governance and environment during planning, design, construction, operation and maintenance of transport infrastructure in highway, railway, aviation and maritime and inland navigation sectors. AGI sees a huge role for geospatial technologies to contribute constructively to this nation building process.

AGI would also like to conclude this white paper by making the following recommendations in this context.

- **Having access to accurate reference spatial data is a pre-requisite for successfully applying geospatial technologies.** The government should implement policies that make the creation and acquisition of spatial data easy and reduce red tape. AGI would like to point out the currently cumbersome process of obtaining licences for aerial photography as a case in point where the government could simplify the application process.

- **Based on worldwide examples, it is clear that construction automation using machine control solutions has a huge potential to accelerate the pace of infrastructure building, improve quality, reduce material wastage and costs and improve governance.** Hence, the government should mandate the use of this technology in major transport infrastructure projects such as the upgradation...
of National Highways and the construction of National Expressways. Civil engineering contractors should also be encouraged by the benefits provided by the use of construction automation using machine control solutions and embrace its use for all transport infrastructure projects.

- Operational efficiency of maintaining the transport infrastructure, including asset management functions, can be improved by the use of geospatial technologies. Parties responsible for the maintenance of transport infrastructure should use GIS based systems to keep track of information about infrastructure assets and their maintenance logs. This can improve operational efficiency reduce maintenance costs.
Bibliography


Bibliography


Wei Wang, Yueguang Zong, and Jinliao He. GIS-aided port area plane design on project for Donghuo island-port in Fuzhou. In Lin Liu, Xia Li, Kai Liu, Xinchang Zhang, and Xinhao Wang, editors, Geoinformatics 2008 and Joint Conference on GIS and Built Environment: The Built Environment and Its Dynamics, volume Proc. SPIE 7144, 2008b. URL http://dx.doi.org/10.1117/12.812730.

## Breakdown of estimated transport infrastructure investment

<table>
<thead>
<tr>
<th>Initiative</th>
<th>Estimated investment (Rs. Crores)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major National Highways</td>
<td>3,23,774</td>
</tr>
<tr>
<td>State Highways Development Programme</td>
<td>6,30,550</td>
</tr>
<tr>
<td>Rural roads</td>
<td>2,00,000</td>
</tr>
<tr>
<td>Delhi-Mumbai Industrial Corridor</td>
<td>14,425</td>
</tr>
<tr>
<td>Arunachal Pradesh</td>
<td>37,674</td>
</tr>
<tr>
<td>National Expressways</td>
<td>4,140</td>
</tr>
<tr>
<td>Left Wing Extremism affected areas</td>
<td>5,376</td>
</tr>
<tr>
<td>Tribal Special Programme</td>
<td>2,976</td>
</tr>
<tr>
<td>Andhra Pradesh, Jharkhand &amp; Orissa border area</td>
<td>1,100</td>
</tr>
<tr>
<td>Jammu &amp; Kashmir</td>
<td>700</td>
</tr>
<tr>
<td>Minor port connectivity</td>
<td>5,000</td>
</tr>
<tr>
<td>Airport connectivity</td>
<td>1,800</td>
</tr>
<tr>
<td>Border Roads Organisation</td>
<td>3,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>12,30,515</strong></td>
</tr>
</tbody>
</table>

*Table A.1: Estimated infrastructure investment in the roadway sector over the next five years*
## Breakdown of estimated transport infrastructure investment

<table>
<thead>
<tr>
<th>Initiative</th>
<th>Estimated Investment (Rs. Crores)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New line construction</td>
<td>1,22,300</td>
</tr>
<tr>
<td>Gauge conversion</td>
<td>17,810</td>
</tr>
<tr>
<td>Track doubling</td>
<td>32,513</td>
</tr>
<tr>
<td>Mumbai-Ahmedabad high-speed corridor</td>
<td>60,000</td>
</tr>
<tr>
<td>Mumbai suburban elevated rail corridor</td>
<td>20,000</td>
</tr>
<tr>
<td>Port connectivity</td>
<td>5,000</td>
</tr>
<tr>
<td>Dedicated freight corridors</td>
<td>10,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2,67,623</strong></td>
</tr>
</tbody>
</table>

**Table A.2**: Estimated infrastructure investment in the railway sector over the next five years

<table>
<thead>
<tr>
<th>Initiative</th>
<th>Estimated Investment (Rs. Crores)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment in airports</td>
<td>67,500</td>
</tr>
<tr>
<td>Investment in air navigation systems</td>
<td>4,400</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>71,900</strong></td>
</tr>
</tbody>
</table>

**Table A.3**: Estimated infrastructure investment in the aviation sector over the next five years

<table>
<thead>
<tr>
<th>Initiative</th>
<th>Estimated Investment (Rs. Crores)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major government owned ports</td>
<td>22,757</td>
</tr>
<tr>
<td>Major private owned ports</td>
<td>51,037</td>
</tr>
<tr>
<td>Non-infrastructure investment included in figures above</td>
<td>(1,980)</td>
</tr>
<tr>
<td>Estimated investment by state governments in non-major port development</td>
<td>1,06,833</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,78,647</strong></td>
</tr>
</tbody>
</table>

**Table A.4**: Estimated infrastructure investment in the maritime sector over the next five years
Appendix B

Remote sensing satellites and available data
Remote sensing satellites and available data

<table>
<thead>
<tr>
<th>Satellite Type</th>
<th>Product</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disaster Monitoring</td>
<td>PAN</td>
<td>2.5m and 5m, Stereo Images</td>
</tr>
<tr>
<td>Constellation</td>
<td>MSS</td>
<td>22m and 32m: Green, Red and NIR bands</td>
</tr>
<tr>
<td>EROS</td>
<td>EROS-A</td>
<td>Panchromatic resolution of 1.9 m</td>
</tr>
<tr>
<td></td>
<td>EROS-B</td>
<td>Panchromatic resolution of 0.70 m</td>
</tr>
<tr>
<td>FORMOSAT-2</td>
<td>PAN</td>
<td>2m</td>
</tr>
<tr>
<td></td>
<td>MSS</td>
<td>8 m: Blue, Green, Red, and NIR bands</td>
</tr>
<tr>
<td>IKONOS</td>
<td>PAN</td>
<td>1m</td>
</tr>
<tr>
<td></td>
<td>MSS</td>
<td>4 m: Blue, Green, Red, NIR bands; Quickbird</td>
</tr>
<tr>
<td></td>
<td>PAN</td>
<td>0.70 m</td>
</tr>
<tr>
<td></td>
<td>MSS</td>
<td>2.5 m: Blue, Green, Red, NIR bands</td>
</tr>
<tr>
<td>RapidEye</td>
<td>MSS</td>
<td>6.5 m: Blue, Green, Red, Red Edge, NIR</td>
</tr>
<tr>
<td>SPOT-5</td>
<td>PAN</td>
<td>5m</td>
</tr>
<tr>
<td></td>
<td>MSS</td>
<td>10 m: Green, Red and NIR bands; 20 m: SWIR band</td>
</tr>
<tr>
<td>TerraSAR-X</td>
<td>RADAR</td>
<td>Flexible resolution (1m / 3m / 18.5m)</td>
</tr>
<tr>
<td>COSMO-SkyMed</td>
<td>Spotlight</td>
<td>1m</td>
</tr>
<tr>
<td></td>
<td>Stripmap: HIMAGE</td>
<td>3m</td>
</tr>
<tr>
<td></td>
<td>Stripmap: Ping Pong</td>
<td>15m</td>
</tr>
<tr>
<td></td>
<td>ScanSAR: Wide Region</td>
<td>30m</td>
</tr>
<tr>
<td></td>
<td>ScanSAR: Huge Region</td>
<td>100m</td>
</tr>
<tr>
<td>WorldView-1</td>
<td>PAN</td>
<td>0.5m</td>
</tr>
<tr>
<td>WorldView-2</td>
<td>PAN</td>
<td>0.5m</td>
</tr>
<tr>
<td>GeoEye-1</td>
<td>PAN</td>
<td>0.41m</td>
</tr>
<tr>
<td></td>
<td>MSS</td>
<td>1.65 m: Blue, Green, Red, NIR bands</td>
</tr>
<tr>
<td>Pleiades-1</td>
<td>PAN</td>
<td>0.50 m (B W and colour)</td>
</tr>
<tr>
<td></td>
<td>MSS</td>
<td>2.0 m: Blue, Green, Red, NIR bands</td>
</tr>
</tbody>
</table>

Table B.1: List of commercial remote sensing satellites
Remote sensing satellites and available data

<table>
<thead>
<tr>
<th>Satellite Type</th>
<th>Product</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRS P4 (Oceansat 1)</td>
<td>Ocean Colour Monitor (OCM)</td>
<td>OCM is a eight channel sensor, operating in the visible and NIR regions</td>
</tr>
<tr>
<td></td>
<td>Multi-frequency Scanning</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Microwave Radiometer (MSMR)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&amp; Microwave region, which</td>
<td></td>
</tr>
<tr>
<td></td>
<td>gives the brightness</td>
<td></td>
</tr>
<tr>
<td></td>
<td>temperature of the surface</td>
<td></td>
</tr>
<tr>
<td>Oceansat-2</td>
<td>Ocean Colour Monitor (OCM)</td>
<td>360 m 8-band multi-spectral camera operating in the Visible-Near IR Spectral</td>
</tr>
<tr>
<td></td>
<td>Ku-Band Pencil Beam</td>
<td>range</td>
</tr>
<tr>
<td></td>
<td>Scatterometer</td>
<td>50 km with Active microwave sensor</td>
</tr>
<tr>
<td></td>
<td>Radio Occultation</td>
<td>For atmospheric studies</td>
</tr>
<tr>
<td></td>
<td>Sounding Unit (ROSA)</td>
<td></td>
</tr>
<tr>
<td>IMS-1</td>
<td>Multi-spectral camera</td>
<td>For Natural resources monitoring / management like agriculture (crop condition</td>
</tr>
<tr>
<td></td>
<td>(Mx) and Hyper-Spectral</td>
<td>assessment and crop acreage yield estimation), forest coverage and deforestation,</td>
</tr>
<tr>
<td></td>
<td>Imager (HySI)</td>
<td>urban infrastructure development, land use and waste land mapping, coastal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>features mapping, coral reef mapping and land slide studies</td>
</tr>
<tr>
<td>CARTOSAT-2</td>
<td>PAN</td>
<td>0.8 m, Stereo Images</td>
</tr>
</tbody>
</table>

**Table B.2:** List of multi-purpose Indian remote sensing satellites
<table>
<thead>
<tr>
<th>Satellite Type</th>
<th>Product</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRS P3</td>
<td>Wide Field Sensor (WiFS)</td>
<td>188 m: R, MIR and NIR bands</td>
</tr>
<tr>
<td></td>
<td>Modular Optoelectronics Scanner (MOS)</td>
<td>For ocean application scientists in developing necessary algorithms for extracting ocean parameters such as phytoplankton, yellow substance and suspended sediments in ocean waters</td>
</tr>
<tr>
<td>IRS 1A</td>
<td>LISS I</td>
<td>70.5 m: Blue, Green, Red and NIR bands</td>
</tr>
<tr>
<td></td>
<td>LISS II (A&amp;B)</td>
<td>36.25 m: Blue, Green, Red and NIR bands</td>
</tr>
<tr>
<td>IRS 1B</td>
<td>LISS I</td>
<td>70.5 m: Blue, Green, Red and NIR bands</td>
</tr>
<tr>
<td></td>
<td>LISS II</td>
<td>36.25 m: Blue, Green, Red and NIR bands</td>
</tr>
<tr>
<td>IRS 1C</td>
<td>PAN</td>
<td>5.8m</td>
</tr>
<tr>
<td></td>
<td>LISS III</td>
<td>23.5 m: Green, Red, NIR and 70.5 SWIR bands</td>
</tr>
<tr>
<td></td>
<td>WiFS</td>
<td>169-188 m: Red and NIR bands</td>
</tr>
<tr>
<td>IRS 1D</td>
<td>PAN</td>
<td>5.2-5.8 m</td>
</tr>
<tr>
<td></td>
<td>LISS III</td>
<td>23.5 m: Green, Red, NIR and 70.5 SWIR bands</td>
</tr>
<tr>
<td></td>
<td>WiFS</td>
<td>169-188 m: Red and NIR bands</td>
</tr>
<tr>
<td>IRS P5 (CARTOSAT-1)</td>
<td>PAN</td>
<td>2.5 m, Stereo Images</td>
</tr>
<tr>
<td>IRS P6 (Resourcesat 1)</td>
<td>LISS IV</td>
<td>5.8 m: Green, Red and NIR bands</td>
</tr>
<tr>
<td></td>
<td>LISS III</td>
<td>23.5 m: Green, Red, NIR and SWIR bands</td>
</tr>
<tr>
<td></td>
<td>A-WiFS</td>
<td>56 m: Green, Red, NIR and SWIR bands</td>
</tr>
</tbody>
</table>

**Table B.3:** List of Indian remote sensing satellites: IRS Series
OGC initiatives in the transport sector

The Open Geospatial Consortium (OGC) is an international industry consortium of 465 companies, government agencies and universities participating in a consensus process to develop publicly available interface standards for geospatial data. Data providers and information service provider collect, process and store current information on traffic and travel conditions and other information about the current state of the transport network. This information can be shared on a need basis with various stakeholders. Such data sharing can be best enabled through an initiative by the Open Geospatial Consortium (OGC). For example, OGC provided support for the Federal Geographic Data Committee (FGDC) led Geospatial One-Stop initiative launched as part of the U.S. e-government programme. OGC developed and tested interoperable capabilities, including (in the Geospatial One-Stop Transportation Pilot Activity) capabilities to address the semantic differences that exist between similar geospatial data sets developed and maintained by federal, state and local government and other organisations. This involved development of Unified Modelling Language (UML) and processes to generate Geography Mark-up Language (GML) representation of the Transportation Framework Standard (roads, transit and rail). This work was related to OGC’s support for the Modelling Advisory Teams (MAT) established by the FGDC to accelerate the US nationwide consensus development of National Spatial Data Infrastructure (NSDI) Framework Data Standards.