KNOWLEDGE BASED TRAIN NAVIGATION SYSTEM

Ph.D. THESIS

by

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A THESIS

Submitted in partial fulfilment of the requirements for the award of the degree

of

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in

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this thesis entitled **"KNOWLEDGE BASED TRAIN NAVIGATION SYSTEM"** in partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy and submitted in the Department of Civil Engineering of the Indian Institute of Technology Roorkee, Roorkee is an authentic record of my own work carried out during a period from December, 2009 to June, 2015 under the supervision of Dr. Kamal Jain, Professor, Department of Civil Engineering, Indian Institute of Technology Roorkee, Uttarakhand and Dr. M. Shashi, Assistant Professor, Department of Civil Engineering, National Institute of Technology Warangal, Warangal, Telangana.

The matter presented in the thesis has not been submitted by me for the award of any other degree of this or any other Institute.

(Mohd Shoab)

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

(Dr. M. Shashi)
Supervisor

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Date: June , 2015

Abstract

Safe and reliable services is a fundamental requirement of the railway as thousands rely on this service as their prime mode of transportation. The railway accidents accounts to death, injury and a large cost to the government. The most significant contributors of accidents involve track and signaling faults. Traditional railway signaling and control systems have problems such as difficulty in enhancing the capability of railway lines, train delay caused by signal failure, large investment and maintenance, incompatibility and non-interoperability between different systems.

In the past several years, GNSS, Communication technologies and GIS have attracted many attentions around the world and these were widely applied in navigation for aviation, ground vehicle and marine application. On the other hand, advanced railway operating systems have been widely used these technologies to guarantee the safety and efficiency of the railway network. The efficiency of these systems is based on the availability of reliable train positioning. According to high navigation performance of GNSS, it is a great choice of train positioning system, since it has such important benefits as lower initial costs and lower maintenance.

In this thesis, a new train navigation and control system is proposed which is integration of GNSS, GIS and GSM technologies. With the rapid development of internet, wireless communication, 3G technologies and the formulation and standardization of related protocols, the integration of GNSS, GIS and GSM technologies have been applied in many fields to provide various users with location information on electronic map. The position and speed of train in terms of Latitude, Longitude and speed is obtained by GNSS. To transmit the data obtained data to the central server, GSM/GPRS is used. By this a user can trace a train on GIS ready map using internet.

To develop this navigation and control system, first a Location Based Asset Management System (AMS-R) is developed which collects various assets information along with their location information. This information is transmitted to central server using GSM/GPRS network. Further, this location information about assets is utilized into Knowledge Based Train Operator Module and Web Based Train Navigation and Tracking System. Knowledge Based Train Operator Module uses rule based knowledge based approach to take decisions in safety critical situations while approaching to various POI's. Another important task of this module is providing track maintenance updates to

loco pilot. While approaching to maintenance segment this module generates warning for loco pilot about speed restrictions. To track real time location of trains over the web a Web Based Train Navigation and Tracking System is developed. This system is a web application which gets location information of trains from central server and displays them on map. The users of this system can be categorized in to three categories administrator, station master and general users which have different roles. Administrator can manage users, trains etc. and track all trains in a single view, station master can track all trains in single view and can change status of signals at last general user can track only one train at a time.

Finally, a Trip Navigation and Analysis System is developed to analyze the running performance of train in terms of table and graph. This system can be used for both trains and individual vehicles like car, bus, truck etc. This is an interactive system, when user move cursor over graph, the corresponding location, speed and time information is shown on integrated Google Earth as well as in data panel also.

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List of Abbreviations

ABS	Automatic Block Signaling
ABU	Automatic Breaking Unit
ACD	Anti-Collision Device
ADTC	Australian Digital Train Control
ADTCS	Australian Digital Train Control System
AFB	Air Force Base
AI	Artificial Intelligence
AJAX	Asynchronous JavaScript and XML
ALSN (АЛСН)	Automatic Locomotive Signaling-Continuous (автоматическая локомотивная сигнализация непрерывного действия)
AMS-R	Asset Management System-Railway
API	Application Programming Interface
AREMA	American Railway Engineering and Maintenance-of-Way Association
ARTC	Australian Rail Track Corporation
AS	Anti Spoofing
ATACS	Advance Train Administration and Communication System
ATC	Automatic Train Control
ATMS	Advance Train Management System
ATO	Automatic Train Operation
ATP	Automatic Train Protection
ATS	Automatic Train Stop
ATS-P	ATS using pattern renewal transponder
ATS-S	ATS using S-type transponder
BOC	Binary Offset Carrier
BPSK	Binary Phase Shift Keying
C/A	Coarse/Acquisition
CBTC	Communication Based Train Control
CCU	Command Control Unit
CDMA	Code Division Multiple Access

CLW	Chittranjan Locomotive Works
CNSA	Chinese National Space Administration
CNSS	Compass Navigation Satellite System
CNY	Chinese Yuan Renminbi
CS	Commercial Service
CSNPC	China Satellite Navigation Project Center
CSS	Cascading Style Sheet
CTCS	Chinese Train Control System
D-ATC	Digital and Decentralized ATC
DF	Dual Frequency
DGNSS	Differential GNSS
DGPS	Differential GPS
DMU	Diesel Multiple Unit
DOD	Department of Defense
DS-ATC	Digital Communication & Control for Shinkansen-ATC
DSS	Decision Support System
ECEF	Earth Centered Earth Fixed
ECONFIN	Economic and Financial Affairs Council
EGNOS	European Geostationary Navigation Overlay Service
EI	Electronic Interlocking
EJTC	East japan Train Control
eMLPP	Priority and Pre-emption
EMU	Electric Multiple Unit
ERTMS	European Rail Traffic Management System
ESA	European Space Agency
ETCS	European Train Control System
ETML	European Traffic Management Layer
EU	European Union
FAA	Federal Aviation Administration
FDMA	Frequency Division Multiple Access
FMOS	Fright traffic Management Operation System
FOC	Full Operational Capability

GAGAN	GPS Aided Geo Augmented Navigation
GBAS	Ground Based Augmentation System
GBP	British Pound
GDP	Gross Domestic Production
GEO	Geosynchronous
GIS	Geographic Information System
GiST	Generalized Search Tree
GLONASS	GLObal NAvigation Satellite System
GNSS	Global Navigation Satellite System
GOI	Government of India
GPRS	General Packet Radio Service
GPS	Global Positioning System
GRAS	Ground based Regional Augmentation System
GSM	Global System for Mobile Communications
GSM-R	Global System for Mobile Communication-Railway
GST	Galileo System Time
GTRF	Galileo Terrestrial Reference System
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol
IDE	Integrated Development Environment
IE	Internet Explorer
IIS	Internet Information Service
IIT-K	Indian Institute of Technology Kanpur
IMO	International Maritime Organization
IMPS	Immediate Payment Service
IP	Internet Protocol
IPPs	Ionospheric Precise Points
IR	Indian Railway
IRCTC	Indian Railway Catering & Tourism Corporation LTD
IRIM	Ionospheric Residual Integrity Monitoring
IRNSS	Indian Regional Navigation Satellite System
ISS	International Space Station

ITRS	International Terrestrial Reference System
ITU	International Telecommunication Union
JNR	Japan National Railway
JR	Japan Railway
JSON	JavaScript Object Notation
KBS	Knowledge Based System
KLUB-U (КЛУБ-U)	Integrated Train Protection System-Unified (Комплексное локомотивное устройство безопасности-Unified)
KRCL	Knonakn Railway Corporation Limited
KRRI	Korea Railroad Research Institute
KRTCS	Korean Radio Train Control System
LAAS	Local Area Augmentation System
LBS	Location Based Services
LC	Level Crossing
LDGPS	Local area DGPS
LGF	LAAS Ground Facility
MCC	Master Control Center
MEDLL	Multipath Estimation Delay Look Loop
MEMU	Main line EMU
MEO	Medium Earth Orbit
MMI	Man-Machine Interface
MSAS	Multi-functional Satellite Augmentation System
NAVSTAR	NAVigation Satellite Time And Ranging
NDGPS	Nationwide DGPS
NMEA	National Marine Electronics Association
OFC	Optical Fiber Cable
OGC	Open Geospatial Consortium
OS	Open Service
POI	Point Of Interest
PPP	Precise Point Positioning
PPP	Public-Private Partnership
PRN	Pseudorandom Noise

PRS	Public Regulated Service
PSLV	Polar Satellite Launch Vehicle
PTC	Positive Train Control
QPSK	Quadrature Phase Shift Keying
QZSS	Quasi-Zenith Satellite System
RAIM	Receiver Autonomous Integrity Monitoring
RAIMS	Risk Assessment Information Management System
RBC	Radio Block Centre
RCDSS	Railway Construction DSS
RDSO	Research Design and Standards Organization
RDSS	Radio Determination Satellite Service
REWD-IDSS	Intelligent Decision Support System of Railway Empty Wagon Distribution
RMS	Root Mean Square
RTK	Real Time Kinematics
RTOS	Real Time Operating System
SA	Selective Availability
SAR	Search and Rescue
SBAS	Satellite Based Augmentation System
SD	Standard Deviation
SDCM	System for Differential Correction and Monitoring
SF	Single Frequency
SIMRAN	Satellite Imaging for Rail Navigation
SIS	Signal in Space
SMS	Short Message Service
SNAS	Satellite Navigation Augmentation System
SOA	Service Oriented Architecture
SOAP	Simple Object Access Protocol
SoL	Safety of Life
SPS	Standard Positioning Service
SQL	Structured Query Language
SU	Soviet Union
SV	Space Vehicle

SVN	Satellite Vehicle Number
TAI	International Atomic Time
TATO	Timetable And Train Order
TCS	Train Control System
TETRA	Terrestrial Trunked Radio
TMIS	Train Movement Information System
TNAS	Trip Navigation and Analysis System
TNT	Train Navigator and Tracker
TOA	Time of Arrival
UI	User Interface
UIC	International Union of Railway
UID	Unique Identification
UK	United Kingdom
URI	Uniform Resource Identifier
USA	United States of America
USNO	U.S. Naval Observatory
UTC	Coordinated Universal Time
UTC-C	Chines UTC
VB	Visual Basic
VBS	Voice Broadcast Service
VGC	Voice Group Call
VHF	Very High Frequency
W3C	World Wide Web Consortium
WAAS	Wide Area Augmentation System
WADGPS	Wide-Area DGPS
WAGE	Wide Area GPS Enhancement
WGS84	World Geodetic System 1984
WMS	Web Map Service
XML	Extensible Markup Language

Chapter 1

Introduction

1.1 Brief History of Indian Railways

United States media reported the following quote about Indian Railway in 1853:

"The railway is a triumph, to which, in comparison, all over victories in the East seem tame and commonplace. The opening of Great Indian Peninsular Railway will be remembered by the natives of India when the battlefield of Plassey, Assaye, Meanee and Goojerat have become landmarks of history" (The Overland Telegraph and Courier, April 1853).

On the April 16th, 1853, at 3:35pm when a train with 14 railway carriage and 400 guests left Bombay's Bori Bunder for Thane, with a 21 gun salute, starts the era of railway in Indian history. It was hauled by three locomotives: Sindh, Sultan and Sahib. This journey took an hour and fifteen minutes (Indian Railways, 2007).

Mr. George Clark, the Chief Engineer of the Bombay Government brought the idea of railway to connect Bombay with Thane, Kalyan and with the Thal and Bhore Ghats inclines first occurred to, during a visit to Bhandup in 1843. Forty-two rail systems were there in India at the time of India's independence in 1947. It became one of the largest networks in the world in 1951 when the systems were nationalized as one unit (Indian Railways, 2007).

In 1832 plan for rail system in India was first put forward, but it took more than a decade to execute that plan. Governor-General of India Lord Hardinge permitted private capitalists to set up a rail system in India in 1844. Two new railway companies were created at that time and the East India Company was asked for assistance. The first train in India became operational on 22nd December, 1851, and was used for the transportation of construction material in Roorkee, A year and a half later, on 16th April, 1853, the first passenger train service was started between Bori Bunder, Bombay and Thana, covering a distance of 34 km (21 miles). This was the formal birth of railways in India (Indian Railways, 2007).

The existing rail networks were unrestrained in favor of zones in 1951 and a six zones came into being in 1952. Almost all railway manufacture units were indigenized, as the economy of India improved. Steam locomotives were phased out in favor of diesel and electric locomotives by 1985. The entire railway reservation system was modernized with computerization in 1995 (Indian Railways, 2007). According to Ministry of Railways, some facts about Indian Railways are as follows:

- Currently Indian Railway is one of the world's largest railway network.
- The Indian Railway act was enforced in 1890.
- The Railway Board was established in 1905.
- The Railway budget was separated from General budget in 1924.
- The first steam locomotive was manufactured by Chittranjan Locomotive Works (CLW) in 1950,
- The Integral Coach Factory was set up in 1956 at Parampur.
- The first Electric Locomotive "LOKMANYA" was manufactured by CLW in 1961.
- The first electric train made its Journey between Mumbai and Pune in 1962.
- In early sixties the Railway Minister Lal Bahadur Shastri was the first Railway Minister who, submitted his resignation following a fatal accident.
- Diesel Locomotive Works, Varanasi started its production in 1964.
- Indian Railways started running of Rajdhani Express trains in 1969.
- Palace on Wheel came into existence in 1982.
- The Metro train at Calcutta came into existence on 24th October, 1984.
- Indian Railways started running of Shatabdi Express train in 1988.
- Computer Reservation on Indian railway started in 1988
- Metro trains at Delhi came into existence from 25th Dec 2002.
- Fastest train in India is Delhi - Bhopal Shatabdi Express running at 150 kmph.
- Indian Railways having route of 65,808 kilometers.
- Indian Railways having 7,112 stations.
- It carries 23 Million passengers daily and 8,397 Million passengers annularity

- Indian Railways generates 12, 81,031.5 million rupees revenue projected on March 31, 2014.

1.2 Railway Signaling and Control System in India

Indian railway was built by the Britishers, most of the tracks were laid during the British Raj (The Signal Box, 2013) and the signaling also done in British way. Conventionally Indian Railways using three types of systems to navigate and control trains (Described in next Chapter) are as follows:

a. Timetable Operation.
b. Signaling System.
c. Block System.

Currently railway signaling and control system is a block signaling system, called Automatic Block Signaling (ABS) control system (Thomas et al., 2007). In this system, the train position is detected by track circuits which divide the railway tracks into many insulated rail blocks. The feed is used to provide the electrical circuit at one end of the blocks whilst the relay is at the other end of the block. When the track is not occupied, the relay completes the electrical current and is energized by the current. In this situation, the clear (or unoccupied) signal for this block is displayed. When a train enters into the block the axle of the train creates a short-circuit and the relay is de-energized and display signal for this block is stop or occupied (Palmer, 2012).

The railway line is divided into a series of blocks with series of signals in ABS and then functions to control the movement of trains between them through automatic signals. ABS operation is designed to allow trains operating in the same direction to follow each other in a safe manner without risk of rear-end collision while reducing costs and increasing capacity from manual block systems that required human operators. The automatic operation comes from an ability to detect if blocks are occupied or otherwise obstructed and then convey that information to approaching trains (Automatic Block Signaling, 2013). The ABS system is providing high level of safety for railway control and operation systems and it is still serving the industry well and continue in revenue service operation in many railway lines around the world. However, this technology has three major problems which restricts its service for future high speed and high density railway operation (Rumsey, 2006). These three problems are as follows:

- In this signaling and control system lots of track side signaling devices such as track circuits, transponders and other equipment’s are installed. All these devices are simplex with low reliability and it costs railway companies large investments and high operational and maintenance fees. The maintenance information is not sufficient of these type of devices which may cause long recovery time in case of a signal malfunction (Ishima et al., 2008).
- The ABS system divides rail track into many blocks, so that at a time only one train can be allowed to enter a fix block. When the train travels into a block, the whole block is reported to be occupied regardless of the length or the speed of the train and the exact position of the train in the block is unknown. Therefore, the length of the fixed block is kept sufficiently long to allow the highest speed and longest train to run within the block. When other trains which are not running at the highest speed travel in the fixed block, they are kept further apart in the minimum Safe Stopping Distance. In this sense, the capability of railway lines does not reach its maximum.
- Finally, the ABS system faces the safety risk and delay problems. In the ABS system if any equipment or wire is out of order or the power supply cut off, or the signal failed to be shown, the train delay would be caused. For the safety problem, the contaminants on the rail and the vandalism would cause the risk for the ABS system (Palmer, 2012).

Furthermore, in the strong competition with other public transport the railway industry is concerned with the customer requirements. Specially, the railway passenger requirements are simple and clear (Kenna, 2006; Alcouffe et al., 2001) some of these are:

- Safe Journey.
- Affordable Price.
- Quick Journey.
- More Frequency.
- Punctuality.
- Information.

Therefore, the future railway navigation and control system should at least have the following features:

- High safety integrity level.
- Low cost.
- High speed train operation.
- High density railway traffics.
- Accurate train positioning and speed.

The existing ABS system does not completely fulfill the above requirements. To meet these goals and objectives, the GNSS based knowledge based train navigation and control system could be an option for the future high speed and high density railway operation.

1.2.1 Limitations and Failures of Conventional Techniques

Indian railway is using three types of conventional systems to navigate and control trains. Like any other system, these systems also having some limitations, which are as follows:

- In time table operation, it is not confirmed that the track ahead is clear, only that it is scheduled to be clear. This system is not made to allow for engine failures and other such types of problems, but during timetable making there should be sufficient time between trains for the staff of a failed or delayed train to walk far enough to set warning flags, flares, and detonators or torpedoes to alert other train staff. Trains cannot be added, delayed, or rescheduled without advance notice in this system. This system is an inflexible system, it is necessity that the timetable must give trains a broad allocation of time to allow for delays, so the line is not in the possession of each train for longer than is otherwise necessary.
- Signaling and Block systems are used to control trains between stations and yards, and not normally within them.
- Signaling and Block system face the safety risk and delay problems. In these systems if any equipment or wire was out of order or power supply cut off, or signal failed to be shown, the train delay would be caused. For safety problem, the contaminants on the rail and the vandalism would cause the risk for signaling and block system.

- In India most blocks are absolute, so the block size is the same for all trains irrespective of their speed and braking performance. Thus the big safety distances required by fast trains are enforced on slower trains as well. This reduces track capacity.

Every year the railway industry incurs heavy losses due to fog. In the last 3 years the Indian Railways lost in access of 1 lakh crores due cancellation of trains, heavy delay in running trains and accidents occurring due to foggy conditions. In the month of extreme winters, winter comes along with fog. On the transportation system, this fog applies many restrictions. Due to extremely low visibility many serious rail accidents occur; causing severe loss to life and property and the trains get late by hours together causing difficulties to passengers and losses to the railways. Railway organizations followed a back-foot policy of cancelling certain trains and reducing the speed of many others by considerable margins causing complete muddle. The basic problem still lies to be the fact of poor visibility and the railways does not want to take any risks against life of passengers. Due to heavy fog and human errors train accidents took place so it raises serious concerns about railway safety. Speed limit during fog condition is 30 km per hour and in dense fog it is 8 km per hour internationally. Railway officials say most accidents are due to the failure of their own staff. But of the 177 accidents that occurred in 2008 to 2010, less than half were due to human errors (Mathur et al., 2012).

Due to above limitations, consequential train accidents over the years has been showing the requirement of improvement and phenomenal growth of traffic so the safety of passengers in Indian Railway remains to be a matter of serious concern. Table 1.1 shows accidents and Table 1.2 shows casualties and compensation due to failure of above conventional techniques.

Table 1.1: Accidents due to failure of conventional techniques (Source: Railway Report, 2013).

Year	Collisions	Derailments	Level Crossing Accidents	Fire in Train	Mics. Accidents	Total
2008-2009	13	85	69	3	7	177
2009-2010	9	80	70	2	4	165
2010-2011*	5	78	53	2	1	139
2011-2012	9	55	61	4	2	131
2012-2013*	6	48	58	8	-	120

* excludes Konkan Railway

Table 1.2: Casualties and Compensation due to failure of conventional techniques (Source: Railway Report, 2013).

Year	Number of Passengers		Compensation Paid (in lakh)
	Killed	Injured	
2008-2009	52	257	218.94
2009-2010	67	253	265.81
2010-2011*	235	385	585.79
2011-2012	98	578	498
2012-2013*	60	248	319.63

* excludes Konkan Railway

1.3 Applications of Global Navigation Satellite System (GNSS) in Railway

The GNSS has advantage of 24 hour real time positioning of users in all-weather conditions, free of charge for users and high navigation performance. The high performance of accuracy, integrity and availability provided by the GNSS and GNSS augmentation system have made the GNSS be widely applied in many applications.

Vehicles can use the GNSS to determine location, speed, direction, all of which can be displayed on the maps. GNSS receivers can also be installed on Boats and ships to enable navigation in lake, seas and oceans. GNSS and their augmentation systems are used in aviation for en-route navigation, approach, landing and departure of all flights. It is also used in surveying, mobile phones, location based services and mapping. The high accuracy performance of the GNSS makes it useful for all non-safety related application. Additionally, in future the integrity information can be provided by the GNSS satellite itself, Receiver Autonomous Integrity Monitoring (RAIM) or GNSS augmentation systems; therefore it brings about good opportunity for using GNSS in safety critical applications in all transport sectors. The successful applications of the GNSS in the safety- critical aviation navigation and maritime applications have suggested its prospect for railway safety-critical applications (Kiss, 2000; Kaplan and Hegarty, 2006).

Railway is commonly used by people as industrial and public transportation. In transportation industry Reliability, Availability, Maintainability, and Safety are the key factors. Considering several parameters such as transferring huge amount of goods and passengers with a high level of security and saving of fuel as well as less environmental impacts have been considered by decision makers and transportation experts (Jandaghi and Reza, 2003). In economic development of each country, Railway industry play a valuable role and Indian Railways is the largest rail network in Asia and the world's second largest under one management. Crisscrossing the country's vast geographical spread, Indian Railway is a multi-gauge, multi-traction system covering over 1 lakh track (Shoab et al. 2013).

In comparison with the ABS system and according to high navigation performance of GNSS, GNSS is a great choice of train positioning system. GNSS has the benefits such as lower initial cost because of all necessary equipment's can be stored on locomotive, less maintenance because of transponders needed to be replaced owing to the vandalism and potentially of increasing the capability of railway lines for both freight and passenger trains due to its high navigation performance. Figure 1.1 shows application of GNSS in various transportation system including railway.

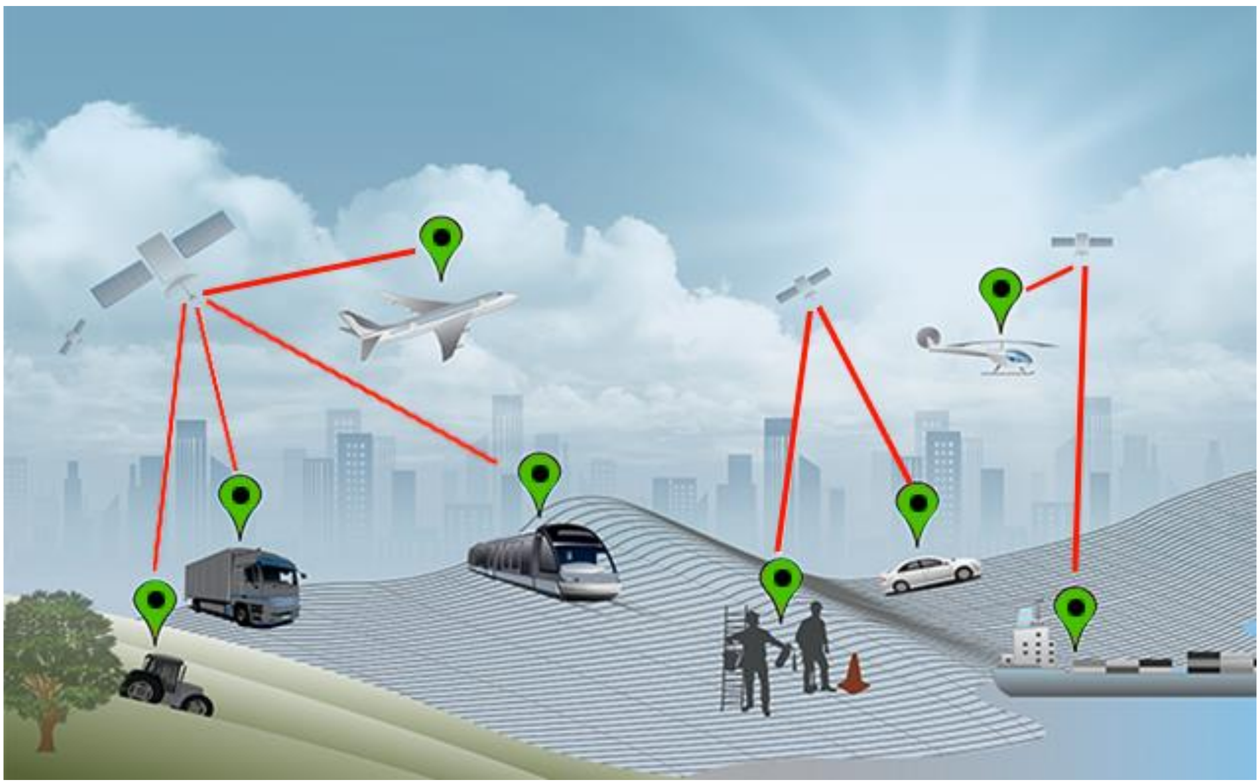


Figure 1.1: Example of GNSS positioning in various transportation system (Source: Guide, 2014).

1.4 Knowledge Based Systems (KBS)

One of the branch of Artificial Intelligence is known as Knowledge Based Systems which can be embedded in diverse applications to perform knowledge specific tasks and to improve decision taking ability of the application (Tiwari, 2001).

A KBS could be a computer program or a rule based program that reasons and knowledge to solve complex problems. Ontology and rules are the tools by which a KBS can represent knowledge explicitly. Knowledge base and inference engine are two subsystems of a Knowledge Based System. To represent logical implications it uses rules such as IF-THEN in coding of knowledge. It represents knowledge explicitly rather than procedural code because of a knowledge based system refers to the architecture of the system. KBS can be used to support controlling railway traffic, decision making and traffic scheduling to improve the efficiency of a railway system (Knowledge Based Systems, 2013).

Fay and Schnieder, (1999) developed two systems 1) Knowledge Based Decision Support System for real-time train traffic control and 2) Fuzzy rule-based expert system for real-time train traffic control for modern public transport and train traffic system to fulfill increasing demands on service reliability and availability. The first system consists a Knowledge Based Decision Support System, a simulation tool and a graphical user interface. The assistance consists of conflict detection, display of relevant information, prediction of certain dispatching measures, impacts, and proposals for appropriate dispatching actions. The second system contains expert knowledge in Fuzzy rules of the "IF-THEN". Fay, (2000) developed a fuzzy knowledge based system for railway traffic control. This system uses Fuzzy Petri Net notion that combines the graphical power of Petri Nets and the capabilities of Fuzzy Sets to model rule-based expert knowledge in a Decision Support System. Komaya, (1991) developed a simulation method using knowledge based system for railway scheduling to emulate human experts, simulating process of train movements on a computer. This system consists three major components, partial simulation, basic command and strategic knowledge. Fringuelli et al., (1992) used knowledge based technology for controlling railway station in Italy. Knowledge based approach was used to design automatic train protection system and station master assistant. In the latest Automatic Train Control (ATC) technology and Communication Based Train Control (CBTC) systems are largest scale knowledge based system (Peng, 2011).

Some advantages and limitations of knowledge based systems are as follows:

1.4.1 Advantages of KBS

- It can take decision automatically.
- It provides expert knowledge at there, where expert is not available.
- Can take knowledge from different sources and fuse them.
- It can provide a reliable database for in-depth analysis.
- It can handle uncertain situation.

1.5 Research Gaps

Review of literature on GNSS application in railway and studying existing system of train control system revealed number of gaps, which are enumerated as:

- Conventional techniques are unable to locate and control trains within blocks.
- In India loco pilot still depends on manual process to get information about signals and level crossings.
- In bad weather conditions (foggy day), loco pilot depends on the track detonators to identify the signals and level crossings ahead.
- Getting information about maintenance segment is a manual process for loco pilot.
- No location based services or web based asset management system is available in India.

1.6 Need of the Study

1. Various systems are already available to navigate and control trains using GNSS but still on screen information about current location, upcoming locations etc. are not available for train operator.
2. Sometime weather also create some critical situations, like in foggy day, the operator unable to see the signals, it means operator doesn't have information about signal. In this situation train operator fully dependent on manual process and there is always a chance for abdication of the duty and delay in the information traversing due to this manual process.

3. Renewal work and maintenance of the railway infrastructure takes place daily. This work must often be carried out close to or on the running track. Some work can be done by machine but all work involves people and that presents considerable risk. In this maintenance process, the real time on screen track maintenance information is not available for train operator.
4. Integration of GNSS and Geographical Information System (GIS) in railway is very important. Web-based GIS makes it easy to exchange information and create better public communication through the Web site. Railway organizations make use of GIS and advanced technology to perfectly monitor safety and security. Because they are responsible for ensuring the safety and security of railway passengers. Indian railway doesn't have this type of system.

1.7 Objective of Current Research

Traditional railway signaling and control systems have problems such as difficulty in enhancing the capability of railway lines, train delay caused by signal failure, large investment and maintenance, incompatibility and non-interoperability between different systems. To improve the railway operational system, especially the future high speed and high density train control system, positioning system plus communication system might be applied to enhance the current signaling and control system.

This research has developed and tested a train navigation and control system integrating GNSS, GIS and GSM. With the rapid development of internet, wireless communication, 3G technologies and the formulation and standardization of related protocols, the integration of GNSS, GIS and Global System for Mobile Communication (GSM) technologies have been applied in many fields to provide various users with location information on electronic map. To get position of the train in terms of Latitude and Longitude, GNSS is used. To transmit the data obtained using GNSS receiver to the server GSM/GPRS is used. This enables a person to trace a train on GIS ready map. In the safety-critical environment, train can take decisions automatically at signals and level crossing using knowledge based approach.

Therefore, the objective of this thesis aims to investigate the following questions:

1. How does the GNSS integrating with the knowledge based approach?
2. How does GIS can be implement in railway?
3. Has the integrated system improve performance of navigation and control of a train?
4. How much this system is cost effective?
5. How does the integration of GNSS with GIS and GSM to perform navigation and control in a real railway line?
6. How does a real time asset management system for railway infrastructure can perform?
7. How to reduce distance between two trains? Running on same track.
8. How does train can take decisions automatically using knowledge based approach?
9. How does the GSM technology used in signal and level crossing?

Through exploration of the question above, this research aims to achieve the following results:

1. Location Based Asset Management System:

   To implement a comprehensive GIS to improve the collection, review, analysis and inspection of railway asset information. Asset management comprises all methods, procedures and tools to optimize costs, performance and risks for complete railway infrastructure.
2. Knowledge Based Train Operator Module:

   To collect current location, upcoming locations, signals, stations, speed limits, level crossings, bridges, diversions and integrate all such information in an expert environment for loco-pilot and reduce possible uncertainties regarding railway track.
3. Web Based Train Navigation And Tracking System:

   To track trains in between the blocks and develop a train tracking system with an essential feature of navigation.
4. Trip Navigation And Analysis System:

   To develop a complete navigation solution for feel safe and sound trip all the way to user's destination. The developed system should automatically keep track of travel data, like distance, time and average speed to analyze the complete trip in terms of halt and congestion delay.

This research aims to examine the performance of the integration of knowledge based approach with GNSS, GIS and GSM based navigation and control system in the safety-critical situations. The system should be cost effective and reliable also.

1.8 Thesis Organization

Chapter 1 brief introduce the current and future railway navigation and control system. The deficiency of GNSS and limitations of the current navigation and control system are summarized. This chapter concludes with the introduction of GNSS for train navigation and control and the objective of this research.

Chapter 2 gives detailed review of the relevant scientific literature related to existing train navigation and control system.

Chapter 3 review the current and future GNSS in detail. The principle of the GNSS and their augmentation systems are described. The current applications and the future possibility for railway applications are also reviewed.

Chapter 4 describe the methodology and architecture of developed train navigation and control system. The advantages of integrating GNSS in railway are also presented in this chapter.

Chapter 5 describe the asset management system and its advantages in managing railway infrastructure. The developed real time asset management system for railway also presented in this chapter.

Chapter 6 elaborate the knowledge based approach and its application in railway. Developed knowledge based approach for train navigation and control is also described in this chapter. This chapter also describe the features of developed module for train operator. The integration of track maintenance updates with the system is also presented in this chapter.

Chapter 7 presents the web based train navigation and tracking system. The advantages of web technology also described in this chapter. The integration of Web GIS and GNSS with railway also described in this chapter.

Chapter 8 present developed trip navigation and analysis system and its advantages.

Chapter 9 summarized the research output of this thesis and provide implication for future research on controlling trains in critical safety situations and limitation of this research.

Chapter 2

Review of Existing Train Navigation and Control Systems

2.1 Introduction

Reliability, Availability, Maintainability, and Safety are important factors in transportation system. In the transportation industry geographic analysis is the key to make better decisions. Whether monitoring rail systems and road conditions, finding the best way to deliver goods and services, tracking fleet vehicles, or maintaining transportation networks, understanding these issues from a geographic perspective is crucial to deploying or spending resources wisely (Guler et al., 2004). Railway industry has a valuable role in economic development of each country. Considering several parameters such as transferring huge amount of goods and passengers with a high level of security and saving of fuel as well as less environmental impacts have been considered by decision makers and transportation experts (Alaei and Delavar, 2003) and in 2014 according to Ministry of Railway, Indian Railways (IR) is the third largest railway network in the world with 7,112 railway stations, 1,31,205 railway bridges, 10,499 locomotives, 50,194 passenger coaches, 2,45,267 freight cars and 65,808 route kilometers. Today IR operates around 11,000 trains each day, comprising 7,000 passenger trains and 4,000 freight trains. It transports 2.65 million tons of freight traffic and 23 million passengers every day and 8,397 million passengers per year. It currently has 1.36 million employees and an annual revenue base of Rs. 1281031.5 million as projected on March 31, 2014. Indian Railways is also home to great talent and excellent organization focused on operation, efficiency and safety (Indian Railway Statistical Publications 2013-14, 2014).

The country presently suffers from a severe and chronic under-investment in railway infrastructure. The resultant disproportionate diversion of freight and passenger traffic to roads while causing substantial loss in revenue to the Indian Railways also imposes a heavy burden on the country which is measurable in terms of a much larger freight cost to Gross Domestic Production (GDP) ratio and higher environmental cost per route Km of Freight and passenger traffic than in other countries (Franco and Mandla, 2014). Undeniably there is an urgent need to enhance capacity of trains and modernize the Indian Railways to meet country's social and economic aspirations in the 21st Century. With modernization and restoration of balance in the inter-modal transport mix railways can be a significant engine of inclusive growth and development for the country and can potentially contribute an additional 1.5% to 2% to GDP. IR will then, provide new jobs, save energy, improve environment, while moving people, raw material and goods more efficiently nationwide. Highly critical industrial inputs like coal which contributes nearly 45% to Railways freight traffic will get the much needed special attention as a modernized Railway system will focus on efficient evacuation, movement, and delivery of coal or other important goods in a much more effective manner (Modernization of Indian Railway, 2012).

The railway network is considered to be the safest and easiest mode of transportation and more than 10 billion of people and 1050 millions of freights traveled by train annually. However, some accidents occur due to improper communication among the network, wrong signaling, worst weather condition and immediate route change (Jain and Tyagi, 2013). The train driver doesn't get proper information on time and before time so that the hazardous condition can occur and would lead to a disruption (Xie et al., 2011). Railway organizations is using manual methods to monitor the trains like signals and level crossings are operated by staff on instructions by telephone from the nearest station. So there is always a chance for abdication of the duty and delay in the information traversing due to this manual process (Shoab et al., 2013). However with recent development in electronic, modern embedded systems and communication technology, many railway organizations have taken the opportunity to use modern and more flexible train control and monitoring systems that utilize these new technologies in order to achieve their required safety and business goals (Neil, 2010).

Using the most modern technologies such as intelligent emergency and safety supervision system, intelligent navigation system, intelligent railway resource management system, modern communication technology, intelligent train control and monitoring system, data and image processing system, decision-making system, storage system, artificial intelligent networks, sensor networks etc. an Efficient and intelligent railway transportation system can be designed (IT Interface, 2001). A wireless communication based intelligent navigation and control system can bring together a number of technologies like computing, sensors, speed control, communications, intelligent control, management, interlocks, customer service, planning and scheduling and many more. This type of system will enable the railway to detect Naxalite or terrorist attacks, notify the appropriate authorities and recover more rapidly from the incidents. The railway can manage their operations by getting real time information from the intelligent navigation and control system. The need of enhancement to passenger service and safety can be achieved by wireless communication based intelligent navigation and control system (Tripathi and Tripathi, 2013).

The statistics show that, huge number of accidents occurred due to human errors. Therefore, having a systematic way for railway operation management and reduction of human intervention, controlling activities, performances etc. may play a significant role to reduce the number and impact of accidents. Reliable, accurate, precise, up-to-date and structured geospatial data is the key for decision making (Das et al., 2009).

2.2 Traditional Train Control and Navigation System

The possibility of train collision is very high because trains are fixed on the track and are not allowed to change the track unless on the switch point. Furthermore, trains cannot be stopped immediately and cannot always be stopped within the sight distance of drivers due to the high speed of train operation. So, a railway traffic control system is needed to make efforts to avoid any possibility of collision. Under the traffic control, trains authorized movements is delivered from a responsible man for each section of a rail network to the train crew. Different rules are set by the different physical equipments. These operational rules are called differently in different countries. Following three types of conventional navigation and control systems are using by Indian railway.

2.2.1 Time Table Operation

Timetable is the simplest train control system, all trains runs according to the fixed timetable and every train crew should be familiar with the fixed schedule (Goverde, 2005; Bryan, 2006). Trains should be traveled on each section of track at their scheduled time and no other train is allowed to enter the same section at the same time. For a single track railroad, meeting point should be scheduled for the train running in the opposite direction, so the train must wait for other one at a passing pass and it was not allowed to move till the other arrived. Figure 2.1 and 2.2 shows passing pass at the passing loop.

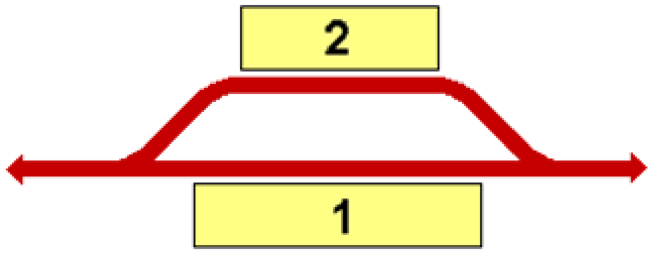


Figure 2.1: Crossing loop (Source: Passing Loop).

Figure 2.2: Trains in a passing loop at Penryn (Source: Passing Loop).

The timetable system had some disadvantages like, the track ahead should be clear and there was no positive confirmation that it is clear. Engine failure and other problems were not allowed in the timetable system. This system was inflexible because of the trains could not be added, delayed or rescheduled without advance notice.

By the invention of telegraph technology, the above problems seems to be moderated. Timetable And Train Order (TATO) was introduced, which was advance version of timetable and based upon telegraph technology. Train crew got train orders by TATO system (Gamst, 1990). Meeting point of trains at passing pass is set up by the dispatcher which is allowed by the train orders. The train had to wait until the other passed and had to keep enough distances between trains if they were in the same direction. Therefore, the TATO operation allowed cancellation, rescheduling and addition of train services. The TATO operation is replaced by the block and signaling system.

2.2.2 Signaling

Signaling consists of systems and devices by which trains are operated efficiently, maximum utilization of track capacity and safe journey. It ensure safety between two or more trains which cross or approach each other's path, this also ensure to safeguard the trains at converging junctions and give directional indication at diverging junctions. Some engineering principles of signaling are as follows:

- Every apparatus and circuit employed in signaling system should be designed that in any condition of system failure, alternate techniques to check the failures must be employed.
- In the design of every apparatus, circuits and systems, the factors like reliability, simplicity and financial aspects should be considered.
- The aspects of signals should be distinctive and unambiguous.
- A given signal aspect must convey the same indication at all time, at all places and under all circumstances.
- Each and every signal should be afford the maximum possible sighting distance.

2.2.2.1 Types of Signals and their Classification

Various types of signals can be classified into various categories on the basis of following characteristics:

1. Operating characteristics
   i. Detonating signals (also called Fog or Audible Signals)
   ii. Hand Signals
   iii. Fixed Signals
2. Functional characteristics.
   i. Semaphore type signals
   ii. Warner signals
   iii. Shunting signals (Disc or ground signals)
   iv. Colored light signals
3. Locational characteristics.
   i. Reception Signals (Outer and Home signals)
   ii. Departure signals (Starter and Advance Starter signals)
4. Special characteristics.
   i. Repeater and Co-acting signals
   ii. Routing signals
   iii. Calling on signals
   iv. Point indicators

1. **(i) Detonating signals:** When hand and fixed signals are not visible during the foggy and cloudy weather, detonators are placed on the rails which explode with a loud sound when the train passes over them. The sound of detonators draws attention of the driver to the proximity of signals. From the safety point, detonators must be placed on the rails at least 400 to 500 meters ahead of the signals to enable the driver to stop train or to obey the signal. These signals consist of containers with explosive and are fixed to the rail by means of clips (See figure 2.3).

Figure 2.3: Railway track detonator.

(ii) Hand signals: Hand signals are given either by flags fixed to a wooden handle or by bare arms when flags are not available during the day time. During the night time, lamps are used in which movable class-slides of green, red and yellow shades are provided (See figure 2.4). The hand signals are generally used by guards, station masters, cabin man, gang man, key man, point man or any other authorized man.

Figure 2.4: Flag and lamps for signaling.

(iii) Fixed signals: These types of signals are usually of semaphore types, fixed at a place which are discussed in next article.

2. **(i) Semaphore type signals:** Semaphore signals are the older style signals seen widely throughout the country, where each signal has an assembly with an arm mounted on a mast, where the arm can move through two or three different positions at different angles, each position providing a distinct signaling aspect (Signalling Systems, 2015). These signals are placed on the signal post, on the left hand side of the direction of movement and the movable arm projects towards the track for indicating the signal. The side of arm facing the driver is painted red with a white vertical band. The height of the center of the arm is kept 7.5 meter above the ground. Table 2.1 shows indications of semaphore signals at different time.

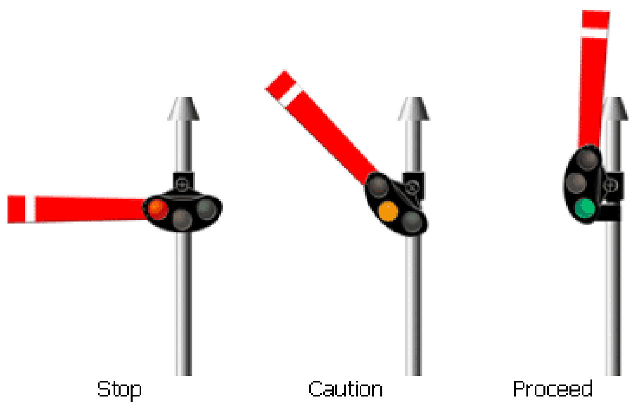


Figure 2.5: Semaphore signal and status.

Table 2.1: Semaphore signals indications.

Operation Time	Position of arm or Color of Light	Position of Signal	Indications Given
Day Time	Horizontal arm Inclined arm (45° to 60°)	On Position Off Position	Stop or Danger Proceed or line clear
Night Time	Red Green Yellow	On Off -	Stop or Danger Proceed or line clear Proceed with Caution
Day or Night	No Signal White	- -	Danger Danger Sign

(ii) Warner Signals: Semaphore signal at the entrance to station is combined with a warner signal. Warner signal is similar to semaphore signal in shape except a V-notch at free end like fish tail. The warner signal is placed on the same post of the semaphore signal at 1.8 to 2.1 meter below the semaphore signal. This signal is painted yellow and exhibits a yellow or amber color at night instead of red color. Figure 2.6 shows semaphore signal combined with warner signal.

Figure 2.6: Semaphore signal combined with warner signal.

(iii) Shunting signals (Disc or Ground signals): These signals are used for shunting operations in stations yards so that they are called shunting signals. Shape of these signals are circular disc with a red band on a white background. This disk can revolve in vertical plane by pulling the lever by hand. Two holes are also provided for red and green lamp for night operation. These are usually mounted on poles but may be close to ground level. Figure 2.7 shows disc signal for shunting purpose.

Figure 2.7: Disc signal for shunting.

When the red band of disc is in horizontal position or it shows red light at night it indicates 'STOP'.

When the red band is in inclined position at 45º or show green light at night, it indicates 'PROCEED'.

(iv) Color light signals: With the introduction of electric traction to meet increased traffic requirements, semaphore signals are being replaced by high intensity beam color light signals, both during day and night. They may be either, Two-aspect (green and red), Three-aspect (green, yellow and red), Four-aspect (green, yellow, red and yellow) or Five-aspects with additional aspect of yellow over green (See figure 2.8).

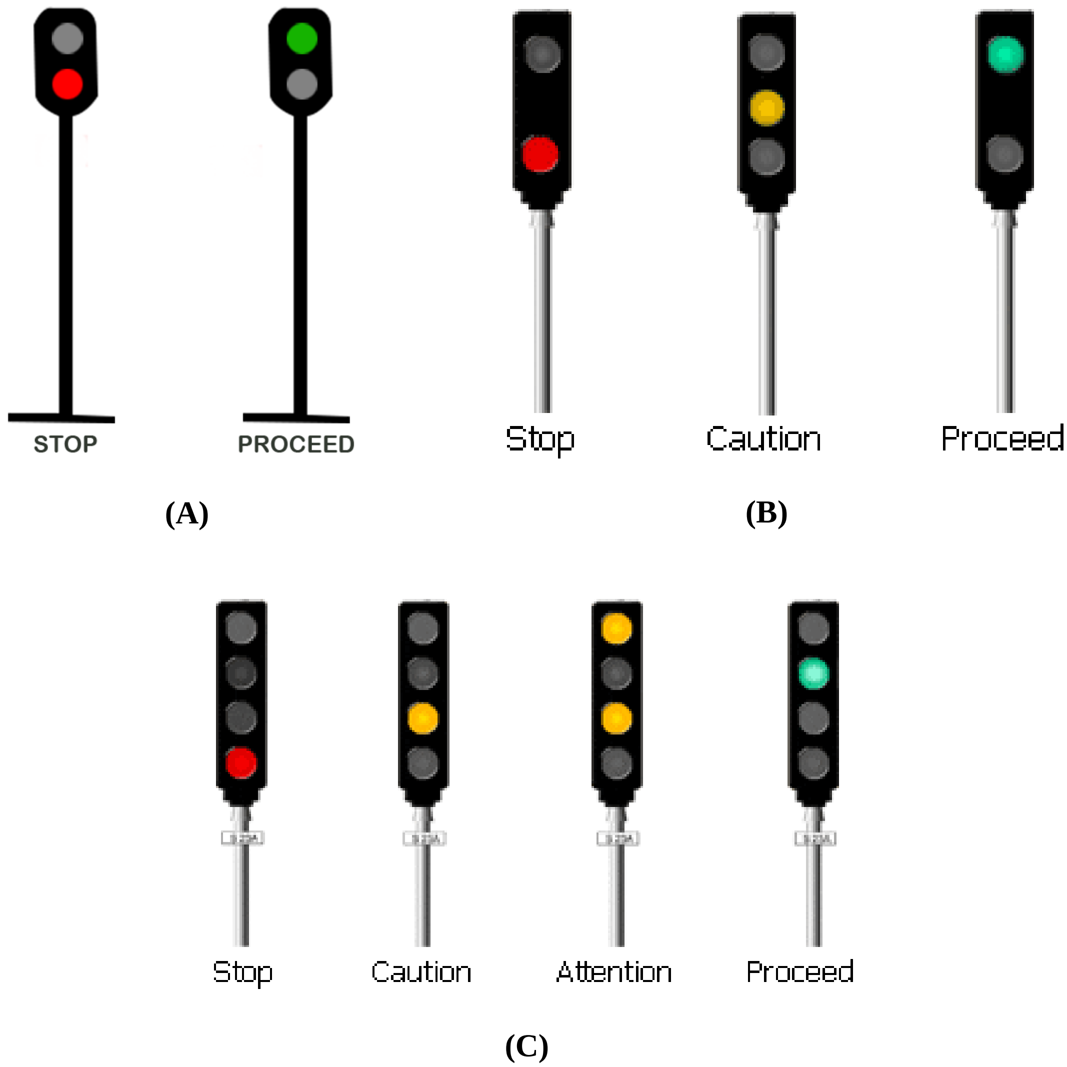


Figure 2.8: A, B and C shows Two-aspect, Three-aspect and Four-aspect color light signals.

3. **(i) Reception signals (Outer and Home signals):** Signals which control the reception of trains into a station are called reception signals. These are two types, Outer and Home signals. Outer is the first 'stop' signal at a station, which indicates the entry of the train from block to the station yard. The distance of this signal from station is on the basis of maximum allowable speed in India comes equal to 0.54 km for broad gage and 0.40 km for meter gage. It have generally one arm but some time warner signal also there on the same post. Home signal is located at the door of the station. The home signal has bracketted arms to indicate which line is to be used. It is one of the important functions of interlocking to ensure that the route is properly set before the signal arm is taken to 'OFF' position. This signal is located not more than 180 meters from the start point.

(ii) Departure signals (Starter and Advance Starter signals): These signals are used to dispatch trains from the station. These are mainly two types, Starter and Advance Starter signals. Starter signal marks the limit up to which trains stopping at the station come to a stand or halt. No train can leave the station unless the starter signal shows the 'proceed' position. Advance starter signal is the LAST STOP SIGNAL at the station where it is provided. In general, advance starter is an indication for the train having left the station and is no more the responsibility of the station master.

4. **(i) Repeater and Co-acting signals:** When a train passes through a station without stopping, the driver comes across the five signals (Warner, Outer, Home, Starter and Advance Starter). But when the driver's vision is obstructed by an over bridge between the signals or sharp curvature in the alignment or due to any other reason, a signal is provided with a duplicate arm of smaller size at a suitable position which repeats the indication of the signal ahead. As these signals work in unison with the main signal, it is also called Co-acting signal.

   (ii) Routing signals: At the big stations, where the number of lines exit at the station taking off different routes from the main line, beside one main home signal, routing signals are provided at the point of diversions. Lowering of any one of the signals indicates the track for which the points are set. The signal for main track is at a higher level while signals for other diversions are at a lower level.

   (iii) Calling on signals: These consist of small arms below and parallel to home signal fixed on the same vertical post. When a train stops with the home signal indication, then a calling on signal permits a train to proceed cautiously by keeping this signal arm at 'PROCEED' position. These signals are very much helpful when maintenance work on the track are going on.

   (iv) Point indicators: These are mainly used to indicate the route to driver as a precaution against bursting of points or running into an occupied line when the signals are not available for this purpose. A point indicator consist a rotating lamp which can rotate about it's central vertical axis. This lamp is enclosed within a box consisting of four side (See figure 2.9). When the points are set for the main track, the indicator shows white target. When the points are changed, the indicator rotates through 90^{o} and the indication shows green target.

Figure 2.9: Point indicator.

Generally operation of signals are combined with the block system (block system will be described in section 2.2.3). The operation of signal can be categorized in two modes (i) Manual signaling and (ii) Automatic signaling.

2.2.2.2 Manual Signaling

In the manual signaling, a signalman must be certain that, block is not already occupied before allowing a train to enter that block. When a train leaves a block, the signalman of that block must inform the signalman who is controlling entry to the next block, this forms train movement control between two blocks by signalman. Even if the signalman receives information that the previous train has left a block, he is usually required to seek permission from the next signal box to admit the next train. Signalman must be able to see the end-of-train marker on the back of the last vehicle when a train arrives at the end of a block section, before the signalman sends the message that the train has arrived. This confirms that no part of the train has become detached and remains within the section. The end of train marker usually be a red colored disc by day or a colored oil or electric lamp (again, usually red). If signalman sees that the disc or lamp is missing, he will ask the next signal box to stop the train and investigate (Railway Signalling, 2015).

2.2.2.3 Automatic Signaling

Automatic signaling controls the movement of trains between the blocks using automatic signals. Following points are illustrating the automatic signaling:

- Automatic signal operation is designed to allow trains operating in the same direction to follow each other in a safe manner without risk of rear end collision.
- The automatic operation comes from the system's ability to detect if blocks are occupied or otherwise obstructed, and conveying that information to approaching trains.
- The most common way that Automatic Signals detect track occupancy is through the use of electrical track circuits.
- A low-voltage current is sent through the track between the signals and is detected to determine whether the circuit is closed, open, or shorted.

2.2.3 Block System

The block system divides the railway lines into a series of sections or blocks. This system control movements of train between the blocks using signals and allows only one train in each block at one time. By the radio signals, color light signals and remote signals, the train movement instructions are delivered. The length blocks are designed to allow trains to operate as frequently as necessary. For low traffic railway lines blocks can be kilometers long and can also be a few hundred meters long for the high traffic railway lines.

There are four types of block systems, Absolute Block, Automatic Block, Permissive Block and Moving Block systems are used by many railway organizations worldwide. But in India Absolute Block, Automatic Block and Permissive Block systems are used by railway. Following sections illustrating these three systems.

2.2.3.1 Absolute Block

This system of working is most extensively used in India and about 90% of the trains are controlled by this system. In this system the entire track is divided into blocks, separated by block stations and stations provided with Block Instruments in pair at each station. These instruments are used to show as to whether the section ahead is clear or reserved for a train. All block sections are linked in series both telegraphically for operation of block instruments and telephonically for verbal exchange of information. Figure 2.10 shows Neal's ball token instrument for absolute block system.

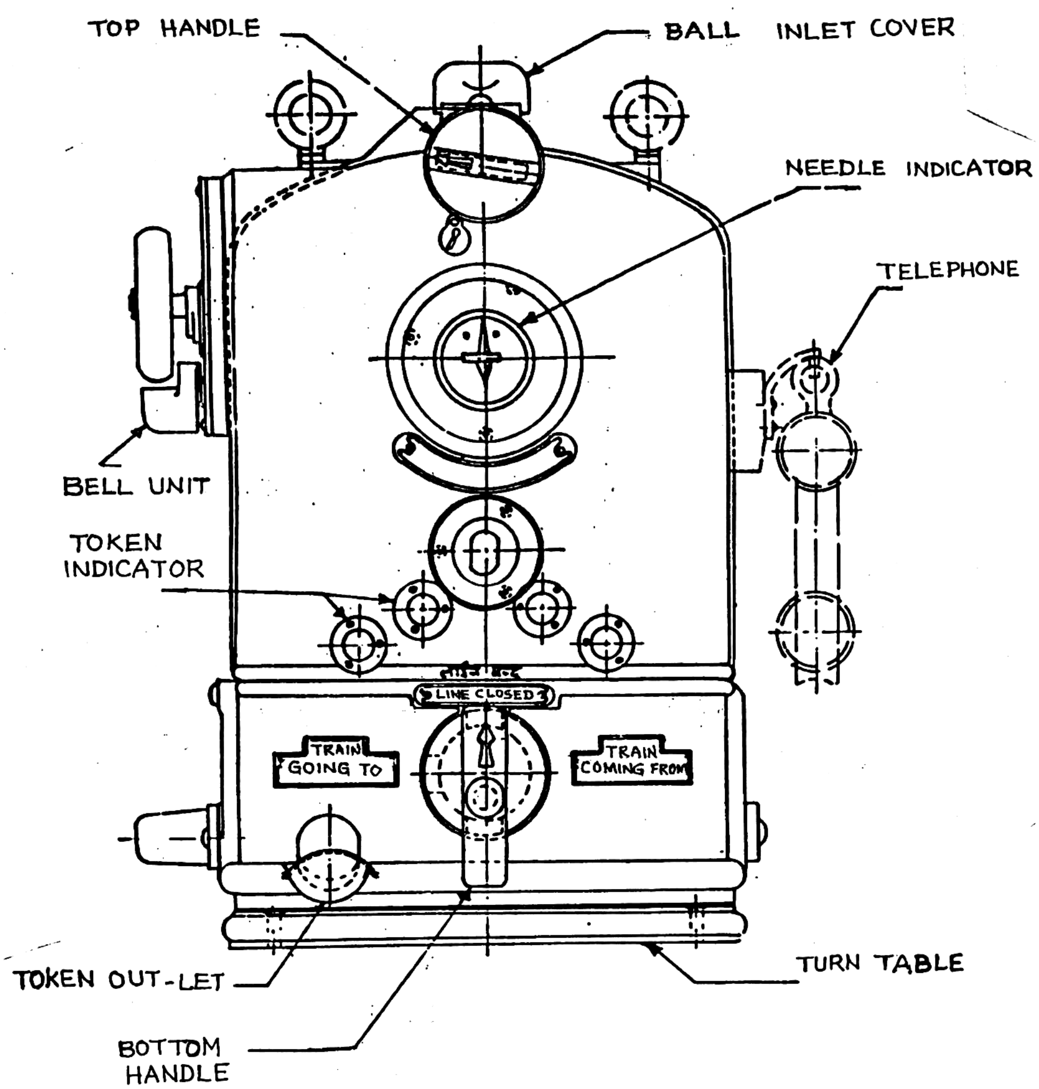


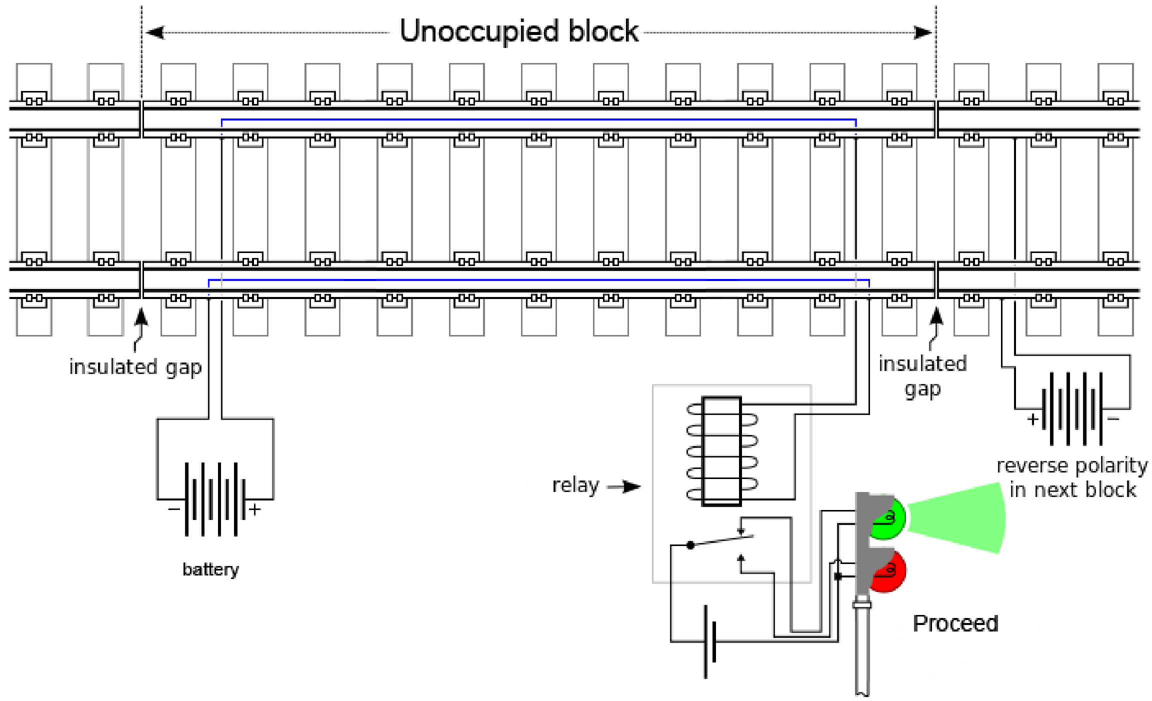
Figure 2.10: Neale's ball token instrument for Absolute Block (Source: Signal & Telecommunication Training Centre, Byculla, Mumbai, 2008).

In the Absolute Block system no train should leave a block station unless permission to do has been received from the receiving block station in advance. This is essential for train dispatching. No train should be given permission to approach a block station unless: (i) in case of double line, when the line on which the train being run is clear up to an adequate distance beyond the first stop signal at the station at which the permission is being given. (ii) In case of single line, when the line is free of trains and is clear up to an adequate distance beyond the first stop signal and is free of trains running in the opposite direction or will be free of the trains after the complete arrival of the train going towards the station to which the permission is being given. These are essential for reception of trains.

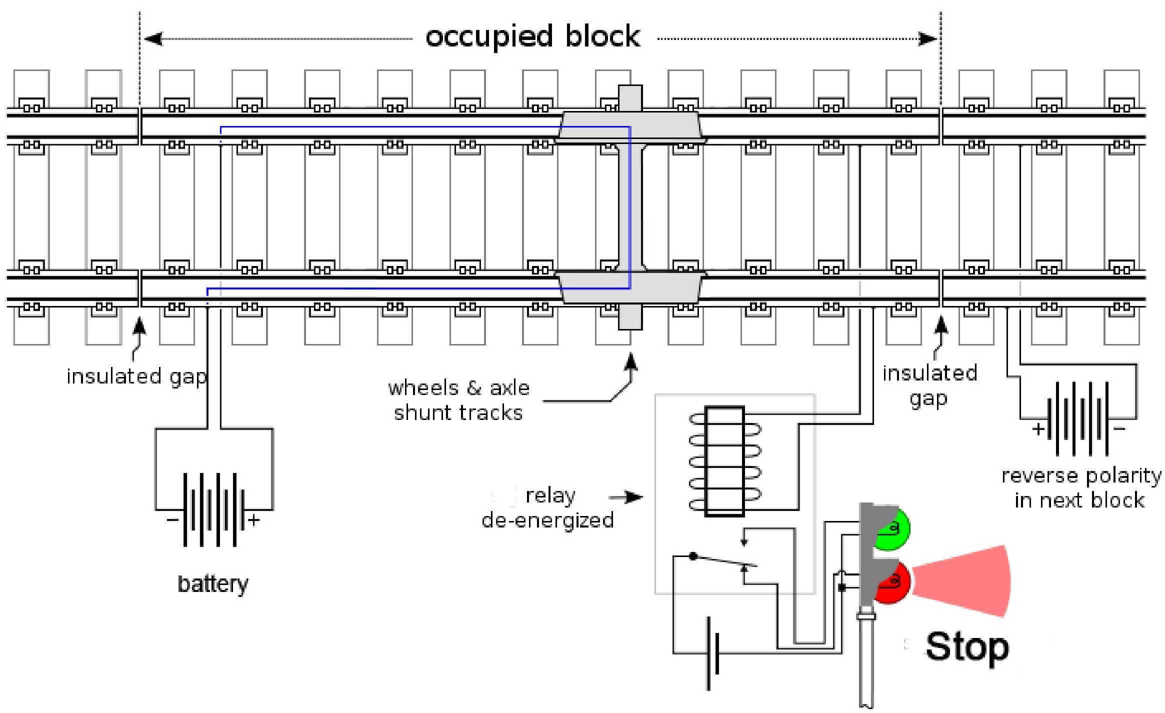
When two trains are running on the same line and in the same direction, the permission of approach for the second train should not be given unless: (i) the first train has arrived at it's proper position within the home. (ii) All the signals behind the first train have been put back to ON positions. (iii) The line is clear not only up to the first stop signal of the station but also for an adequate distance beyond it. (iv) All the switches or points have been set, facing points locked and trailing points bolted for the second train.

2.2.3.2 Automatic Block

The Automatic Block or Automatic Block Signaling (ABS) system is widely used block signaling system worldwide. This system is an improvement on absolute block system and avoid the possibility of accidents due to negligence on the part of human beings. This system used automatic train detection technology to detect the train location so that it can indicate whether the block is occupied or not. ABS systems detect track occupancy is through the use of electrical track circuits (Takashige, 1999). A low-voltage current is sent through the track between the signals and is detected to determine whether the circuit is closed, open, or shorted. If the ABS system detects that the circuit is shorted between two signals, it understands that a train, or obstruction is occupying that block and will "drop" the signals on either side of that block to prevent another train from entering (Automatic Block Signaling, 2014). Figure 2.11 A and B are showing how track circuit detect and protect trains.



(A)



(B)

Figure 2.11: A and B shows unoccupied and occupied block using track circuit.

The characteristics of automatic block system are as follows:

- The movement of train is controlled by stop signals which are operated automatically by the passage of train passed the signals.
- No automatic signal assumes 'OFF' unless the line is clear, not only up to the stop signal ahead but also an adequate distance beyond it.
- The line is track circuited throughout it's length and divided into a series of automatic signaling sections or blocks, each of which is governed by an automatic stop signal.

2.2.3.3 Permissive Block

Permissive block control system can be used in the emergency and rescue situation. At the slow safety speed, both systems allow multiple trains to enter a block. In emergency situation, the permissive block control system can be used, like in the situation when communication between the train driver and the signalman is disconnected, the system still permits train to enter the occupied block at a low speed. However, permissive block control system is not allowed to use in any poor visibility environment (fog, heavy rain, snowing etc.). For rescuing failed trains, permissive block control system can be used. The signalman must inform the driver of the precise information about the failed train and permits the train to enter the occupied block to rescue the failed train.

2.3 Advanced Systems Used by Other Countries

Railway is a popular public transportation in many countries so to achieve reliable and safe journey many countries are using advance systems to navigate and control trains, some of them are as follows:

2.3.1 European Train Control System (ETCS)

The European railway network raised from separate national networks with little more in common than standard gauge. By the end of the 1980s there were 14 national standard Train Control Systems in use across the European Union (EU), and the advent of high-speed trains showed that signaling based on lineside signals is insufficient. On 4 and 5 December 1989, a working group including Transport Ministers resolved a master plan for a trans-European high-speed rail network, the first time that ETCS was suggested. ETCS is a signaling, control and train protection system designed to replace the many anomalous safety systems used by European railways, especially on high-speed lines (European Train Control System, 2014). This is the train-control element and includes Automatic Train Protection (ATP). There are five levels of application, each offering different degrees of signaling protection and control, and sixteen different Operating Modes. Not all Operating Modes are available in all Application Levels.

In normal operation, ETCS works on the principle of providing to the train a maximum distance that it can travel, the speed profile of the track ahead and other track information about the route that has been set. The train then permits the driver to drive the train, but should the distance or speed limit to be exceeded, or to be in danger of being exceeded, then the ETCS onboard equipment intervenes to control the train, bringing it to stand if necessary (Railway Safety and Standards Board Limited, 2010).

ETCS is not a signaling system in and of itself. Along with other items, it forms part of a signaling system. ETCS is divided into two parts:

- The ETCS Onboard equipment
- The ETCS Trackside equipment.

The ETCS Onboard equipment consists of:

- European Vital Computer.
- Train Interface Unit.
- Balise Reader.
- Driver Machine Interface.
- Odometry System.
- Juridical Reorder Unit.
- Specific Transmission Module.

The ETCS trackside equipment consists of:

- Balise.
- Radio Block Center.
- Euroloop.
- Radio In-fill Unit.

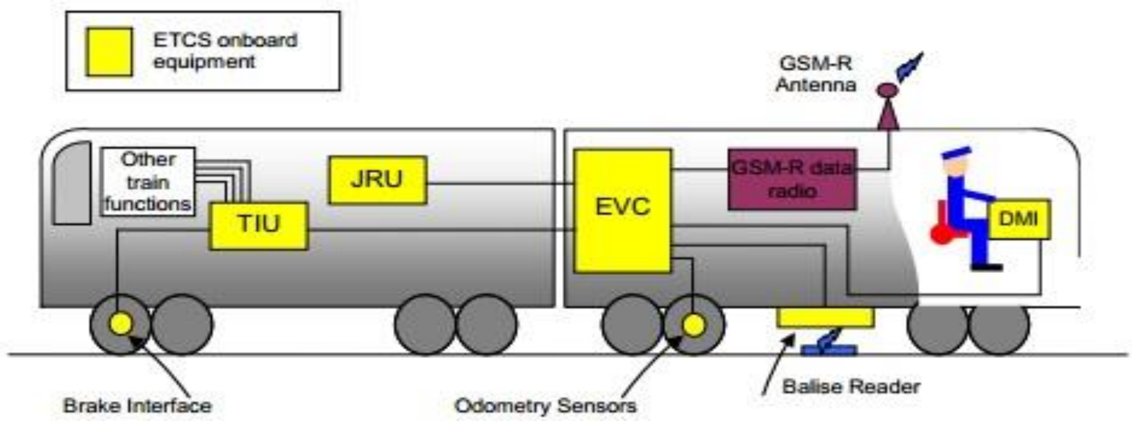


Figure 2.12: ETCS Onboard Devices (Source: Railway Safety and Standards Board Limited, 2010).

GSM-R is not the part of ETCS but GSM-R data radio is used in some ETCS Application Levels to communicate between the RBC and ETCS onboard equipment. The train borne GSM-R data radio equipment includes roof-mounted antennae to enable the train to communicate with the ETCS trackside equipment.

ETCS is specified at four different levels -

- Level 0: ETCS-compliant locomotives or rolling stock interact with lineside equipment that is non-ETCS compliant.
- Level 1: ETCS is installed on lineside (possibly superimposed with legacy systems) and on board; spot transmission of data from track to train via ETCS balises.
- Level 2: as level 1, but ETCS data transmission is continuous; the currently used data carrier is GSM-R.
- Level 3: as level 2, but train location and train integrity supervision no longer rely on trackside equipment such as track circuits or axle counters (European Train Control System, 2014).

ETCS Implementation Handbook, 2008 describes the main features of ETCS as:

- Improved Safety – Precise Running Limits Given By movement authorities.
- Improved Safety – Supervision of Train Driving.
- Higher Performance – Increasing Speed and Capacity.
- Interoperability – Capability to Operate In Different Countries.

2.3.2 European Rail Traffic Management System (ERTMS)

The ERTMS is a EU's major industrial project to improve cross border interoperability and signaling realization by creating a single Europe-wide standard for railway signaling with the final aim of improving the competitiveness of the rail sector (What is ERTMS?, 2014).

ERTMS contains three basic elements:

GSM-R (Global System for Mobiles - Railway) - communication element containing both a voice communication network between driving vehicles and line controllers and a bearer path for ETCS data. It is based on the public standard GSM with specific rail features for operation e.g. Priority and Pre-emption (eMLPP), Functional Addressing Location Dependent Addressing, Voice Broadcast Service (VBS), Voice Group Call (VGC), Shunting Mode, Emergency Calls, General Packet Radio Service (GPRS option), Fast call set-up.

ETCS (European Train Control System) - signaling element of the system which includes the control of movement authorities, automatic train protection and the interface to interlocking. It allows the stepwise reduction of complexity for train drivers (automation of control activities). It brings track side signaling into the driver cabin. It provides information to the onboard display, it allows for permanent train control so train driver can concentrates on core tasks. ETCS and it's components are already described in section 2.3.1.

ETML (European Traffic Management Layer) - the operation management level proposed to optimize train movements by the *intelligent* interpretation of timetables and train running data. It involves the improvement of: real-time train management and route planning, rail node fluidity, customer and operating staff information (What is ERTMS?, 2014).

2.3.3 How ERTMS Works?

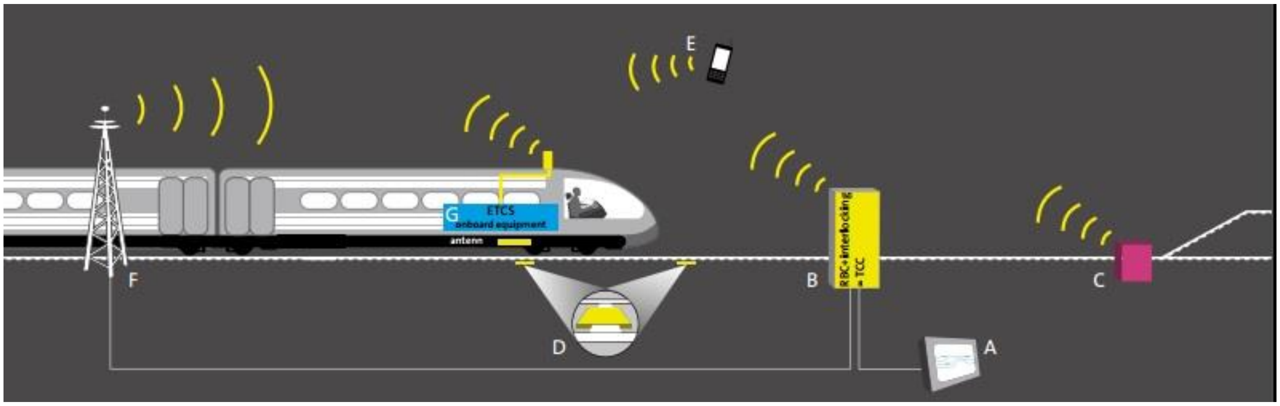


Figure 2.13: ERTMS working (Source: ERTMS Regional, 2009).

From the Traffic Control Centre (A) the traffic controller requests a train path from one location to next. The interlocking (B) sets points (C) and verifies that the requested path is free from obstacles. The interlocking reserves required path and notifies the Radio Block Centre (B) that the movement authority may be issued to the train. The Radio Block Centre sends the movement authority via GSM-R radio (F) to the locomotive's onboard system (G) and a message on the driver's screen confirms that the train may proceed. The antenna of the passing locomotive activates a balise (D) which sends a message to the onboard system, which in turn updates the train's kilometer counter (ERTMS Regional, 2009).

However, interoperability is far from being the only advantage brought by ERTMS. Indeed, ERTMS has also been designed to be the most performant Train Control System in the world. It therefore brings considerable benefits in addition to interoperability:

- Increased capacity.
- Higher speed.
- Higher reliability rates.
- Lower production cost.
- Reduced maintenance costs.
- An opened supply market.
- Reduced contract lead time.
- Simplified approval process.
- Improved safety and passengers.

2.3.4 Automatic Train Control for Shinkansen (Bullet Train) in Japan

Earlier Japan's railway was not using any signaling system. Gesture control mechanism is followed for signaling by an authorized person. As this was a manual approach, human error/negligence in signaling causes fatal accident thus it is essential to switch over an automated approach that not only let the operator understand permitted speed but also apply automated breaking as per the real time control commands on both the high speed and high density lines. So, because of the limitations of earlier signaling system that were causing threat to precious human life an ATC was introduced on the Tokaido Shinkansen (Matsumoto, 2005).

For Yamanote and Keihin Tohoku Railway line, Japan Railway started using an advance controlling system which was an predecessor cab warning device, a predecessor to Automatic Train Stop (ATS) From December 1954, but JR East decided in 2000 to develop a more advance digitally handled Digital and Decentralized ATC (D-ATC) and Digital Communication & Control for Shinkansen-ATC (DS-ATC) taking into consideration the facts that the current ATC should be renewed. In the beginning of 2002 DS-ATC was introduced in Hachinohe Shinkansen Railways and in 2003 D-ATC was introduced in Keihin-Tohoku Railway line. Japan Railways East currently working on a modern Train Control System that will adopt wireless communications, referred as Advance Train Administration and Communication System (ATACS). After combining previous control systems (ATC, D-ATC and DS-ATC) and currently developing system ATACS, the complete system is known as East Japan Train Control system (EJTC) and it is similar to ETCS. Table 2.2 shows the comparison between EJTC and ETCS (Mori, 1993; Kobayashi et al., 1999; Matsumoto, 2005).

Table 2.2: Comparison of EJTC and ETCS (Source: Matsumoto, 2005).

<table>
<tr><th></th><th>EJTC
Level 0</th><th>EJTC/ETCS
Level 1</th><th>EJTC
Level 2</th><th>ETCS
Level 2</th><th>EJTC/ETCS
Level 3</th></tr>
<tr><td>Signaling System</td><td colspan="2">Wayside signal</td><td colspan="3">Cab Signal</td></tr>
<tr><td>Block System</td><td colspan="4">Fixed Block</td><td>Moving Block</td></tr>
<tr><td>Train Detection</td><td colspan="4">By Track Circuit</td><td>Train itself</td></tr>
<tr><td>Transmission to Train</td><td colspan="3">Transponder (Balise + Loopcoil)</td><td colspan="2">Wireless</td></tr>
<tr><td>Transmission to Ground</td><td>Nothing</td><td colspan="2">Onboard Antenna</td><td colspan="2">Wireless</td></tr>
<tr><td>Position Recognition</td><td colspan="2">Nothing</td><td colspan="3">Onboard</td></tr>
<tr><td>Control Method</td><td colspan="2">Point Control</td><td colspan="3">Continuous Control</td></tr>
</table>

2.3.4.1 Level 0 (ATS-S)

This is the first level of train control system in Japan. At this level Block System and ATS are used for safe train operation. A Track Circuit detects the train into Block Section, and Control Devices (relay logic, ATS or interlocking system) turns the signal to red for that section. This indicates that no other train can be permitted into that section so the approaching train must stop before the section. Signals of other block sections can be Green or Yellow to allow trains to enter in those blocks. Figure 2.14 illustrates the relation between signal status of a section and position of a train.

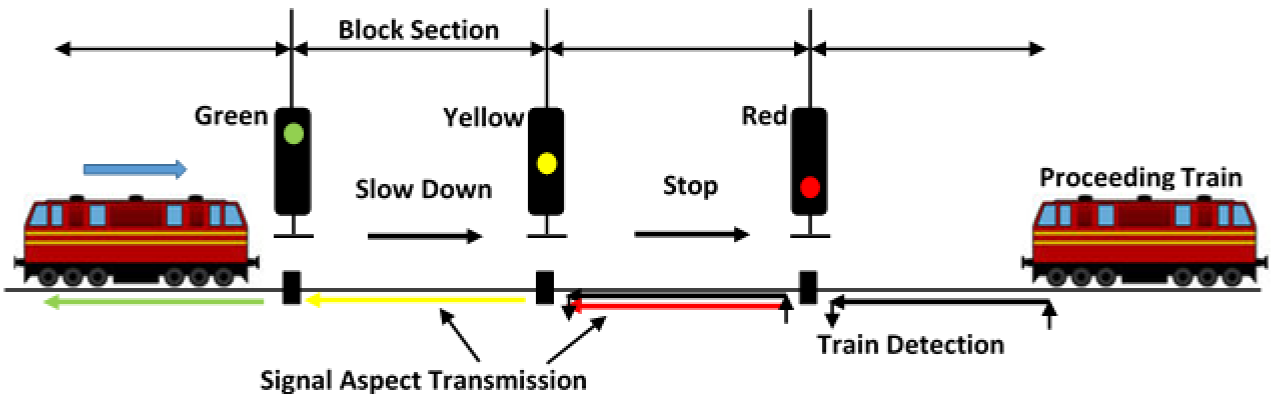


Figure 2.14: Block system and signal (Source: Matsumoto, 2005).

If a driver does not apply brake, the ATS even secures the braking operation. ATS warns the driver to confirm the status of signal, when a train approaches to a stop signal. If the driver does not approve the situation within a set period (5 seconds), the brakes are automatically applied and the train is stopped. Operations can continue under the preference of the driver if confirmation takes place. However, wrong handling of ATS-S has been the cause of accidents and this is also a weakness of the ATS-S (Matsumoto et al., 2001). Figure 2.15 shows the working of ATS-S system.

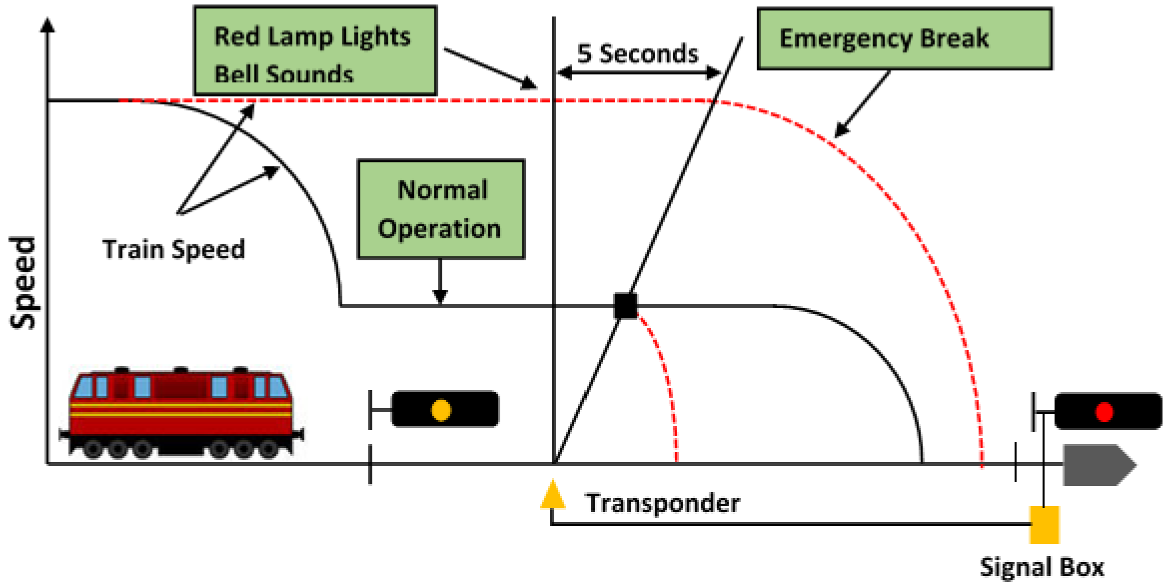


Figure 2.15: ATS-S System (Source: Matsumoto, 2005).

2.3.4.2 Level 1 (ATS-P)

Introduction of ATS-P on the Chuo, Joban, and other Lines was started in September 1988 when JR East established the first phase of a construction plan. ATS-S have some weakness so to overcome the weakness of ATS-S, ATS-P was developed. ATS-P transmits information about signal and the distance to next stop signal from trackside to the train and uses this information to generate a train speed checking pattern by using digital information from a Transponder. The comparison of train speed and pattern leads the situation where brakes are engaged if the speed of the train is exceeding the speed of the pattern. It doesn't require driver verification like ATS-S, and it pulls the attention of the driver by sounding an alarm when the train speed is approaching to danger pattern and the system engages the service brake at maximum power automatically (Matsumoto, 2005). Figure 2.16 shows the overall structure of the ATS-P.

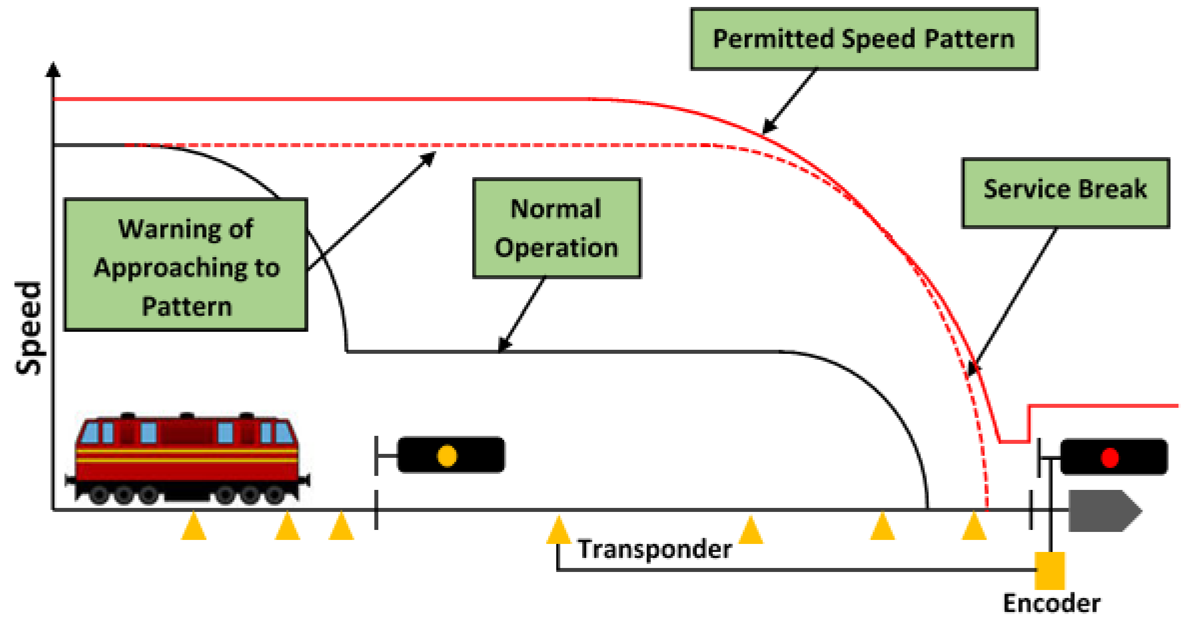


Figure 2.16: ATS-P System (Source: Matsumoto, 2005).

This system is efficient to prevent various accidents which occurs due to entry/exit block signal violations, shunting signals related to main track, calling-on signals and it avoids accidents resulting from exceeding speed limits on turnouts, curves and down gradients. Information about high, mid and low deceleration, train ID and other information is transmitted from on-board device to the trackside. This data is evaluated at the trackside and many operations like signals, operational control of trains, control of level crossings according to train speed, automatic public announcements at stations, etc. are controlled (Matsumoto, 2005).

2.3.4.3 Level 2 (D-ATC)

In this method, a system identifies the distance between two trains and ensures safe train operation by controlling speed of these trains. In order to identify the distance between trains, various new functions are required to get accurate train location and high-speed communication between trains and ground equipment. D-ATC system is an on-board intelligent system, this makes the major difference between D-ATC and conventional ATC. (Matsumoto, 2005). The structure of the D-ATC is illustrated in Figure 2.17.

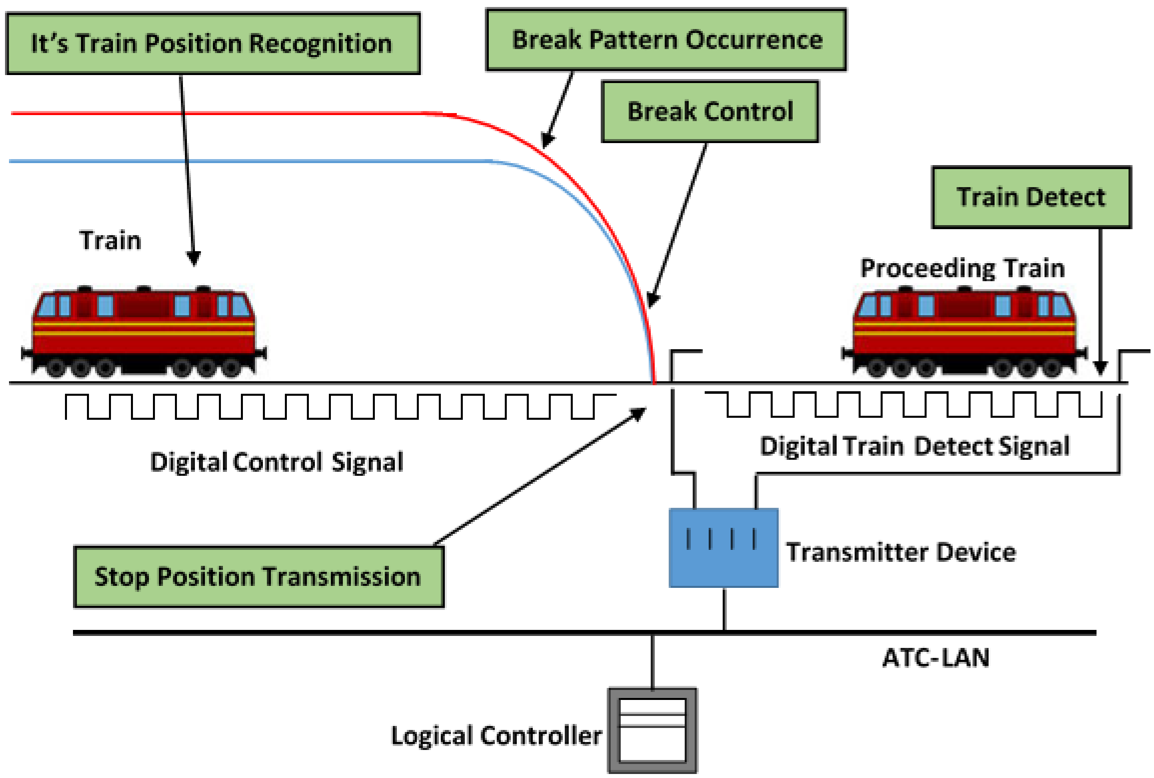


Figure 2.17: D-ATC System (Source: Matsumoto, 2005).

Characteristics of D-ATC are as follows:

- High density traffic is possible because of brakes are continuously engaged up to the stop point using pattern control.
- It is possible to make ground facility slim down and cost-effective by using general equipment and a decentralized system.
- By indicating the train usage on routes to driver the operability can be improved.

Subsequently, D-ATC system is a cost-effective system than conventional ATC and has also allowed the train headway to be reduced to two minutes from the two minutes and thirty seconds of the conventional ATC systems. Also, construction costs can be reduced by twenty percent compared to traditional methods.

2.3.4.4 Level 3 (ATACS)

Using wireless communications, JR East developed a train control system known as "ATACS". A Ground Controller and a Radio Base Station were set up in each control area which was made by dividing a section into many control areas. Ground Controller having some functions such as Interval Control, Train Location, Level Crossing Control, Switching Control and security for maintenance work. On-board computer gets the information by Radio Base Station. Brakes are controlled by onboard computer according to control data supplied by the ground controller and data about train location is transmitted to ground controller using on-board mobile radio station. Subsequently, by detecting train speed and processing the speed data, on-board computer keeps track of train location. Train location is corrected when the train passes a balise set at appropriate points (Matsumoto, 2005). Figure 2.18 shows the structure of ATACS.

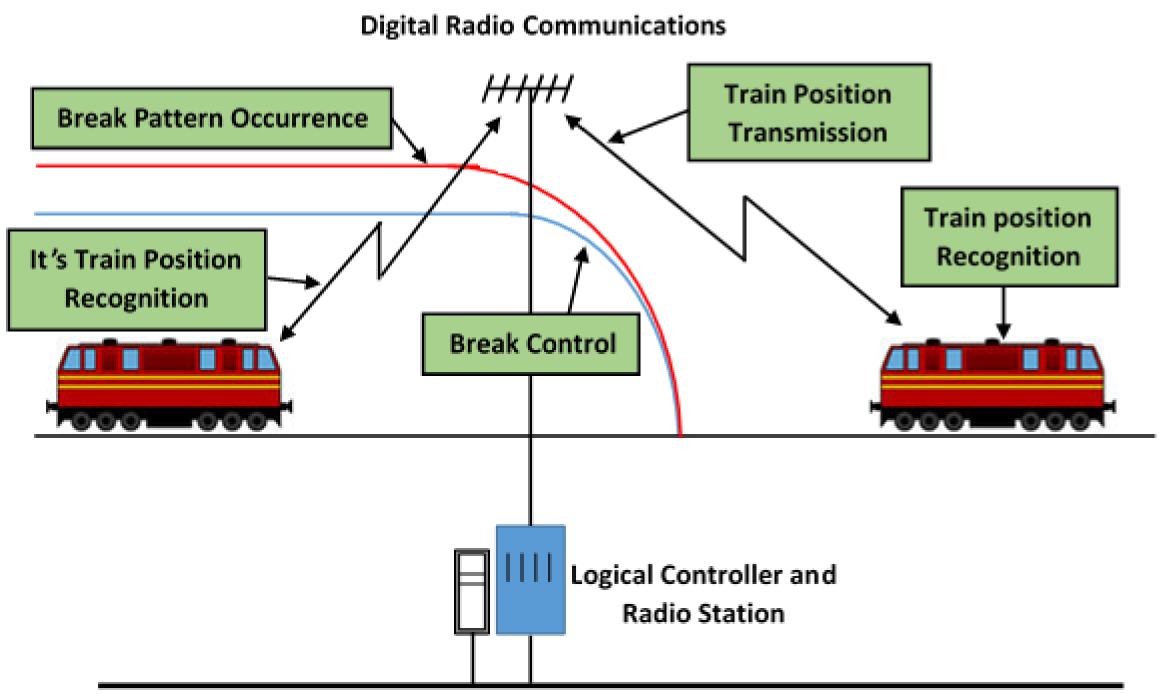


Figure 2.18: ATACS System (Source: Matsumoto, 2005).

The applications conditions of information technology within JNR and JR East particularly focused on the Train Control System. In the case of the Control System, "the development of information and communications technology" and "heightening of transport needs" both progressed as critical features of the era. D-ATC and DS-ATC is developed by JR East, and is still moving forward with the introduction of these system. JR East is providing safer and more comfortable travel to passengers using digital ATC in Shinkansen with conventional railways operation (Matsumoto, 2005).

2.3.5 Chinese Train Control System (CTCS)

CTCS is a train control system used in Public Republic of China and this system is similar to ETCS. There are more than six types of signaling system in China and these are not interoperable due to historical and technical development. So the concept of CSTS was put in 2002 for Chinese Railways by the Ministry of Railway, China.

The configuration of Chinese railway signaling system can be classified into four parts, as follows:

- Onboard System.
- Wayside System.
- Control Center System.
- Communication Network (Ning, 2002).

As Control Center system, it has all data to calculate and control by Communication Network. For Wayside System it consists sensors, actuators, Radio Block Center (RBC) etc. The communication network connects control center with on board system on trains, sensors and actuators installed along the line and at station. Figure 2.19 shows the all four parts of signaling system.

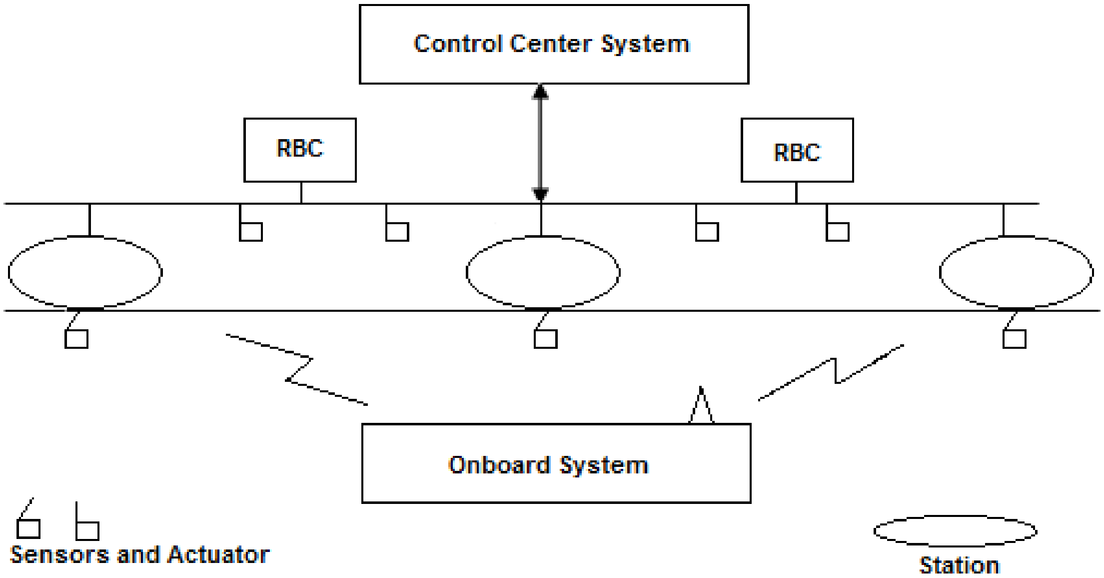


Figure 2.19: Parts of signaling system.

Onboard System consists of vital computer units, Man-Machine Interface (MMI), Train Speed Measurements Unit, Train Position Unit, Train Integrity Checking Unit, Radio Receiver, Train Data Recorder Unit, Train Speed Control Interface etc. Architecture of Onboard System is shown in figure 2.20.

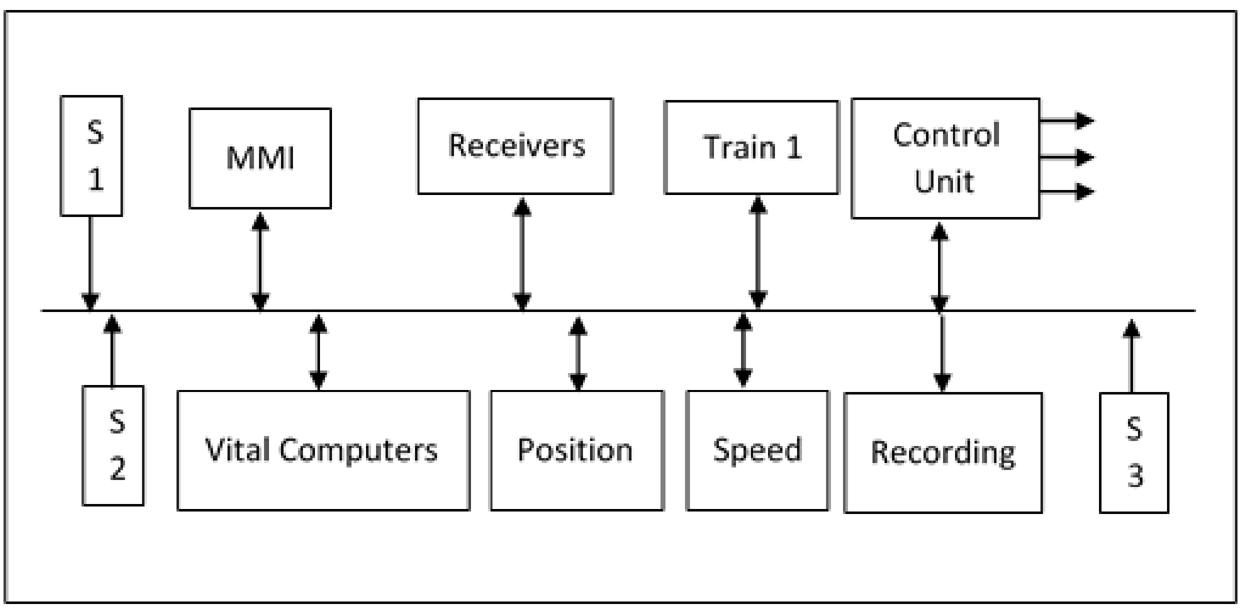


Figure 2.20: Architecture of on board system.

It is decided by the Chinese Railway that GSM-R will be used as standard of Radio System for CTCS. CSTS is divided into the following five levels (Ning, 2003):

2.3.5.1 Level 0

This level consists existing Track Circuits, Universal Cab Signaling and Train Operation Supervision System. Wayside Signals are the main signals and Cab Signals are auxiliary signals in this level. This is the most basic mode to CSTS and it is not necessary to upgrade the Wayside System for this level. The only way to realize level 0 is to equip with onboard system. CSTS level 0 is only for trains with the speed less than 120 km per hour.

2.3.5.2 Level 1

It consists existing Track Circuits, Transponders or Balises and ATP system. This is for train with the speed between 120 km per hour and 160 km per hour. On this level, the block signals could be removed and train operation is based on the on-board system, ATP which is called as the main signals. Transponders or Balises must be installed on the line and requirements for Track Circuit in Blocks and at Stations are higher than that in level 0.

2.3.5.3 Level 2

It consists of Digital Track Circuits or Analog Track Circuits with multi-information, Transponders or Balise and ATP system. This level is used for trains with the speed higher than 160 km per hour. There is no need of wayside signaling in block for this level anymore. Digital Track Circuit can transmit more information than Analog Track Circuit so ATP system can get all the necessary information for train control. With this level, Fixed Block Mode is still applied. This system indicates the special feature of Chinese Railway Signaling and it is also called “a points and continuous system”.

2.3.5.4 Level 3

This level consists of Track Circuits, Transponders or Balises and ATP with GSM-R. In this level, the function of Track Circuit is only for train occupation and Train Integrity Checking. Track Circuits no longer transmit information concerning train operation. All the data concerning train operation information is transmitted by GSM-R. GSM-R is the core of this level. At this level, the philosophy of fixed block system is still applied.

2.3.5.5 Level 4

The highest level of CTCS is Level 4 and Moving Block System function can be grasped by this level. GSM-R is used to transmission information between trains and Wayside Devices. GPS or Transponders or Balises are used for train position. Onboard system is used for Train Integrity Checking. Track Circuits are only used at stations. The amount of Wayside System is reduced to the minimum in order to reduce the maintenance cost of the system. Train dispatching can be made to be very flexible for different density of train operation on the same line.

CTCS is the result of modern mobile communication development. Based on reliable and fail-safe communication, Train Control System (Moving Block System or Train Control System based on communication) become a close loop safety control system to ensure train operation safety and efficiency. In CTCS, Track Circuits still play a very important role. On Chinese Railway Network, Track Circuit is mostly used and the basic requirement of Train Control Systems. It is not possible to construct CTCS without Track Circuit. This is the reality of Chinese Railway. The so called “a point and continuous mode” will be the special feature of CTCS. Moreover, MMI with Chinese characters is different with the MMI in ETCS. Research on MMI for onboard system have been done in Chinese railways (Ning et al., 2004).

2.3.6 Korean Radio Train Control System (KRTCS)

The Korea Railroad Research Institute has developed a KRTCS for Ministry of Land, Transport and Maritime Affairs to put the Radio Based Train Control System for urban transit which supports the driverless automatic operation into practical use and to secure the interoperability (Oh et al., 2012).

Radio Based Train Control System has several advantages in comparison with conventional Track Circuit Based Train Control System. It is a bi-directional communication system which have various features like high throughput, real time train location report between onboard and wayside etc. Controlling distance between proceeding and following trains based on real time train location information is the key functional requirement of any Train Control System. To prevent train collisions with speed restriction and applying breaks, ATP is a primary function. Figure 2.21 illustrate the processing procedure between Wayside ATP and Onboard ATP (Oh et al., 2012).

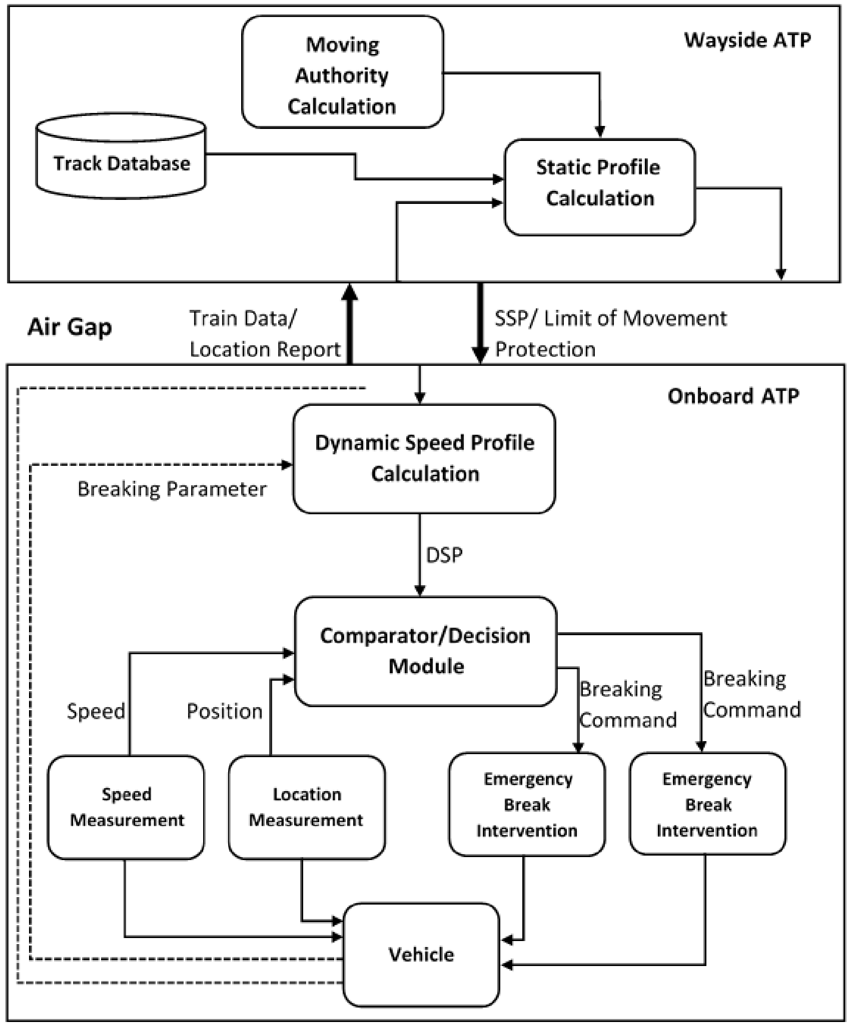


Figure 2.21: Processing procedure between wayside ATP and onboard ATP (Source: Oh et al., 2012).

The components of KRTCS are Automatic Train Supervision (ATS), Wayside and Onboard ATP, Automatic Train Operation (ATO), Electronic Interlocking (EI) and the Train Control Communication Networks. The Transponder Tag is installed at the Wayside and used for the compensation for train location and the Precision Stop Marker is used to check the Precise Stop Position of train. KRTCS applying in urban transit where the track is double and its target is to turn back the vehicle at the turn back point automatically. It is not operated with linkage to railway lines where other existing Train Control Systems are installed, and the train not equipped with KRTCS is excluded from control target. So KRTCS is installed at the new revenue line or after removal of existing train control system. One Wayside ATP of KRTCS takes charge in one control area, and one control area has to handle more than 20 trains to the maximum.

KRTCS ATP function design was performed on the basis of the IEEE 1474.3 (IEEE Recommended Practice for Communications-Based Train Control (CBTC) System Design and Functional Allocations) with its target to build its standard system. The functional configuration of ATP system of KRTCS is illustrated in figure 2.22.

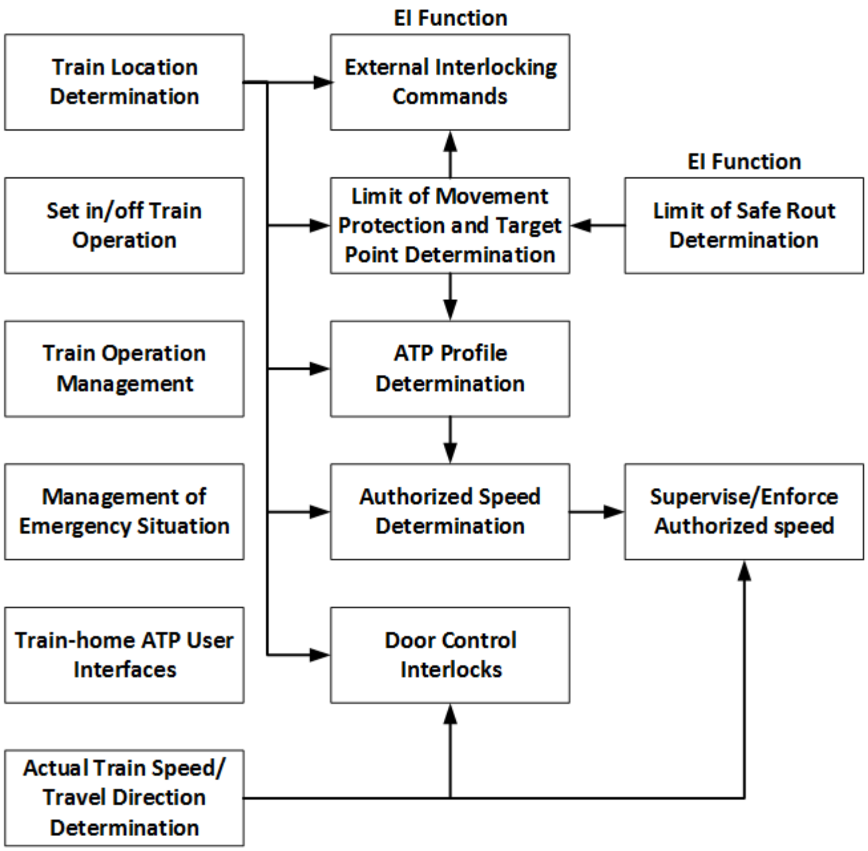


Figure 2.22: KRTCS ATP function (Source: Oh et al., 2012).

To determine the train location first initialize train location. Exact location of train is initialized in case where train enters into the Control Area and where it was recovered from the failure also. From the Initial Location of train, the Onboard ATP transmits to the Wayside ATP by calculating its own train together with Train Length Determination and Parted Train Detection. Onboard ATP determines locations of whole trains on its own control area. If any Wayside ATP fails to trace the location of a certain train, emergency braking is applied to the corresponding train.

In KRTCS, movement of train is controlled by safety margin. For the limit of movement protection it consider ATP Target Point and ATP Speed Profile which is never allowed to be passed over, train speed, braking performance and the uncertainty of train length. Wayside ATP generates Static Speed Profiles with the value of Fixed Infrastructure Speed Limit and the value of Temporary Speed Limit between train and wayside. By using the Static Speed Profile and Target Point generated in the Wayside ATP, Onboard ATP generates its Dynamic Speed Profile. In this case, in consideration of braking performance of vehicle, the emergency braking curve, full service braking curve, and the warning braking curve for driver's alarm are generated. The onboard ATP supervises allowable speeds of train which are controlled by Train Control System (TCS) so as to ensure that the train speed is existed within the train ATP profile (Oh et al., 2012).

2.3.7 KLUB-U (КЛУБ-U) by Russia

KLUB-U is the modern train control system in Russia. The abbreviation "КЛУБ" stands for "Комплексное локомотивное устройство безопасности", Integrated Train Protection System, where U stands for Unified. In Cab Signaling System KLUB-U enables to decode the track side ALSN codes. ALSN is a Train Control System meaning Continuous Automatic Train Signaling used widely on main lines of the ex-Soviet states (ALSN, 2014). In newer block control the KLUB-U systems decode signals by TETRA digital radio including a remote initiation of a train stop. ITARUS-ATC connects the KLUB-U in-cab system via GSM-R digital radio with the ERMTS Level 2 RBC block control in those area where the position of train is derived from GNSS (KLUB-U, 2014).

Figure 2.23: KLUB-U cab signaling (Source: KLUB-U, 2014).

2.3.8 Australian Digital Train Control System (ADTCS)

Australia proposed a train control system called *ADTC* in 2008. ADTC provide a nation-wide approach to rail traffic control management thereby enabling rail industry to rapidly advance to a new digital communications era and in doing so unleash a surge in productivity and capacity whilst significantly improving its safety and reliability. The ADTCS is interoperable across different networks and also be constructed to a level of complexity appropriate to the level of traffic operating in network.

ADTCS is a highly effective signaling/traffic control system which also controls train speeds. It will build on the Advanced Train Management System (ATMS) that is subject to "proof of concept" assessment by the ARTC, and ATP system being trialled by RailCorp in New South Wales, and it is configured for utilizing the standards accepted in the European ETCS level 1 and 2, with potential to move to the future standard ETCS level 3.

The system integrates a monitoring system that exchanges information between the ground and the train to locate precise position of the train, and a movement control system which allows speed limits to be transmitted to the train driver whilst monitoring driver's response and if necessary, applying train brakes in an unsafe situation. This technology provides real time monitoring of train positions and speed etc. using differential Global Positioning Systems (GPS), Digital Radio Communications (such as GSM-R), Transponders and Wayside Devices that provide Track Detection Capacity (Australian Railway Association Inc., 2008).

2.3.9 Positive Train Control (PTC) by US

The Rail Safety Improvement Act of 2008, as enacted by US Congress requires all Class I railroads and passenger rail operators to implement a mandatory PTC Collision Avoidance System by December 31st 2015. The technology must be installed on all main-line track where intercity passenger railroads and commuter railroads operate, as well as on lines carrying toxic-by-inhalation hazardous materials (The Joint Council on Transit Wireless Communication, 2012).

Existing safety systems use spaced, track-side equipment to determine train location within a block of track, and a relatively simplistic colored-light notification system for drivers. Federal Communications Commission, 2014, describe that PTC system is designed to prevent train-to-train collisions, derailments caused by excessive speeds, unauthorized train movements in work zones, and movement of trains through switches left in the wrong position. PTC networks enable real-time information sharing between trains, rail wayside devices, and "back office" applications, regarding train movement, speed restrictions, train position and speed, and the state of signal and switch devices. PTC introduces continuous GPS-based location and speed tracking, with more sophisticated on-board wireless technology for enforcing movement authority from a centralized control center, wherever the vehicle may be (The Joint Council on Transit Wireless Communication, 2012).

The American Railway Engineering and Maintenance-of-Way Association (AREMA) describes PTC's primary characteristics:

- Train separation or collision avoidance.
- Line speed enforcement.
- Temporary speed restrictions.
- Rail worker wayside safety.

Architecture of PTC is illustrated in figure 2.24:

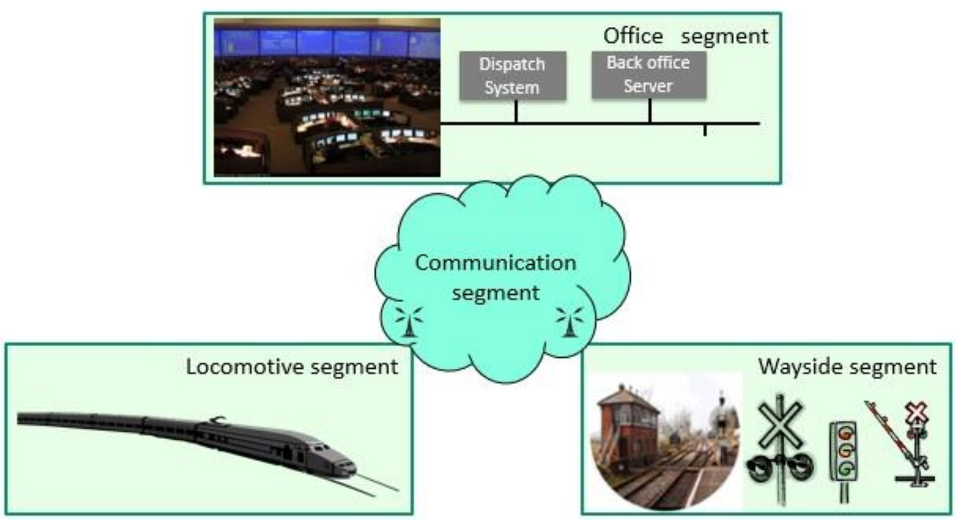


Figure 2.24: PTC Architecture (Source: Li, 2011).

Every technology has some limitations, likewise PTC also have some limitations. Badugu and Movva, 2013, describes limitations of PTC. The advanced processor-based speed control algorithms found in PTC systems claim to be able to properly control the speed of freight trains over 5000 feet in length and weighing over 10,000 tons, but concerns remain about taking the final decision out of the hands of skilled locomotive engineers. Improper use of air brake can lead to a train running away, derailment, or unexpected separation. PTC will not prevent certain low speed collisions caused by Permissive Block Operation, accidents caused by trains pushing in reverse, derailments caused by track or train defect, grade crossing collisions, or collisions with previously derailed trains. Wherever PTC is installed in absence of track circuit blocks, it will not detect broken rails, flooded tracks, or cars that have been left or rolled onto the line.

The above described train control systems are fewer from the whole world which having some international standards. Some of the legacy systems are shown in table 2.3:

Table 2.3: Various railway systems used by different countries (Source: Train Protection system, 2014).

No.	Systems	Countries
1	ALSN	Russian Federation, Belarus, Estonia, Latvia, Lithuania, Ukraine.
2	ASFA	Spain.
3	ATB	Netherlands.
4	ATC	Sweden, Denmark, Norway, Brazil, South Korea, Japan, Australia (Queensland), Indonesia.
5	ATP	United Kingdom, United States of America, Brazil, Australia (Queensland), Indonesia, Ireland.
6	AWS	United Kingdom, Queensland, South Australia, Indonesia.
7	BACC	Italy.
8	CAWS	Ireland.
9	CBTC	Brazil, United States of America, Canada, Singapore, Spain, Gabon.
10	CONVEL	Portugal.
11	CROCODILE/ MEMOR	Belgium, France.

12	EBICAB	Bulgaria, Finland, Norway, Portugal, Spain, Sweden.
13	EVM 120	Hungary.
14	HKT	Denmark.
15	Integra-Signum	Switzerland.
16	KVB	France.
17	LZB	Germany, Austria, Spain.
18	LS	Czech republic, Slovakia.
19	PZB Indusi	Germany, Austria, Romania, Slovenia, Croatia, Bosnia-Herzegovina, Serbia, Montenegro, Macedonia, Israel.
20	SHP	Poland.
21	SCMT	Italy.
22	TASC	Japan.
23	TBL	Belgium, Hong Kong.
24	TPWS	United Kingdom, Victoria.
25	TVM	France, South Korea.
26	ZUB 123	Denmark.
27	ZUB 262	Switzerland.

2.4 Advance Systems Used in India

2.4.1 Anti-Collision Device (ACD)

ACD Network is a Train Collision prevention system patented by Konkan Railway Corporation Limited (A Public Sector Undertaking of Ministry of Railways, Government of India). Anti-Collision Device (ACD) is a self-acting microprocessor-based data communication device designed and developed by Kankan Railway. When installed on locomotives along with an Automatic Braking Unit (ABU) (See figure 2.25), guard vans (See figure 2.28), stations (See figure 2.26) and level-crossing gates (both manned and unmanned) (See figure 2.27), the network of ACD systems prevents high-speed collisions in mid-sections, station areas and at level-crossing gates. The ACD uses both radio frequency and GPS through satellites, whereby a train is automatically brought to a halt if the track ahead is not clear. The train starts braking 3 kms ahead of a blockade.

Figure 2.25: Driver console and loco ACD.

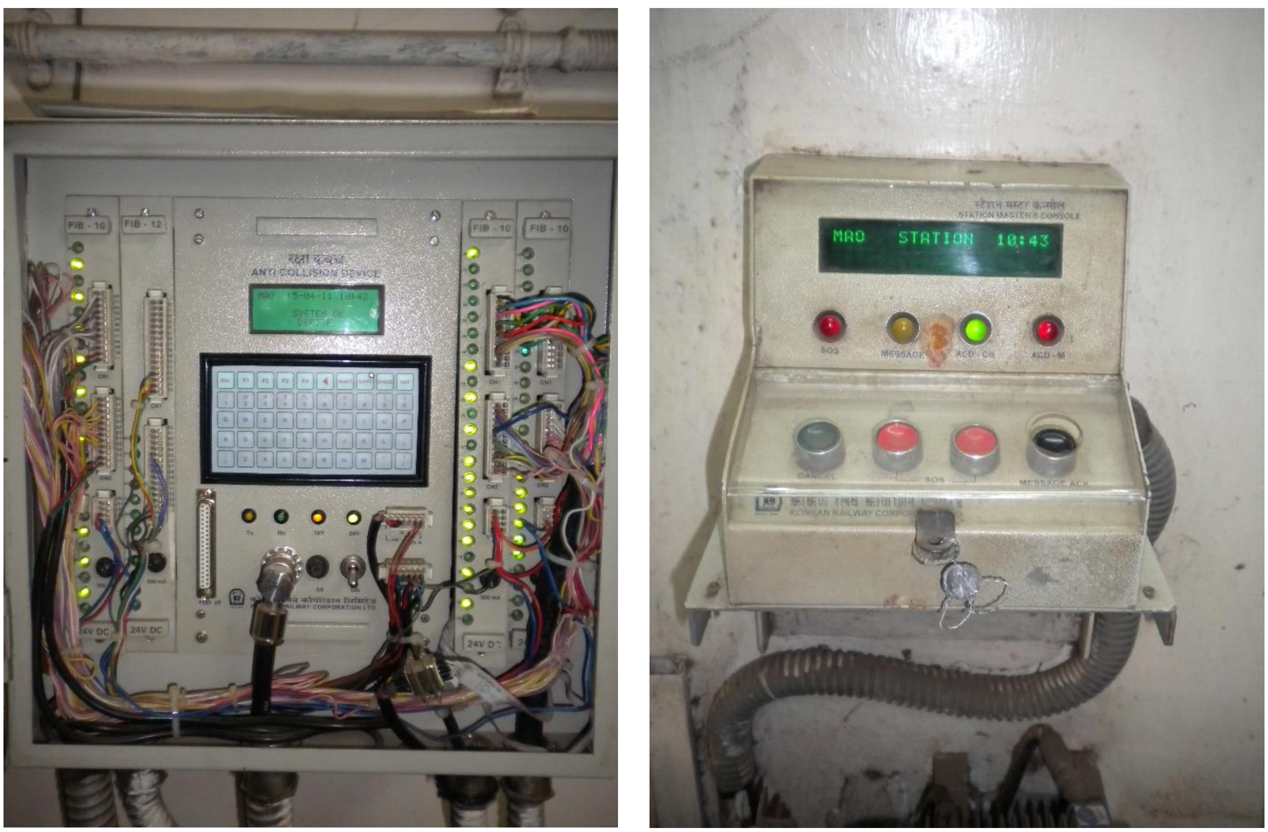


Figure 2.26: Station ACD.

Figure 2.27: Unmanned level crossing ACD.

Figure 2.28: Guard van ACD.

Figure 2.29: Automatic breaking unit for locomotives.

ACD also called ‘Raksha Kavach’, envisages setting up a network of “self-activating” micro-processor based communication devices which automatically apply brakes on trains that are unknowingly getting into a "collision-like situation," including before stations and at mid-sections. “At the mid-sections, where neither the protection of signals nor guidance is available to the driver, the ACD makes the loco intelligent and extends its capability to detect any collision-like situations in a range of 3 km, which the driver cannot detect on his own. Situations like collision between two approaching trains or between a derailed train on one track and an approaching train on the adjacent track can thus be prevented,” according to the KRCL official (Bhatt, 2007).

The "silent" network of ACD systems can be installed on the locomotives, guard vans and at stations, which could ensure that trains do not collide at while travelling at high speeds. Further, if the ACD systems are provided at the level crossing gates (both manned as well as un-manned), the project could provide protection to the lives of road users also. The ACDs are capable of multi functions. For example, while approaching a station, the Loco ACD gives the "station approach" warning to the driver about 2 km in rear of the first STOP signal of the station and in case the driver ignores the warning it will automatically regulate the train speed.

The pilot project implementation of ACD was successfully commissioned on the North-East Frontier Railway this year. Survey for expanding the system to another 10,000 km falling on the critical and busy sections of the network is almost complete (Rajaram, 2005).

2.4.1.1 Technology Used in ACD

The heart of the ACD is an Intel 80386 processor that uses the DM&P M617 Intel chipset. It has an integrated digital radio modem and works on the VxWorks Real Time Operating System (RTOS). Rajaram adds, "VxWorks, as a platform, is most suitable for real-time applications" (Rajaram, 2005),

2.4.1.2 Working of ACD in Indian Railway

The loco ACD is the heart of ACD network. In ACD the radio single from the consolation of GPS satellite are received by GPS receiver through by antenna. This signal is sent to the Command and Control Unit (CCU) of ACD and the CCU is a microprocessor based module. And as like a brain of ACD system.

The GPS submits the data to the CCU to extract the parameters related to the movement of locomotive like

- Latitude.
- Longitude.
- Speed.
- Angle.
- Date and time.

It processed the data and generated command from the ACD. A part from the GPS receiver there is a radio Trans-receiver inside the ACD. A transmits information such as:

- Identification no.
- Speed.

Location in terms of Latitude, Longitude, and status of it working with the help of separate radio antenna.

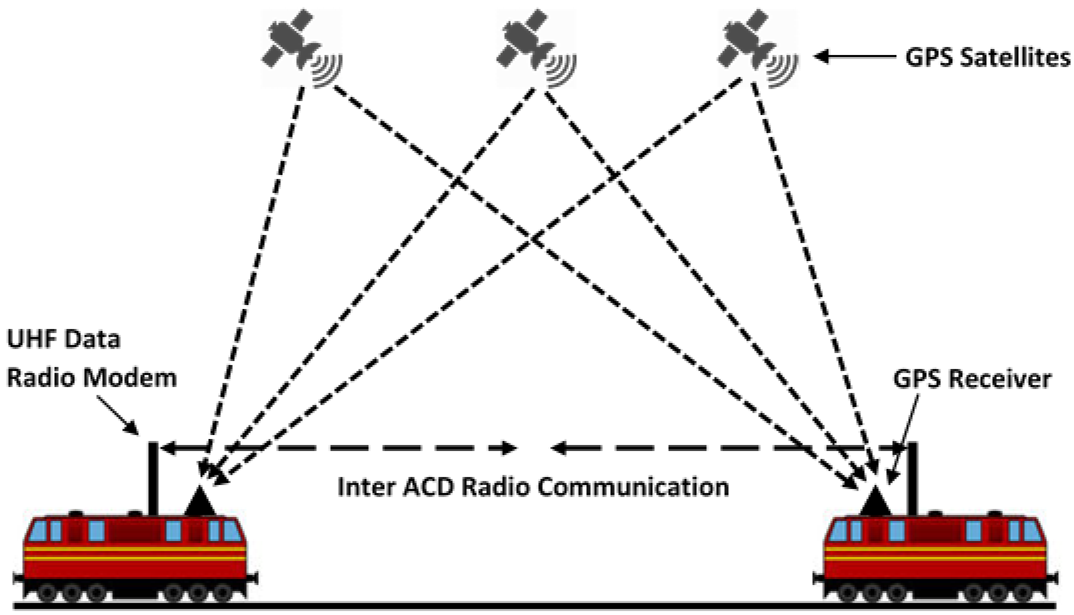


Figure 2.30: Working of on board ACD's

It also receive the information being send by other ACD range within range 3 Km. This information also send to the CCU for processing with all received information from other ACD and the data from the GPS receiver. The CCU unit take a design for apply either a normal & emergency break or the locomotive break as the case may be (Bhatt, 2007).

This is active with the help of auto breaking unit of on board mobile loco ACD and guard room ACD, both having a GPS receiver and radio Trans-receiver. The GPS receiver received the data from the satellite and radio Trans-receiver communicate with the other GPS. Within range of 3.Km. the tracks side and sates nary module. Such as: - station ACD, level crossing ACD, and loco side ACD (Bhatt, 2007).

Both mobile and stationary ACD exchange information and take decision based on trains working rule. And embedded software to a apply breaks automatic with art any input users. All the ACD work on the principle of distributed control system. It's very simply but it two ACD on locomotive within pre define distance and proceed and risks on collision system. Automatically active the breaking to the train and prevent collision relay in accident (Bhatt, 2007).

2.4.1.3 Benefits of ACD

- Very economical and cost effective.
- Easily adaptable and expandable.
- Does not degrade the existing safety level.
- Employs state-of-art hardware and software technology.
- No way had side equipment required, hence no requirement of Power.
- No cabling on the track required (which is more expensive and cumbersome).
- Less susceptible to Vandalism.
- It does not require any inputs to be fed by the crew at the start of journey, thus human error is eliminated.

2.4.1.4 Limitations of ACD

- Visual information of train on map is not available for Loco Pilot and station master.
- No track POI's information is available.
- Signal and Level Crossing status is not available for Loco Pilot.
- It doesn't prevent from maintenance segment accidents.
- Range of collision is depends on range of radio which require specific license.

2.4.2 Satellite Imaging for Rail Navigation (SIMRAN)

The objective of this project was to develop an effective way to collect and disseminate information dynamically of every train in a given geographical boundary for its location, speed and direction of movement, (ii) ensure better and selective dissemination of information to passengers. Train tracking system using GPS was developed. Each train has a train locator unit to receive information from GPS satellites and continuously identify the position of the train with information about its location (latitude and longitude values). GSM is used for connectivity and wherever needed as an alternate location identifier.

SIMRAN is a joint initiative of IIT-K and Research Designs and Standards Organization (RDSO), Lucknow. The device is more of an information-sharing type which will display details of the next station, the expected arrival time in reaching the next stop. The information is displayed on the two facing walls of the coaches (OneWorld Foundation India, 2012).

2.4.2.1 Features and Technology Used in SIMRAN

- Indian Railway GIS Map.
- Unified Information Database for whole IR (it can be compared with UID Project of GOI)
    - Locomotives/EMU/DMU/MEMU
    - Rake, Coaches, Wagon etc.
    - Station, Loco Shed, Car Shed and other locations
    - GIS
    - Routes, Sections & Various Control Section
- Fault diagnostic Data Logging
- Traffic analysis

2.4.2.2 Silent Features

- No manual data entry- all automated, no scope of human error.
- Data logging from two independent sources - Train & Station Devices in order to ensure 100% availability of desired information.
- Two independent communication schemes, used for Data Logging - GPRS and SMS, in order to ensure no communication failure.
- No Communication Shadow Zone - Trains & Locomotives are tracked using Station Module, also in GPS shadow zones (Zones where GPS satellites are unavailable). In this case station level granularity is provided.
- Station device can be connected through Local LAN (OFC). In absence of GSM signal also data from station can be logged to central server using OFC Network.

Architecture of SIMRAN is described in figure 2.31.

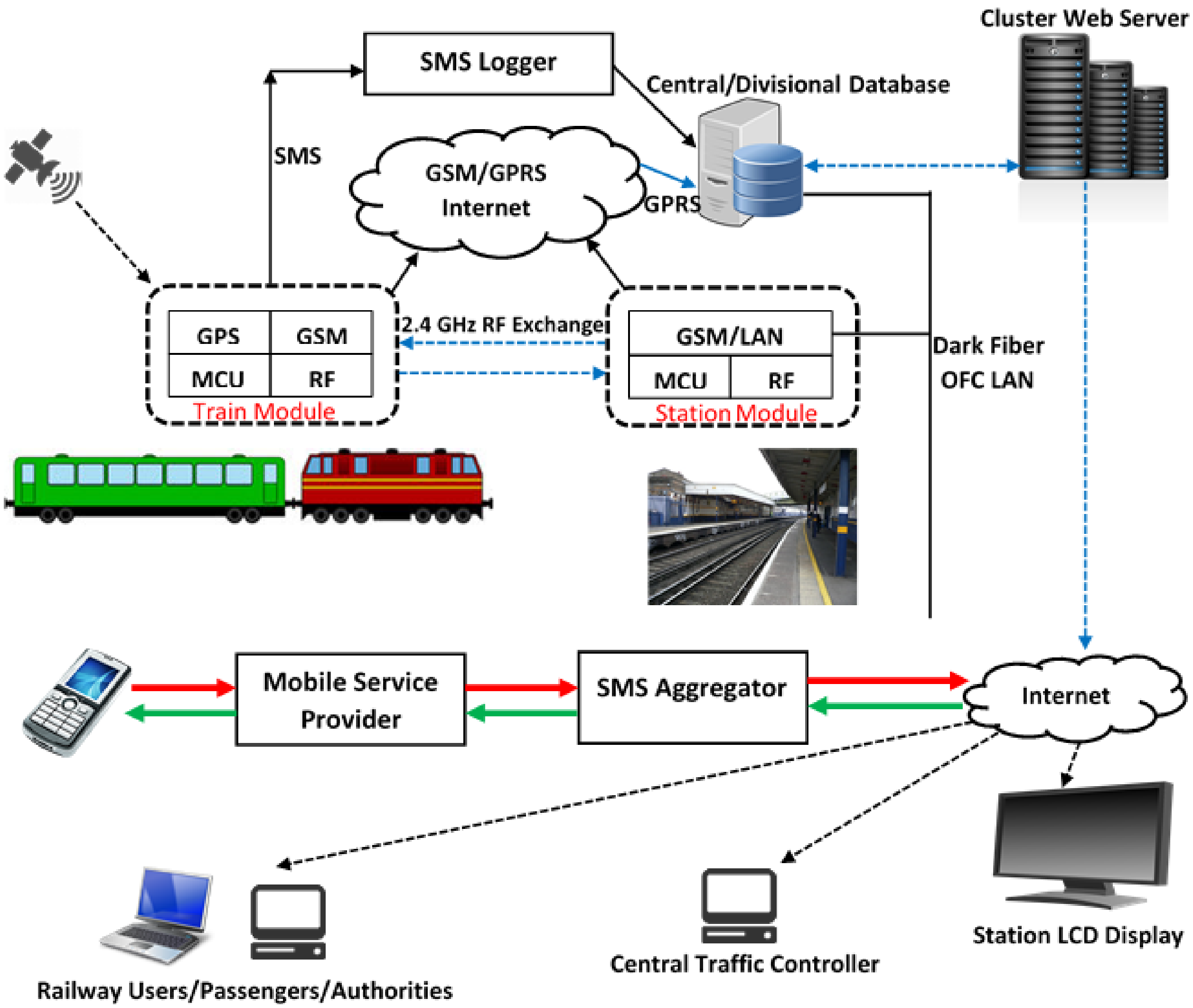


Figure 2.31: SIMRAN Architecture (Source: OneWorld Foundation India, 2012).

2.5 Conclusion

This chapter reviewed many train controlling systems with their key features and the modern technologies which is used by these systems. Various countries are using various systems for controlling trains like India having two systems called ACD and SIMRAN, China having CTCS etc. ACD was developed by Konkan Railway and SIMRAN was developed by IIT-K and Research Design and Standards Organization (RDSO). SIMRAN was closed on 30th September, 2012 due to that this system is trial and Indian Railway will develop it's own system but the ACD is still working in some trains of Konkan Railway. Many countries having train controlling systems with international standards like, China having CTCS, Japan having ATC, Korea having Korean Radio Train Control System, Russian having KLUB-U, Australia having ADCS, Europe having two systems ETCS and ERTMS and USA is developing PTC. Some systems are using trackside equipment and some are using GNSS technology to get the train location information.

Although the above systems are used by many countries but every system have some limitations like in ACD and SIMRAN had no GIS integration and some communication gaps are also there, PTC having some limitations with freight trains by their weight and low speed. Balise placement on the track is not as easy as it look like, so the systems which are using Balises have limitations by Balises positioning like ETCS is depending on position of Balises, Balise linking and Odometer accuracy. The Russian KLUB-U have very less literature available so limitations of this system are not identified. The Korean KRTCS and Japanese ATC get location of train by using wayside equipment. The maintenance of these equipment is very difficult and expensive task.

Chapter 3

GNSS Fundamentals

3.1 Introduction

Satellite navigation systems has become vital part of all applications where mobility plays an important role (Heinrichs et al., 2005). There are multiple satellite constellations of GNSS satellites orbiting the earth. This chapter reviews the background of GNSS and its fundamentals. Review of current fully operational GNSS and future GNSS is described in section 3.2. In section 3.3, principle of GNSS operation, error sources and current augmentation systems for GNSS are introduced. Source of errors in GNSS positioning is described in section 3.4. This chapter concludes with the review of current applications of GNSS in railway (see section 3.5) and future possibility for railway applications. Review of GNSS principles in this chapter is fundamental rather than comprehensive. More comprehensive details about GNSS are well described and discussed in the reference books.

3.2 Global Navigation Satellite System (GNSS)

GNSS is a general concept for the satellite navigation/positioning system which can provide position information receivers with global coverage. GNSS is now defined as a worldwide set of satellite navigation system (Kaplan and Hegarty, 2006; Kray and Kortuem, 2007; Chu and Yang, 2014). GNSS receiver can get its position in three dimension (e.g. latitude, longitude and altitude) with few meter accuracy by using satellite signals transmitted from satellites to the receiver and also calculate precise time and velocity (Panigrahi, 2004; Hazas et al., 2005; Groves, 2008).

United States GPS and Russian GLONASS are only two fully operational GNSS till now. More GNSS are under development. EU and European Space Agency (ESA) is developing Galileo which is second generation GNSS and expected to be in full operation around 2012 (Hein et al., 2007). China also developing satellite system called BeiDou which will be another GNSS system. It became operational in China in December 2011 with 10 satellite in use and began offering services to customers in Asia Pacific region in December 2012. It is expected to begin serving global customers upon its completion in 2020 (Beidou Navigation Satellite System, 2014). Therefore in next five to ten years more choices for GNSSs will emerge and there will be more than 120 satellites in orbit used for the satellite navigation. Figure 3.1 illustrates the Comparison of GPS, GLONASS, Galileo and Compass (medium earth orbit) satellite navigation system orbits with the International Space Station, Hubble Space Telescope and Iridium constellation orbits, Geostationary Earth Orbit, and the nominal size of the Earth.

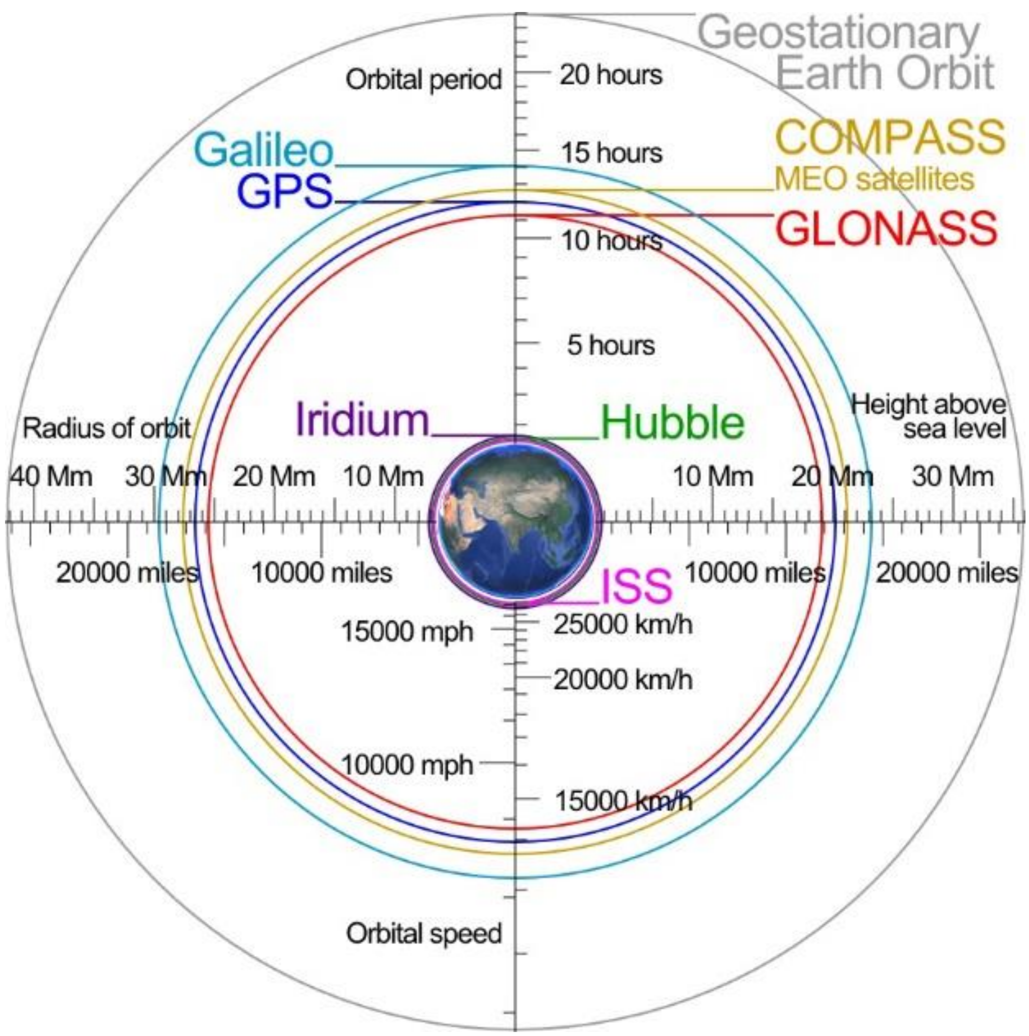


Figure 3.1: Compression of different satellite navigation system with ISS, Hubble, Iridium and Geostationary Earth Orbit. (Source: GLONASS, 2014)

Other regional satellite navigation systems and augmentation systems are also included in GNSS. Chinese BeiDou I, Japan's proposed Quasi-Zenith Satellite System (QZSS) and Indian Regional Navigation Satellite System (IRNSS) are the regional navigation system which provide navigation service in the coverage area. In order to improve performance of GNSS system for different applications, many augmentation systems like LAAS, WAAS, EGNOS, DGPS, RTK have been developed. Therefore GNSS system can not only bb global coverage system but also the combination of all satellite navigation and augmentation system. Overviews of some GNSS systems are as follows:

3.2.1 Global Positioning System (GPS)

GPS is the first GNSS system which was developed by the Department of Defense (DOD) United States. Initially name of GPS is NAVigation Satellite Timing And Ranging (NAVSTAR). The first GPS satellite was launched in 1978. Originally GPS was designed and developed as a navigation system for U.S. military users. But it is also available for civilians, and therefore is a dual use system for both military and civilian users (Tiwari, 2009). GPS is one way ranging (passive) system which provides accurate, continuous, worldwide, three-dimensional position and velocity information to users with appropriate receiving equipment (Kaplan and Hegarty, 2006). GPS consists of three segments, Space Segment, Control System and User Segment. Space Segment consists of the GPS satellites. Control Segment is made by a system of tracking stations located around the world. Master Control facility is located at Schriever Air Force Base (formerly Falcon AFB) in the State of Colorado, USA. GPS User Segment consists of GPS receivers and user community. GPS receivers convert Space Vehicle (SV) signals into position, velocity, and time estimates.

GPS constellation contains 24 satellites in six earth centered orbital planes with an inclination of about 55° to the equator and radius 26,560 km (i.e., the satellite altitude of about 20,200 km above the Earth's surface). The corresponding GPS orbital period is about 12 sidereal hours (~11 hours, 58 minutes). GPS system was officially declared to have achieved Full Operational Capability (FOC) on July 17, 1995, ensuring the availability of at least 24 operational, non-experimental, GPS satellites (EL-Rabbany, 2002). The first satellite was launched on 22nd February, 1978. It is one of the first generation of GPS satellites include as Block 1. Block 1 was the composition of 12 satellites, 11 were successfully launched and one was failed to be launched from 1978 to 1985. Purpose of Block1 was to build up the ground track network and test the GPS receiver performance and the possibility of GPS operation.

The second generation of GPS satellites are known as Block II/IIA which were developed for first operational constellation. Block IIA (where A denotes advance) is an advanced version of Block II with an enhancement of the navigation message storage. First Block II satellite was successfully launched on 26th November, 1990. From 1989 to 1997, a total of 28 Block II/IIA satellites were launched. Fully operational constellation of GPS was declared in April 1995.

Table 3.1: Summery of GPS satellites launches

Block	Launch Period	Satellite Launches		Currently in Orbit and Healthy
		Success	Failure	
I	1978-1985	10	1	0
II	1989-1990	9	0	0
IIA	1990-1997	19	0	9
IIR	1997-2004	12	1	12
IIR-M	2005-2009	8	0	7
IIF	From 2010	4	0	4
IIIA	From 2014	0	0	0
Total:		62	2	31

Block II/II1 was designed for 7.5 years so the new generation of GPS Block IIR satellites were developed. R denotes replenishment or replacement. Total 21 satellites in orbit was planned for the Block IIR. The first Block IIR satellite was launched on 23rd July, 1997. Over the next seven years, 11 Block IIR satellites were launched and from 2005, a GPS modernization plan was introduced in order to improve the quality and protection for military and civil use (Tasi et al., 2008). The rest of Block IIR satellites were converted to the Block IIR-M (where M denotes Modernization) satellites. New generation constellations introduced a new military M-code (for accuracy enhancement) and a second civil signal L2C. The first Block IIR-M satellite was launched in September 2005, and the last launch occurred in August 2009. Block IIR-M offer modernized antenna panel that provides increased signal power, improving encryption and anti-jamming capabilities for the military. As of

December 24, 2013, there were 7 healthy Block IIR-M satellites in the GPS constellation, plus one more (SVN-49) designated "unusable." As of December 2012, 32 satellites are available in the GPS constellation. Three notations are used to refer to a satellite, one is to assign a letter and a number to each satellite. The letter A, B, C, B E and F represents the orbital plane of satellite and number 1 to 6 denotes the number of satellites on the plane. The second notation is Pseudorandom Noise (PRN) which denotes the PRN code generators on the satellite. The last notation is the Space Vehicle Number (SVN).

Block IIF (Where F stands for Follow-on) is the fourth generation satellites and the future generation of GPS is called GPS III. Compared to previous generations, Block IIF satellites have a longer life expectancy and a higher accuracy requirement. Each spacecraft uses a mix of rubidium and cesium atomic clocks to keep time within 8 billionths of a second per day. GPS III is currently under development. GPS III will provide more powerful signals in addition to enhanced signal reliability, accuracy, and integrity, all of which will support precision, navigation, and timing services (GPS Space Segment, 2014). Both of them will broadcast a new civil signal L5 to provide the safety-of-life services. The plan is to build up 12 satellites for the Block IIF and 32 satellites for GPS III (8 GPS IIIA, 8 GPS IIIB and 16 GPS IIIC).

Two carrier frequencies (or sine waves) are used to transmit navigation signal, which are called L1 (frequency 1575.42 MHz), the primary frequency, and L2 (1227.60 MHz), the secondary frequency. Each satellite transmits on these frequencies, but with different ranging codes than those employed by other satellites. These codes were selected because they have low cross-correlation properties with respect to one another. Each satellite generates a short code referred to as the Coarse/Acquisition or C/A code and a long code denoted as the precision or P code. Both codes are transmitted on L1 frequency, but only P-code is modulated onto the L2 frequency. The C/A code is available for civilian users. Since 1994, the P-code has been encrypted by the Y-code, normally indicated as P(Y) code. Feature of this code is known as Anti Spoofing (AS). The encrypted P(Y) code is only available for U.S. military and other authorized users.

As for the GPS modernization program development, new civil code (C/A code) is modulated on L2 frequency which is called L2C and the new military code (M-code) is broadcast on both L1 and L2 frequencies. These available two C/A code allows the standalone GPS receiver to calibrate the ionospheric delay. After launch of GPS Block IIF satellite, a new third frequency is introduced known as L5. L5 is claiming to be a GPS “Safety of Life” signal which intends to increase precision and robustness of the navigation solution due to mitigation of ionospheric refraction errors and an enhanced signal design which includes a higher signal strength and advanced code structure compared to the existing GPS civil signal (Erker et al., 2009).

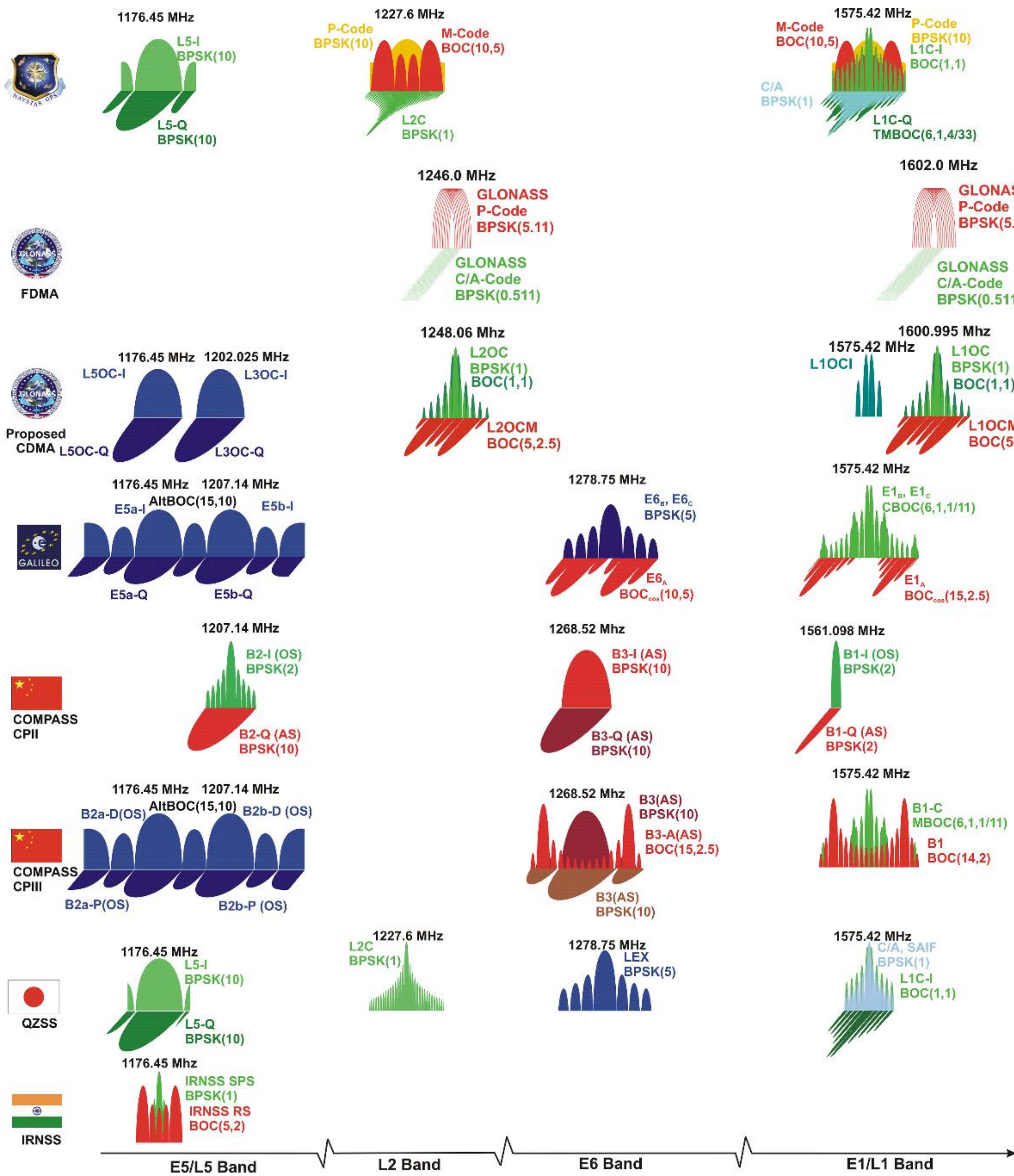


Figure 3.2: Frequency used by the different GNSS systems. (Source: GNSS Signal, 2014)

GPS navigation data is also added in the navigation signal to transmit the navigation message. It is binary data stream which is transmitted at a low rate of 50 kbps. Navigation message contains keplerian elements which define the actual location of satellites, precise satellite clock parameters, satellite health status, satellite almanac and ionospheric data. There are three components in the satellite navigation signal, carrier frequencies (L1, L2 and L5), PRN codes (C/A, P(Y) and M code) and navigation data (Parkinson et al., 1996; Misra and Enge, 2001; Kaplan and Hegarty, 2006).

Two services are provided by the GPS, one is Standard Positioning Service (SPS) for civil users and the other one is the Precise Point Positioning (PPP) service for the DoD authorized military and government agency users which can provide better accuracy than SPS. SPS is free to all users worldwide. It provided accuracy of 100m in horizontal plane and 156m in vertical plane until May 2000, because the Selective Availability (SA) technology was intentionally degraded the performance of SPS. SA was discontinued by the U.S. President Clinton on 1st May, 2000. Now performance of SPS is better than 13m in horizontal plane and 22m in vertical plane (FRP, 1999; Sandhoo and Shaw, 2000; Mcdonald and Hegarty, 2000; Kaplan and Hegarty, 2006).

3.2.2 GLONASS

GLONASS (Глобальная навигационная спутниковая система), acronym for Globalnaya navigatsionnaya sputnikovaya sistema or Global Navigation Satellite System, is a space-based satellite navigation system operated by the Russian Aerospace Defense Forces. It provides an alternative to GPS and is the only alternative navigational system in operation with global coverage and of comparable precision (GLONASS, 2014). GLONASS was developed to provide position, velocity and timing determination. Currently it is operated by Russian government but it was initially developed by the former Soviet Union. In 1976, the development of GLONSS was started and the first GLONASS satellite was launched on 12th October, 1982. Originally, GLONASS was designed for the Soviet Union military user, but now it also defines as a dual use system for both civil and military users. By 2010, GLONASS had achieved 100% coverage of Russia's territory and in October 2011, the full orbital constellation of 24 satellites was restored, enabling full global coverage. The constellation have 21 active satellites and 3 active sphere satellites in three orbital planes separated by 120 degree. The satellites are located in middle circular orbit at 19,100 km altitude with a 64.8 degree inclination to earth’s surface and a period of 11 hours and 15 minutes (Kazantsev et al., 1994; Leick, 2004; Kaplan and Hegarty, 2006).

In February 1996, Russian government declared full operational constellation of GLONASS. But due to some financial problems of Russian government, the system fell down rapidly in following five years without sufficient constellation maintenance. It was operated with eight satellites by the end of 2001. The Russian government decided to rebuild the GLONASS on 20^{th} August, 2001. According to the declaration, the GLONASS aimed to restore its FOC in 2011. India's space agency and Russian space agency made an agreement to develop and maintain GLONASS together in 2004 and new funding was introduced into the GLONASS by the Russian federation. After this, GLONASS program appears to have been speeded up.

GLONASS uses FDMA technology but GPS and Galileo use CDMA technology to recognize signals received by receivers. As the previous section introduced, each GPS satellite transmit different C/A and P(Y) codes on the same frequency (L1 and L2), but each GLONASS satellite transmits the same PRN code (C/A and P code) on different frequencies around L1 and L2. GLONASS satellite navigation signal contains of three components: two L band carriers (1602-1615.5 MHz for L1 and 1246-1256.5 for L2), C/A and P code, and a navigation message. The carrier frequency is derived from the following equation:

$$f_L^k = (178.0 + k * 0.0625).L \qquad (MHz) \qquad (3.1)$$

Where k was an integer which takes the value from 1 to 24, i.e. each satellite was assigned a number for the GLONASS channel. The Russians have modified two carrier frequencies to 1598.0625-1604.25 MHz for L1 and 1242.9375-1247.75 MHz for L2 (i.e. k= -7 to 4) after 2005. Therefore, k can only use 12 values for all satellites and satellites on the opposite side of the earth need to share same k number. L is the factor number for the two L-band carrier frequencies,

$$L = \begin{cases} 9 & for\ L1\ band \\ 7 & for\ L2\ band \end{cases} \qquad (3.2)$$

GLONASS also have C/A code and P code similar to GPS, where C/A code for civil users is on L1 and P code for military users is on both L1 and L2. Chipping rate for C/A code and P code are 0.511 Mbps and 5.11 Mbps, respectively. Navigation message is a 50 bps data stream and it modulates on both C/A code and P code to generate two types of navigation message. Navigation message provides the major information related to satellite location, channel number and satellite health status (Parkinson et al., 1996; Leik, 2004; Kaplan and Hegarty, 2006; Ginnons, 2007).

Another difference between GPS and GLONASS is time reference system. GPS time system is linked to Coordinated Universal Time, U.S. Naval Observatory (UTC (USNO)) whereas GLONASS time system is linked to Coordinated Universal Time, Soviet Union (UTC (SU)). One more difference between GPS and GLONASS is that these two systems using different coordinate frames to express the position of their satellite. GPS uses the World Geodetic System if 1984 (WGS84) and GLONASS uses the Earth Parameter System 1990 (PZ-90). Maximum difference between these two systems could be 20m on the earth surface. For integration of GPS and GLONASS, above two differences need to be considered. Compression of GPS and GLONASS is shown in table 3.2.

Table 3.2: GPS and GLONASS comparison (Source: Zheang, 2010)

	GPS	**GLONASS**
Number of satellites	32	24
Orbital planes	6	3
Satellite per orbital plane	4	8
Inclination of orbit (deg)	55	64.8
Altitude (km)	20163	19100
Orbital period	11h58m	11h15m
Repeat ground path	1 sidereal day	1 sidereal day
Signal separation technique	CDMA	FDMA
Satellite coordinate frame	WGS 84	PZ-90
Time reference	UTC (USNO)	UTC (SU)
Carrier frequency	L1: 1575.42 MHz	L1: 1602.5625-1615.5 MHz
	L2: 1227.60 MHz	L2: 1246.4375-1256.5 MHz
C/A Code rate	1.023 MHz	0.511 MHz
P Code rate	10.23 MHz	5.11 MHz

From 1982 to 2005, over 60 first generation GLONASS satellites were launched. They were defined as two blocks, Block I and Block II. Lifetime is the main difference between these two blocks. Lifetime if GLONASS Block I satellites are around 14 months whereas GLONASS Block IIc satellites have increased lifetime to three years. Like GPS modernization project, Russian government also continues to improve their GNSS. Second generation of GLONASS constellation is called GLONASS-M, where M stands for Modified. GLONASS-M program was started to develop in 1990 and the first GLONASS satellite was launched on 10th December, 2003. This new generation possesses a longer lifetime, improved navigation signals, improve navigation message and improved navigation performance. The latest designed generation of GLONASS is known as GLONASS-K, which is the third generation of GLONASS. Reshetnev Information Satellite Systems is developing GLONASS-K and first satellite was launched on 26th February, 2011. GLONASS-K satellites are designed with a longer lifetime of 10 to 12 years and a reduced weight about 800 kg then GLONASS-M satellites. A third L-band civil signal for safety of life application with the band of 1190-1212 MHz will also be put in this series constellation.

Russia successfully launched three GLONASS-M satellites on 25th September, 2008, which made the total operational constellation to 16 satellites. GLONASS claims its accuracy about 55 meter in horizontal plane and about 70 meters in the vertical plane for civil users and approximate 20 meters in horizontal plane and 34 meter in vertical plane for military users.

Table 3.3: Roadmap of GLONASS constellation modernization (Source: GLONASS, 2014).

Satellite Series	Launch	Current Status	FDMA Signals		CDMA Signals			Interoperability CDMA Signals		
			1602 + n x 0.5625 MHz	1246 + n x 0.4375 MHz	1600.995 MHz	1248.06 MHz	1202.25 MHz	1575.42 MHz	1207.14 MHz	1176.45 MHz
GLONASS	1982-2005	Out of Service	L1OF, L1SF	L2SF						
GLONASS - M	2003-2016	In Service	L1OF, L1SF	L2OF, L2SF			L3OC++			
GLONASS - K1	2011-2014	In Service	L1OF, L1SF	L2OF, L2SF			L3OC			
GLONASS - K2	2015-2024	Design Phase	L1OF, L1SF	L2OF, L2SF	L1OC, L1SC	L2OC, L2SC	L3OC			
GLONASS - KM	2025-	Research Phase	L1OF, L1SF	L2OF, L2SF	L1OC, L1SC	L2OC, L2SC	L3OC, L3SC	L1OCM	L3OCM	L5OCM

"O": open signal (standard precision), "S": obfuscated signal (high precision); "F": FDMA, "C": CDMA,
++ GLONASS-M series will include L3OC signal from 2014.

The development of GLONASS has focused on the interoperation with GPS. In market some companies have already producing the receivers which are taking both GPS and GLONASS signals. The integration of GPS/GLONASS is useful for civil applications because it is providing more satellites in view and thus get better accuracy, continuity and availability. This would be extremely helpful when GNSS is used in railway applications because trains would travel through the tough environments wherein the performance of GNSS is suffered by low satellite visibility.

3.2.3 Galileo

Galileo is a global navigation satellite system, currently being built by EU and ESA. The €5 billion project is named after the Italian astronomer Galileo Galilei. One of the aims of Galileo is to provide a high-precision positioning system upon which European nations can rely, independently from the Russian GLONASS, US GPS, and Chinese Compass systems, which can be disabled in times of war or conflict (Galileo, 2014). Different from GPS and GLONASS, the Galileo system is specifically designed for civilian use by providing high accuracy and global coverage positioning services. The idea of Galileo began in early 1990s, and different concepts for Galileo were unified to one by the agreement of four EU countries (UK, Germany, Italy and France) at the end of 1999. The feasibility and definition phase of Galileo system were completed in late 2000. In March 2002, EU and ESA confirmed that they would fund the Galileo program. Development and validation phase of Galileo started from 2001 and it is still going on. The phase consists of the consolidation of space segment, ground-based infrastructure and validation of the system. The constellation deployment phase was scheduled to be started from 2006 and completed in 2008, but it is now delayed to 2014.

At the beginning Galileo was only developed by the EU and ESA. However as the time of Galileo project going on, many countries outside the EU showed their interest in this program. In September 2003, China joined the Galileo project. China was to invest €230 million (US$302 million, GBP 155 million, CNY 2.34 billion) in the project over following years. In July 2004, Israel signed an agreement with the EU to become a partner in the Galileo project. On 3 June 2005 the EU and Ukraine signed an agreement for Ukraine to join the project. As of November 2005, Morocco also joined the program. On 12 January 2006, South Korea joined the program. In Mid-2006, the Public-Private Partnership fell apart and the European Commission decided to nationalize Galileo as an EU program. China opted instead to independently develop the BeiDou navigation system satellite navigation system in November 2006. On 3 April 2009, Norway too joined the program pledging €68.9 million toward development costs and allowing its companies to bid for construction contracts.

Five companies Arianespace, Telespazio, Thales Alenia Space, OHB and Airbus Space and Defense are involved in development of Galileo project. Progress of Galileo project is very dramatic because this system is expected to have better accuracy than GPS and to be available for all civil and military users, it might eliminate the influence of US GPS. The potential to apply SA to GPS could also be a challenge to the development of GPS market. Therefore, EU has been under a big pressure by the US government from the beginning of Galileo project. After terrorist attack on 11th September, 2001, Galileo project was almost dead due to the pressure from US government. After insisted of EU on their development of Galileo project, US signed the agreement with EU on the cooperation of GPS and Galileo in 2004. The political peril was not only reason for the delay of Galileo program, finance appeared to be another peril for this project. Public-Private Partnership (PPP) which was the original plan, private investment would provide two-third of the investment needed to launch Galileo infrastructure, seems to be impossible. The EU finance ministers submitted a proposal about all public funding of the Galileo program which was approved by the EU's Economic and Financial Affairs Council (ECONFIN) on 23rd November, 2007. Till the time of this thesis writing, only four satellite were launched.

Table 3.4: Galileo satellites names and launch details (Source: Galileo, 2014).

No.	Satellite	Name	Date	Launch Vehicle
1	Galileo-IOV PFM	Thijs	21/10/2011	Soyuz-2-1b Fregat-MT
2	Galileo-IOV FM2	Natalia	21/10/2011	Soyuz-2-1b Fregat-MT
3	Galileo-IOV FM3	David	12/10/2012	Soyuz-2-1b Fregat-MT
4	Galileo-IOV FM4	Sif	12/10/2012	Soyuz-2-1b Fregat-MT

Galileo system will consist of 30 satellites in Medium Earth Orbit (MEO) at an altitude of 23,222km. Ten satellites will occupy each of three orbital planes inclined at an angle of 56° to the equator. Satellites will be spread evenly around each plane and will take about 14 hours to orbit the Earth. One satellite in each plane will be a spare; on stand-by should any operational satellite fail (Galileo: A Constellation of 30 Navigation Satellite, 2014). The geodetic coordinate reference frame for Galileo constellation is called Galileo Terrestrial Reference System (GTRF) which is also an independent realization of International Terrestrial Reference System (ITRS). GTRF only has the few centimeter difference from the GPS WGS-84. Therefore, the GTRF and WGS-84 are compatible for most users with this accuracy level. The time reference frame of Galileo system is also different from the GPS time system. Galileo will use the Galileo System Time (GST) based on International Atomic Time (TAI) whereas GPS uses the UTC (USNO). Once Galileo is operational, the difference between these two time systems can be broadcast by Galileo satellites (Kaplan and Hegarty, 2006).

Galileo system will provide five major services such as: Open Service (OS), Safety of Life (SOL), Commercial Service (CS), Public Regulated Service (PRS) and support to Search and Rescue service (SAR). These services will be provided worldwide and independently from other satellite navigation systems. Table 3.5 and 3.6 shows the performance of Galileo system. To provide Position, Velocity and Time information, OS is designed. By OS these information can be accessed free of charge and suitable for such as in-car navigation and location system in mobile phones. The OS will be available for all the users which have receivers compatible with Galileo signals. The navigation performance will be improved in severe environments such as the urban canyon areas and the forest, if the receivers are integrated with other GNSSs (Onidi, 2002; Dutton et al., 2002; Heni et al., 2002; Galileo Brochure, 2005; JI, 2007).

Table 3.5: Galileo open service performances (Source: Galileo Performances, 2014).

	Galileo Open Service (Positioning & Timing)	
	Single Frequency (SF)	**Dual Frequency (DF)**
Coverage	Global	
Accuracy (95%)	Horizontal: 15m	Horizontal: 4m
	Vertical: 35m	Vertical: 8m
Availability	99.8%	
Timing Accuracy w.r.t. UTC/TIA	N/A	30 ns
Ionospheric Correction	Based on SF model	Based on DF Measurements
Integrity	No	

Table 3.6: Galileo public regulates service performances (Source: Galileo Performances, 2014).

		Galileo Public Regulated Service (PRS)
		Dual Frequency (DF)
Coverage		Global
Accuracy (95%)		Horizontal: 6.5 m
		Vertical: 12 m
Availability		99.5%
Timing Accuracy w.r.t. UTC/TIA		100 ns
Ionospheric Correction		Based on DF Measurements
Integrity	Computes	Yes
	Alarm Limit	H: 20 m – V:35 m
	Time-To-Alarm	10 s
	Integrity Risk	3.5x10e – 7/150 s
Continuity Risk		10e – 5/15 s

The users who have concern with human safety, the SOL services will be provided by the Galileo system. The transportation industry which have rigorous safety requirements like railway, aviation and maritime are main users for this service. The positioning and timing accuracy is same as the OS service in SOL service. However, SOL service will offer integrity information to assure users to received signals that are truly broadcast by the actual Galileo. The SOL service signals are carried on two frequency bands as the E5a +E5b and L1 bands.

Professional applications which require high accuracy positioning performance will use CS services of Galileo system. It will provide enhanced navigation performances and added value data than that is offered by the OS. Predicted applications will be based on, dissemination of data with a 500 bps rate, for value added services and broadcasting of two signals separated in frequency from the OS signals to ease advanced applications. CS service signals will be OS signals and another two encrypted signals which are on the E6 frequency band.

The PRS service is a restricted service which is only available for government authorized users who require a high level of protection against the Galileo Signal in Space (SIS) jamming or interference. To encrypt and broadcast PRS signals, separate frequencies are used. Access of PRS will be controlled through a secure key management system by member state government. Main application for this service will be the European police office, civil protection services, safety services and emergency services in EU or law enforcement, customs and intelligence services in member states.

Galileo satellites will also support the humanitarian search and rescue service to fulfil the requirements and regulation of the International Maritime Organization (IMO), and backward compatible with the COSPAS-SARSAT system.

Galileo system will use similar CDMA technology to GPS. The differences are ranging code type, data type and carrier frequencies. Ten frequencies will be provided by the Galileo constellation and one SAR signal in following frequency ranges E5 band (1164-1215 MHz), E6 band (1260-1300 MHz), E1-L1-E1 band (1559-1592 MHz) and L6 (1544-1545 MHz only for SAR signal). In case of E5 carrier, lower E5a and upper E5b signals are modulated onto the signal E5 band, therefore composite of E5a and E5b can be denoted as E5 signal and be broadcast on a single extra-wide channel. Among these ten signals six are used for the OS and the SOL service, two are specifically devoted to CS and two are specifically designed for the PRS. Ranging code is a sequence of +1 and -1 generated by highly stable, autonomous atomic clocks aboard Galileo satellites. Five types of data can be delivered in the Galileo navigation signal, navigation data, integrity data, commercial data, PRS data and SAR data. Navigation data are separated through E5a, E5b and E2-L2-E1 carriers. Commercial data are transmitted on E5b, E6 and E2-L1-E1 carriers. The integrity data are transmitted on the E5b and E2-L1-E1 carriers. PRS data are only transmitted on E6 and L1 carriers. Carrier L6 is only transmit SAR data (Hein et al., 2002; Hein et al., 2004; Rodriguez et al., 2007). Table 3.7 gives service and data plan of Galileo program.

Table 3.7: Galileo service and data plan (Source: Zheng, 2010).

Carrier Frequencies	Services	Data Type
E5a	OS/SOL	Navigation data
E5b	OS/SOL/CS	Navigation data/Commercial data/Integrity data
E6	PRS/CS	Commercial data/PRS data
E2-L1-E1	OS/SOL/CS	Navigation data/Commercial data/Integrity data/PRS data
L6	SAR	SAR data

3.2.4 BeiDou

BeiDou Navigation Satellite System is China's global navigation satellite system which has been developed independently. Compass Navigation Satellite System (CNSS), also named as BeiDou-2 is China's second-generation satellite navigation system that will be capable of providing positioning, navigation, and timing services to users on a continuous worldwide basis (Chen et al., 2009; COMPASS General Information, 2014). CNSS is a multistage program operated by the China Satellite Navigation Project Center (CSNPC). The first stage called as BeiDou-1 navigation system, is the test navigation system. In 2000, China set up a BeiDou navigation test system, which made China the third country in the world capable of developing such a system on its own since the United States and Russia. Three prototype BeiDou-1 satellites were launched between October 2000 and May 2003. All three satellites were based on the Chinese DFH-3 geostationary communications satellite and had a launch weight of 1,000 kilograms (2,200 pounds) each. Unlike the U.S. GPS, Russian GLONASS and European Galileo systems, which use medium Earth orbit satellites, BeiDou-1 uses satellites in geostationary orbit. This means that the system does not require a large constellation of satellites, but it also limits the coverage to areas on Earth where the satellites are visible. The area that can be serviced is from longitude 70°E to 140°E and from latitude 5°N to 55°N. A frequency of the system is 2491.75 MHz (BeiDou Navigation Satellite System, 2014). The BeiDou-1 was fully operational at the beginning of 2004 and provided the service to consumer over China and surrounding countries. Therefore, the BeiDou-1 system is actually a regional satellite navigation system. Different from GPS, GLONASS and Galileo, which are the passive system employed one way TOA measurements, the BeiDou-1 system provide a Radio Determination Satellite Service (RDSS) which require two way range measurements to avoid synchronizing the receiver clock. RDSS requires only two satellites to locate the two-dimensional user position at the operation center with estimated user altitude. BeiDou-1 satellites transmit the signals at a frequency of 2491.75 MHz (s band). 1954 Beijing coordinate system which is based on Krassovsky ellipsoid (Izotove A., 1959) with α = 6378245 m, α = 1/298.3, e^2 = 0.00669342 is the geodetic reference frame for Beidou-1 system. BeiDou-1 system also uses its own time reference system which is Chinese Coordinated Universal Time (UTC-C) observed by the atomic clocks in the Beijing control center. BeiDou-1 system can provide positioning service with an accuracy of about 20 to 100 meters and timing service with about 20 ns (Bian et al., 2005).

Chinese National Space Administration (CNSA) decided to upgrade and fully implement BeiDou-1 system to the next stage in October 2006, which is designed as BeiDou-2 system. BeiDou-2 system consists of a constellation of 35 satellites which include 5 geostationary orbit satellites for backward compatibility with BeiDou-1, and 30 non-geostationary satellites (27 MEO and 3 in inclined geosynchronous orbit), that will offer complete coverage of the globe. These 30 satellites will be equally split to six orbital planes at an altitude of about 21500 km above the earth's surface and with an inclination of 55^o. BeiDou provide services in two modes: an open service and an authorized service. Open service is provides free of charge location, velocity and timing, with positioning accuracy of 10 meters, velocity accuracy of 0.2 meters / second and timing accuracy of 10 nanoseconds. Authorized service provides a more secure position, velocity, timing, and communications services as well as a higher level of integrity (BeiDou Navigation Satellite System, 2014). According to International Telecommunication Union (ITU) filings by China in May 2004, each satellite of BeiDou-2 will broadcast signals in four carrier frequencies, 1561 MHz (E2), 1590 MHz (E1), 1268 MHz (E6) and 1207 MHz (E5b). BeiDou-2 navigation signals are also CDMA signals using binary or quadrature phase shift keying (BPSK, QPSK). In February 2007, the fourth and last satellite of the BeiDou-1 system, was sent up into space. It was reported that the satellite had suffered from a control system malfunction but was then fully restored. In April 2007, the first satellite of BeiDou-2, namely Compass-M1 (to validate frequencies for the BeiDou-2 constellation) was successfully put into its working orbit. CNSS is expected to provide global coverage around 2020. CNSS is a government project for the military use, so that not much information about this system has been released in public but surely it will be unveiled in the near future (Gao et al., 2007;

Forden, 2004; Liu, 2006; Liu et, al., 2013; Liu, 2013; Grelier et al., 2007; Kaplan and Hegarty, 2006; Lu, 2010; Wilde et, al., 2007; Report on the Development of BeiDou (COMPASS) Navigation Satellite System, 2011). Table 3.8 shows BeiDou satellites, their launch dates and status.

Table 3.8: BeiDou satellites and their details (Source: Beidou Navigation Satellite System, 2014).

Date	Launcher	Satellite	Orbit	Usable	System
31/10/2000	LM-3A	BeiDou-1A	GEO 59^o E	No	BeiDou - 1
21/12/2000	LM-3A	BeiDou-1B	GEO 80^o E	No	
25/05/2003	LM-3A	BeiDou-1C	GEO 110.5^o E	No	
03/02/2007	LM-3A	BeiDou-1D	Supersync orbit	No	
14/04/2007	LM-3A	Compass-M1	MEO ~21,5000 km	Testing only	BeiDou - 2 (Compass)
15/04/2009	LM-3C	Compass-G2	-	No	
17/01/2010	LM-3C	Compass-G1	GEO 144.5^o E	Yes	
02/06/2010	LM-3C	Compass-G3	GEO 84^o E	Yes	
01/08/2010	LM-3A	Compass-IGSO1	118^o E incl 55^o	Yes	
01/11/2010	LM-3C	Compass-G4	GEO 160^o E	Yes	
18/12/2010	LM-3A	Compass-IGSO2	118^o E incl 55^o	Yes	
10/04/2011	LM-3A	Compass-IGSO3	118^o E incl 55^o	Yes	
26/07/2011	LM-3A	Compass-IGSO4	95^o E incl 55^o	Yes	
02/12/2011	LM-3A	Compass-IGSO5	95^o E incl 55^o	Yes	
24/02/2012	LM-3C	Compass-G5	59^o E	Yes	
29/04/2012	LM-3B	Compass-M3	MEO incl 55^o	Yes	
29/04/2012	LM-3B	Compass-M4	MEO incl 55^o	Yes	
18/09/2012	LM-3B	Compass-M5	MEO incl 55^o	Yes	
18/09/2012	LM-3B	Compass-M6	MEO incl 55^o	Yes	
25/10/2012	LM-3C	Compass-G6	80^o E	Yes	

3.2.5 Indian Regional Navigation Satellite System (IRNSS)

IRNSS is an independent regional navigation satellite system being developed by India. It is designed to provide accurate position information service to users in India as well as the region extending up to 1500 km from its boundary, which is its primary service area (IRNSS, 2014). IRNSS is being developed by the Indian Space Research Organization (ISRO) which would be under complete control of the Indian government. IRNSS system would consist of a constellation of seven satellites and a support ground segment. Among the seven satellites, three satellites will be located in geostationary orbit at 32.5° East, 83° East, and 131.5° East longitude respectively. Expected positioning accuracy is better than 10 meters throughout Indian landmass and better than 20 meters in the Indian Ocean. Full constellation is planned to be placed in orbit by 2015.

IRNSS-1A is the first satellite of IRNSS which was launched on 1st July, 2013. It is one of the seven satellites constituting the IRNSS space segment. Two types of payload, navigation payload and ranging payload was carried by the IRNSS-1A satellite. IRNSS will provide two types of services, Standard Positioning Services (SPS) open for civil users and the Restricted Services for military and authorized users. Both will be carried on L5 (1176.45 MHz) and S band (2492.08 MHz). The SPS signal will be modulated by a 1 MHz BPSK signal. The Precision Service will use Binary Offset Carrier (BOC) (5, 2). Navigation signals themselves would be transmitted in the S-band frequency (2-4 GHz) and broadcast through a phased array antenna to maintain required coverage and signal strength. Approximately weigh of satellites is 1,330 kg and their solar panels generate 1,400 watts. A highly accurate Rubidium atomic clock is also part of the navigation payload of the satellite. Ranging payload of IRNSS-1A consists of a C-band transponder which facilitates accurate determination of the range of the satellite. IRNSS-1A also carries Corner Cube Retro Reflectors for laser ranging. IRNSS-1B will be the second satellites out of the seven IRNSS satellites. It is scheduled to be launched in first quarter of 2014 aboard PSLV-C24 rocket.

Ground segment of IRNSS constellation would consist of a Master Control Center (MCC), ground stations to track and estimate the satellites orbits and ensure the Ionospheric Residual Integrity Monitoring (IRIM) of the network, and additional ground stations to monitor the health of the satellites with the capability of issuing radio commands to the satellites. MCC would estimate and predict the position of all IRNSS satellites, calculate integrity, makes necessary ionospheric and clock corrections and run navigation software. Applications of IRNSS include mapping and geodetic data capture, terrestrial, aerial and marine navigation, disaster management, integration with mobile phones, vehicle tracking and fleet management, precise timing, terrestrial navigation aid for hikers and travelers and visual and voice navigation for drivers (IRNSS, 2014). IRNSS is government project and is in the beginning stage so that not much information and literature about this system has been released but surely it will be unveiled in the near future.

3.3 GNSS Operation

This section discuss the GNSS operation. Introduction of position estimation by standalone GNSS is discussed in 3.3.1. Technology called as Differential GPS (DGPS) is discussed in 3.3.2. The real time kinematic is discussed in 3.3.3 and section ends with augmentation system of GNSS which is discussed in 3.3.4.

3.3.1 Standalone GNSS Operation

To determine the position of users, GNSS utilize the concept of Time of Arrival (TOA) which calculates the range between users and satellite. The range is derived from measured time difference by comparing the received PRN codes in satellite signal and receiver generating PRN code (Hofmann-Wellenhof et al., 2001). Satellite to user range is illustrated in figure 3.3. and figure 3.4 shows the basic idea to determine the user position.

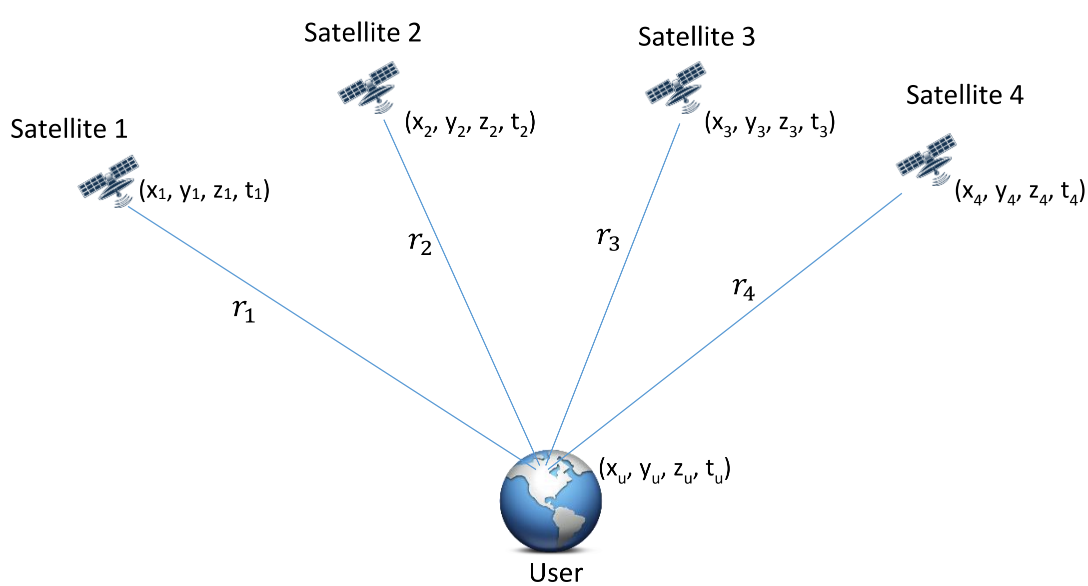


Figure 3.3: Satellite to user ranges.

Figure 3.4: Satellite Triangulation for Positioning. (Source: Positioning Through Satellite, 2014).

The r_i represents the geometric range between the i^{th} satellite and the user in figure 3.3. If t_s is satellite system time at which signal was left and t_u is receiver system time at which signal was arrived then

$$r = c.(t_u - t_s) = c.\Delta t \tag{3.3}$$

Where c stands for speed of light. Receiver clock and satellite atomic clock will generally have a bias error from the system time. Transmitted signals in space is affected by various error components, such as ionospheric error, tropospheric error and multipath error. Therefore the observed range, differed from the geometric range which is called as pseudorange measurement, which is denoted as ρ and can be expressed as

$$\rho_i = r_i + c.(t_u - t_s) + d\rho_i + I_{\rho_i} + T_{\rho_i} + \varepsilon_{\rho_i} \tag{3.4}$$

Where

t_u is the receiver clock offset with respect to the system time.

t_s is the satellite clock offset with respect to the system time.

$d\rho_i$ is ephemeris error.

I_{ρ_i} is ionospheric delay.

T_{ρ_i} is tropospheric delay.

ε_{ρ_i} is the error including multipath error, hardware bias and receiver noise.

(x_i, y_i, z_i) is the satellite position and the (x_u, y_u, z_u) is the user position in the figure 3.3, where x, y, z are the values in the Earth-Cantered Earth-Fixed (ECEF) coordinate system. Therefore, geometric range, r can be computed by following equation:

$$r_i = \sqrt{(x_i - x_u)^2 + (y_i - y_u)^2 + (z_i - z_u)^2} \quad (3.5)$$

Pseudorange equations can be expressed as:

$$\begin{cases} \sqrt{(x_1 - x_u)^2 + (y_1 - y_u)^2 + (z_1 - z_u)^2} + c.t_u + \varepsilon_1 = \rho_1 \\ \sqrt{(x_2 - x_u)^2 + (y_2 - y_u)^2 + (z_2 - z_u)^2} + c.t_u + \varepsilon_2 = \rho_2 \\ \sqrt{(x_3 - x_u)^2 + (y_3 - y_u)^2 + (z_3 - z_u)^2} + c.t_u + \varepsilon_3 = \rho_3 \\ \vdots \\ \sqrt{(x_i - x_u)^2 + (y_i - y_u)^2 + (z_i - z_u)^2} + c.t_u + \varepsilon_i = \rho_i \end{cases} \quad (3.6)$$

Where i depends on the number of satellites which have been tracked in view. Therefore, GNSS receiver can find a three-dimensional (3D) position only when GNSS antenna can receive at least four satellite signals to solve four unknowns, including three coordinates of user position (x_u, y_u, z_u) and the receiver clock offset (t_u). Normally the GNSS solution can be solved by iteration techniques of the least square method (El-Rabbani, 2006; Kaplan and Hegarty, 2006; Leick, 2004). To use least square method the nonlinear mathematical model equation (3.6) can be denoted as following matrix:

$$f(x) = l \tag{3.7}$$

Where $X = (x_u, y_u, z_{u,}, ct_u)^T$ are parameters and $l = (\rho_1, \rho_2, \dots, \rho_i)^T$ are observations. If X_0 = $(x_0, y_0, z_{0,}, ct_0)^T$ is assumed as the approximate estimate coordinates for the user and the associated estimate predicted receiver clock offset, then:

$$X = X_0 + \Delta X \tag{3.8}$$

Where $\Delta X = (\delta x_u, \delta y_u, \delta z_u, c.\delta t_u)^T$. Therefore,

$$f(X) = f(X_0 + \Delta X) \tag{3.9}$$

The right hand function can be linearized around the approximate parameters X_0 by using Taylor series:

$$A\Delta X = B + v \tag{3.10}$$

Where

$$A = \begin{bmatrix} \frac{\partial f_1}{\partial x_u} & \frac{\partial f_1}{\partial y_u} & \frac{\partial f_1}{\partial z_u} & \frac{\partial f_1}{\partial t_u} \\ \frac{\partial f_2}{\partial x_u} & \frac{\partial f_2}{\partial y_u} & \frac{\partial f_2}{\partial z_u} & \frac{\partial f_2}{\partial t_u} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{\partial f_i}{\partial x_u} & \frac{\partial f_i}{\partial y_u} & \frac{\partial f_i}{\partial z_u} & \frac{\partial f_i}{\partial t_u} \end{bmatrix} \tag{3.11}$$

$$\frac{\partial f_i}{\partial x_u} = \frac{x_i - x_u}{\sqrt{(x_i - x_u)^2 + (y_i - y_u)^2 + (z_i - z_u)^2}}$$

$$\frac{\partial f_i}{\partial y_u} = \frac{y_i - y_u}{\sqrt{(x_i - x_u)^2 + (y_i - y_u)^2 + (z_i - z_u)^2}}$$

$$\frac{\partial f_i}{\partial z_u} = \frac{z_i - z_u}{\sqrt{(x_i - x_u)^2 + (y_i - y_u)^2 + (z_i - z_u)^2}}$$

$$\frac{\partial f_i}{\partial t_u} = 1$$

A is the design matrix which contains direction vectors pointing from approximate user position to available satellites, and $B = [\rho_1 - \hat{\rho}_1, \rho_2 - \hat{\rho}_2, \dots, \rho_i - \hat{\rho}_i]^T$. v is residual pseudorange error and is assumed as normally distributed with zero mean and variance $Cov(l)$. Where $Cov(l)$ is the variance covariance matrix of observations. Generally, $Cov(l)$ is diagonal, which means observations are uncorrelated. So variance-covariance matrix of pseudorange can be shown as:

$$Cov(l) = \begin{bmatrix} \sigma_{\rho_1}^2 & 0 & \dots & 0 \\ 0 & \sigma_{\rho_2}^2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \sigma_{\rho_i}^2 \end{bmatrix} \tag{3.12}$$

Because a small standard error associated with an observation means that a high weight is assigned to it, the weight matrix would be $W = Cov(l)^{-1}$.

Least square method is to minimize the function $v^T W v$. Replace v form equation (3.10).

$$\begin{aligned} v^T W v &= (A\Delta X - B)^T W (A\Delta X - B) \\ &= (\Delta X^T A^T - B^T)(WA\Delta X - WB) \\ &= \Delta X^T A^T W A \Delta X - B^T W A \Delta X - \Delta X^T A^T W B + B^T W B \end{aligned} \tag{3.13}$$

The minimum of $v^T W v$ must occur at the value of ΔX that gives a zero for the gradient to be zero and seek a value that will minimize $v^T W v$:

$$\frac{\partial v^T W v}{\partial \Delta X} = 2A^T W A \Delta X - 2A^T W B = 0; \tag{3.14}$$

$$\Delta X = (A^T W A)^{-1} A^T W B \tag{3.15}$$

Use improved estimate ΔX to iterate until the change in the estimate is sufficiently small. Once the unknowns ΔX is obtained, user coordinates and receiver clock offset can be computed by equation (3.8).

3.3.2 DGNSS Overview

Differential Global Navigation Satellite System (Differential GNSS or DGNSS) is a technique for reducing the error in GNSS derived positions by using additional data from a reference GNSS receiver at a known position. DGNSS involves determining the combined effect of navigation message ephemeris and satellite clock errors at a reference station and transmitting corrections, in real time to a user's receiver (Grewal et al., 2007; Katiyar and Dikshit, 2011). Figure 3.5 gives basic concept if the Local area DGPS (LDGPS).

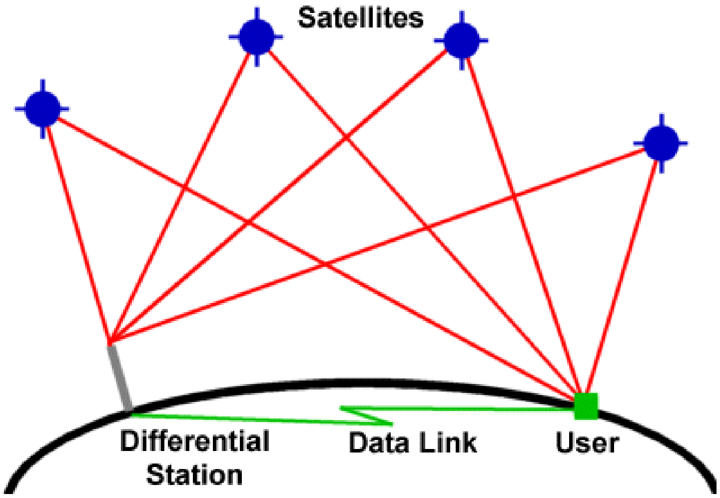


Figure 3.5: Concept of LDGPS

Reference station calculates differential corrections for its own location and time. Users may be very far from the station, so some of the compensated errors vary with space: specifically, satellite ephemeris errors and those introduced by ionospheric and tropospheric distortions. Due to this accuracy of DGPS is proportional to distance from reference station i.e. accuracy of DGPS decreases with distance from the reference station. This problem can be intensified if user and station lack inter visibility, when they are unable to see same satellites (Differential GPS, 2014). Reference station T_0 is equipped with a GPS receiver, and the accurate position of the station in ECEF coordinate is (x_0, y_0, z_0) known by the previous surveying. From the ephemeris data in the navigation message, the reference station can get all the satellite position in view. Therefore, any geometric range between the station and the satellite R_i can be calculated by:

$$R_i = \sqrt{(x_i - x_0)^2 + (y_i - y_0)^2 + (z_i - z_0)^2} \quad (3.16)$$

where (x_i, y_i, z_i) are visible satellite positions in the navigation message. Additionally, pseudorange of each satellite also received at reference station, so the differential correction for each satellite can be computed by:

$$\Delta\rho_i = R_i - \rho_i = -ct_0 - \varepsilon_i \quad (3.17)$$

where ct_0 represents reference station clock offset from the GPS system time and ε_i is the ith satellite pseudorange error from the satellite to the reference station. Corrections are broadcast to rover/user receiver when reference station gets corrections. Same satellite pseudorange measurement for the rover/user can be corrected by:

$$\rho_{cor}^{i} = \rho_{u}^{i} + \Delta\rho_{i} = R_{u}^{i} + ct_{u} + \varepsilon_{u} + \Delta\rho_{i}$$

$$= \sqrt{(x_i - x_u)^2 + (y_i - y_u)^2 + (z_i - z_u)^2} + cdt + d\varepsilon \qquad (3.18)$$

where dt is the difference between user and the reference clock and $d\varepsilon$ is the residual pseudorange error. Therefore, if more than four satellites are tracked, the position of the user can be computed. More accurate solution can be achieved if the correction pseudoranges are used (Kaplan and Hegarty, 2006).

Differential correction can only correct the spatial and time correlated errors in pseudorange like: satellite ephemeris, satellite clock error, tropospheric and ionospheric errors. So errors such as multipath, receiver noise and interference still cannot be corrected by DGPS. Further, accuracy of DGPS depends on closeness of user to reference station and also on time delay of transmission of the corrections. With increasing distance of baseline and time latency between user and reference station, the correlation between errors is reduced.

Wide-Area DGPS (WADGPS) is introduced to extend coverage of LDGPS and reduce spatial decorrelation impact. In WADGPS, user's GPS receiver receive corrections determined from a network of reference station distributed over a wide geographic area and each of them process measurement differential corrections. Corrections are provided to central processing site, and then are broadcast separately to the users for different error sources. So, users get more accurate solution by using weighted corrections from stations. The weight is depends on geometric of user and reference stations. Which means, largest weight is assigned to the closest reference station.

Sub-meter accuracy can be achieved by DGPS. This technique is very useful for many civil applications, such as guidance and approach situations in aviation navigation, safety critical train controls, as well as harbor's and restricted waterways in marine navigation. All of these applications require high accuracy and integrity for which the standalone GPS is hard to offer. This technology is now widely used by navigation users in all GNSS area.

3.3.3 Real Time Kinematic (RTK) Overview

To improve the accuracy of position data derived from satellite-based positioning systems, uses a technique called Real Time Kinematic (RTK). Normally, satellite navigation receivers align signals sent from satellite to an internally generated version of a pseudorandom binary sequence which is also contained in the signal. These two sequences do not initially coincide because of satellite signal takes time to reach the receiver. Therefore, satellite copy is delayed in relation to the local copy. The distance can be calculated by correct delay time (Real Time Kinematic, 2014).

RTK follows same concept as DGPS, but use carrier phase measurements as its signal rather than code pseudorange measurements in DGPS. So that sometimes RTK method is denoted as carrier phase differential technique (Hofmann-Wellenhof et al., 1997). RTK system uses single base station receiver at a known location, measures carrier phase measurements for differential corrections, then rebroadcast to number of rovers. Then rover corrects its own carrier phase measurements to mitigate correlated errors between reference station and rover. Carrier phase measurements are much more precise than code pseudorange measurements, but they contain an integer ambiguity which is an unknown integer initialization constant. This integer ambiguity has to be resolved by RTK positioning in order to obtain high level of precision. RTK algorithm is based on double differenced observables that can eliminate selective availability effects as well as other biases. At a given epoch, and for a given satellite, the simplified carrier phase observation equation is the following:

$$\emptyset = \rho - I + Tr + c(b_r - b_s) + N\lambda + \varepsilon_{\emptyset} \qquad (3.19)$$

Where:

I is signal path delay due to ionosphere.

Tr is signal path delay due to troposphere.

b_r is receiver clock offset.

b_s is satellite clock offset.

c is speed of light in vacuum.

λ is carrier nominal wavelength.

N is integer ambiguity of carrier phase.

$\varepsilon_{\emptyset}$ are measurement noise components, including multipath and other effects.

ρ is geometrical range between the satellite and the receiver.

Following three steps are involved in fixing the integer ambiguity:

- Ambiguities are first fixed to float numbers using standard least-square techniques.
- The set of integer ambiguities is set to one that optimizes the residuals in surroundings of the float solution.
- Carrier measurements are corrected with integer ambiguities and they are used to obtain relative position of rover to base station (RTK Fundamentals, 2014).

Within the baseline less than 15 km, expected positioning accuracy of RTK method is about 2 to 5 cm. In order to provide a reliable RTK service in a large are, multiple reference stations are needed to form a RTK network. RTK and RTK network techniques are now widely used for a range of applications such as land surveying, marine surveying, high precise navigation, auto driver or auto pilot system and precise farming (El-Rabbany, 2002; Langley, 1998).

3.3.4 Augmentation Systems Overview

To improve performance of accuracy, integrity and availability of navigation system, GNSS augmentation systems are designed (Retscher and Kealy, 2006). According to different applications the augmentation system can be divided into two categories, Ground Based Augmentation System (GBAS) and Satellite Based Augmentation System (SBAS).

DGPS and RTK systems are both GBAS systems. The U.S. Federal Aviation Administration (FAA) has also developed a GBAS system for aircraft landing application, called Local Area Augmentation System (LAAS). The system provides monitoring functions via LAAS Ground Facility (LGF) and includes individual measurements, ranging sources, reference receivers, navigation data, data broadcast, environment sensors and equipment failures (Grewal et al., 2007). It support precision approach, landing and departure of all flights in the coverage area. LAAS consists of central monitoring station and a reference receiver. Central monitor station receive pseudorange measurement date from reference receiver then process data to form pseudorange corrections and correction rate, and broadcast to airborne users via a Very High Frequency (VHF) data link. Aircraft receiver uses these corrections to correct its own GPS signals and to improve a position solution.

Other GBAS systems around the world includes Australia's Ground Based Regional Augmentation System (GRAS), Russian's proposed differential correction and monitoring service and U.S. Nationwide Differential Global Positioning System (NDGPS).

SBAS is a system that supports wide-area or regional augmentation through the use of additional GEO satellites to broadcast differential corrections and integrity information message. GEO satellites broadcast DGPS data through transponders on same band as GNSS constellation. SBAS system contains a network of reference stations which monitors GNSS satellite signals, monitoring station network collect data from satellites that are to be augmented. The processing facility center process data which are provided by monitoring station network to generate messages to be broadcasted to GEO satellites. GEO satellite control center generate signal with message provided by processing facility center and up-linking it to GEO satellites. Communication layer interconnects the different elements of Ground Segment (SBAS Fundamentals, 2014). At the time of this thesis writing, several SBAS systems are available or under development, Table 3.9 showing list of these systems.

Table 3.9: Summery of SBAS systems (Source: GNSS Augmentation, (2014)).

No.	SBAS	Country/Organization	Status
1.	Wide Area Augmentation System (WAAS)	United States Federal Aviation Administration (FAA)	Operational
2.	European Geostationary Navigation Overlay Service (EGNOS)	European Space Agency.	Operational
3.	Multi-functional Satellite Augmentation System (MSAS)	Japan's Ministry of Land, Infrastructure and Transport Japan Civil Aviation Bureau (JCAB)	Operational
4.	Quasi-Zenith Satellite System (QZSS)	Japan	Proposed
5.	GPS Aided Geo Augmented Navigation (GAGAN)	India	Operational
6.	System for Differential Correction and Monitoring (SDCM)	Russia	Proposed
7.	Satellite Navigation Augmentation System (SNAS)	China	Proposed
8.	Wide Area GPS Enhancement (WAGE)	United States Department of Defense for use by military and authorized receivers	Operational
9.	StarFire navigation system	John Deere.	Operational
10.	Starfix DGPS System and OmniSTAR system	Fugro	Operational

3.4 Source of Errors in GNSS Positioning

Unfortunately, GNSS measurements are not perfect and absolute. So there is always some error in measurements because of measurements are affected by noise due to propagation of signals through atmospheric layers and due to noise measurements (Retscher, 2007). These errors described briefly as below:

3.4.1 Satellite Clock Error

Although, satellite clock is made by a high stable atomic clock which controls all timing operations including broadcast signal generation, satellite clock error may deviate from GNSS time due to the bias and drift. Stability of GPS satellite is about 1 to 2 parts in 10^{13} over a period of one day. This means that satellite clock error is about 8.64 to 17.28 ns per day. Performance of satellite clocks is monitored by ground control system. The amount of drift is calculated and transmitted as a part of navigation message in the form of three coefficients of a second-degree polynomial. Satellite clock errors cause additional errors to GPS measurements.

These errors are common to all users observing same satellite and can be removed through differencing between receivers. Applying satellite clock correction in navigation message can also correct satellite clock errors (El-Rabbany, 2002).

3.4.2 Ephemeris Error

Ephemeris is a couple of values that gives the positioning information of a satellite at a given time, and ephemeris error is caused by the difference between transmitted ephemeris in navigation message and true satellite location. Ground station estimates effect of satellite ephemeris. All satellite ephemeris effects are computed by stations based on previous measurements of satellite motion and uplinked to the satellite in navigation data message for rebroadcast to users. It is hard to model and predict precisely ephemeris from ground monitoring station because of satellites in space are affected by various forces such as the moon, sun and the gravity of earth. Therefore ephemeris effect in navigation message contains a residual error. Ephemeris error can be projected to three directions related to satellite orbit: radial, along track and across track. Fortunately, error in radial direction is smallest and along track and across track error are also small along the line of sight direction which directly affects the pseudorange measurement error (Kaplan and Hegarty, 2006).

Due to ephemeris parameters, current estimate of Root Mean Square (RMS) range error is about 1.5 m (Misra and Enge, 2001). Figure 3.6 shows the ephemeris error.

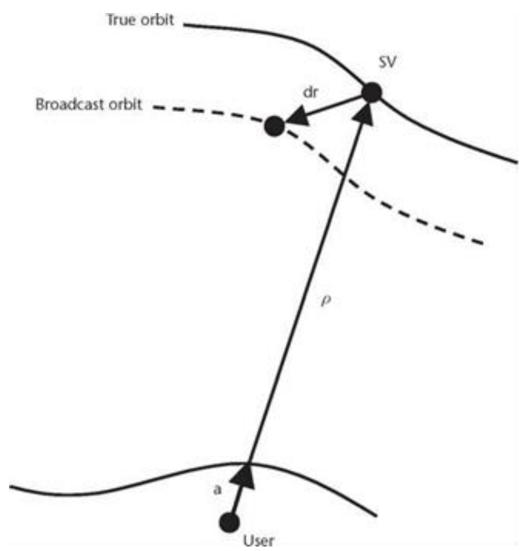


Figure 3.6: Ephemeris error.

3.4.3 Ionospheric Error

GNSS signals are also affected by the medium they pass through when they travel from satellite to user receiver. Ultraviolet and X-ray radiations coming from the sun interact with the gas molecules and atoms, at the uppermost part of earth atmosphere. Result of this interaction is gas ionization, a large number of free negatively charge electrons and positively charged atoms and molecules. Such region of atmosphere is called ionosphere, where ionization taken place (El-Rabbany, 2002). When GNSS signals transmitted through the atmosphere they do not travel at the vacuum speed of light. Atmosphere change the velocity of propagation of radio signals due to refraction. Earth's atmosphere mainly divided into two regions, upper atmosphere and lower atmosphere. Upper atmosphere, normally called as ionosphere. Region of ionosphere is located between 50 km and about 1000 km above the earth surface. The speed of propagation of GNSS signal at some point in ionosphere is determined by the density of electron (Kolbuchar, 1991). Signal is delayed due to the proportion of the total number of free electrons encountered and is also inversely proportional to the carrier frequency square $(1/f^2)$ (Parkinson et al., 1996). The code phase measurements are delayed by same amount by which carrier phase measurements are advanced. Therefore three ways can be used to correct the ionospheric effect. First, it can be estimated by the internal broadcast ionospheric model, second, it can be reduced by dual frequency receivers and third is, it can be modulated by real time update from multi-monitor stations (Klobuchar, 1991). Figure 3.7 illustrate the ionospheric effect.

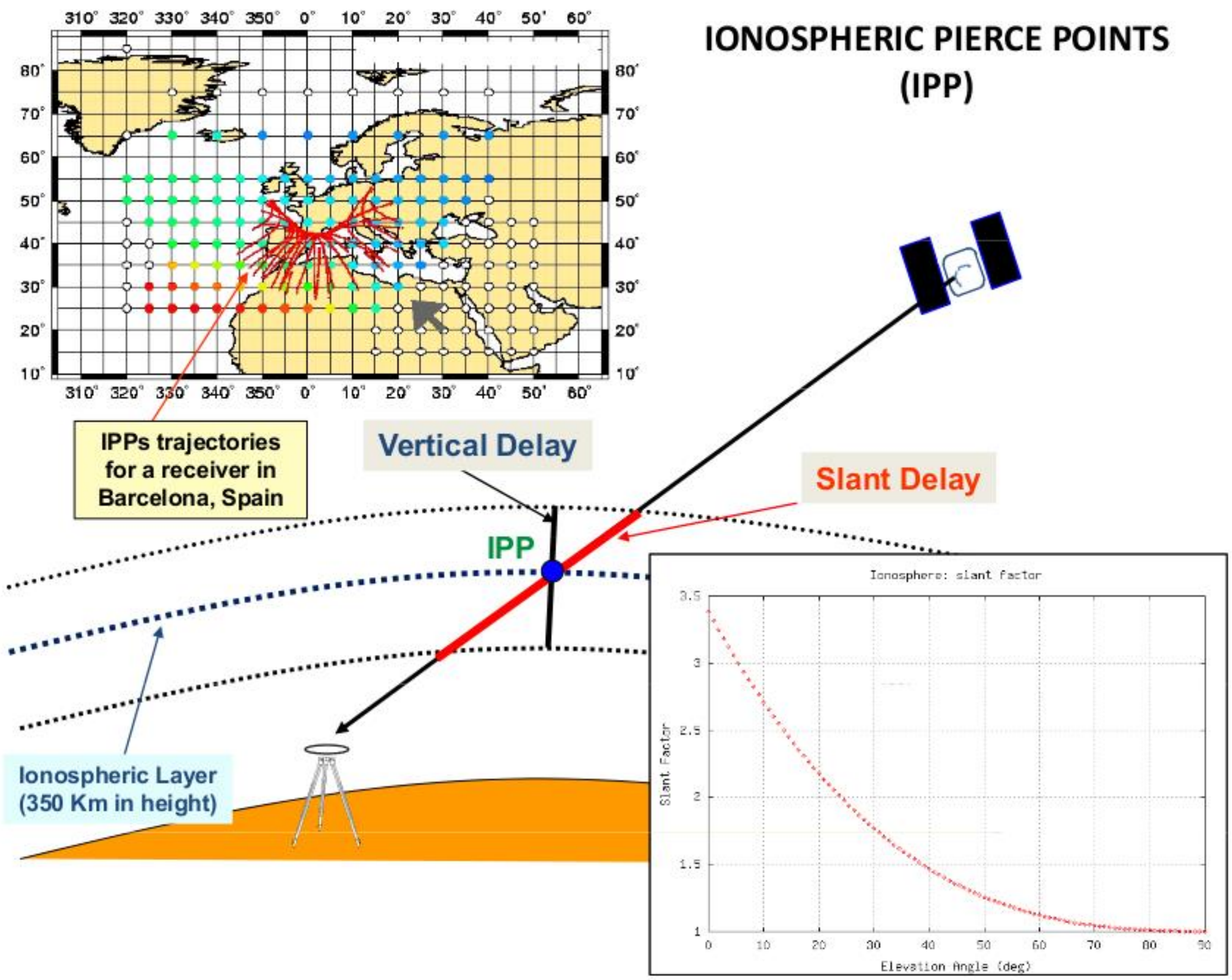


Figure 3.7: Ionospheric Pierce Points (IPPs), Vertical and Slant delay illustration. The IPP's trajectories for a receiver in Barcelona, Spain are shown in the map. The figure at bottom right shows the obliquity factor variation with the elevation of ray (Source: Klobuchar Ionospheric Model, 2011).

3.4.4 Tropospheric Error

Troposphere is the lowest layer of atmosphere. It is the non-ionised part of atmosphere and it is primarily composed of nitrogen and oxygen. It is located from the earth's surface up to 50 km. Troposphere is a non-dispersive medium with respect to radio waves up to frequencies of 15 GHz thus the propagation is frequency independent (Troposphere, 2014). It will delay all GNSS signals by the same amount. That is, the measured satellite-to-receiver range will be longer than the actual geometric range, which means that a distance between two receivers will be longer than the actual distance. Unlike ionospheric delay, tropospheric delay cannot be removed by combining L1 and L2 observations. Tropospheric delay depends on temperature, pressure, and humidity along the signal path through troposphere. Signals from satellites at low elevation angles travel a longer path through the troposphere than those at higher elevation angles. Therefore, tropospheric delay is minimized at user's zenith and maximized near horizon (El-Rabbany, 2002). Tropospheric delay may be broken into two components, dry and wet components. Accordingly, the refractivity of troposphere, N_{trop} , can be expressed as follows:

$$N_{trop} = N_{dry} + N_{wet} \tag{3.20}$$

Dry part typically contributes about 90% of the entire tropospheric delay, and it can be predicted with an accuracy of about 1%. The remaining 10% is the contribution from the wet component. Unlike dry component, wet component is not easy to predict. Several mathematical models use surface meteorological measurements (atmospheric pressure, temperature, and partial water vapor pressure) to compute the wet component. The Hopfield (Hopfield, 2001), Saastamoinen (Saastamoinen, 1972) and UNB3 (Collins, 1999) are some of the tropospheric models that are used by commercial GNSS processing software suites today. Figure 3.8 illustrate the thickness of dry and wet layers which are defined in the Hopfield model:

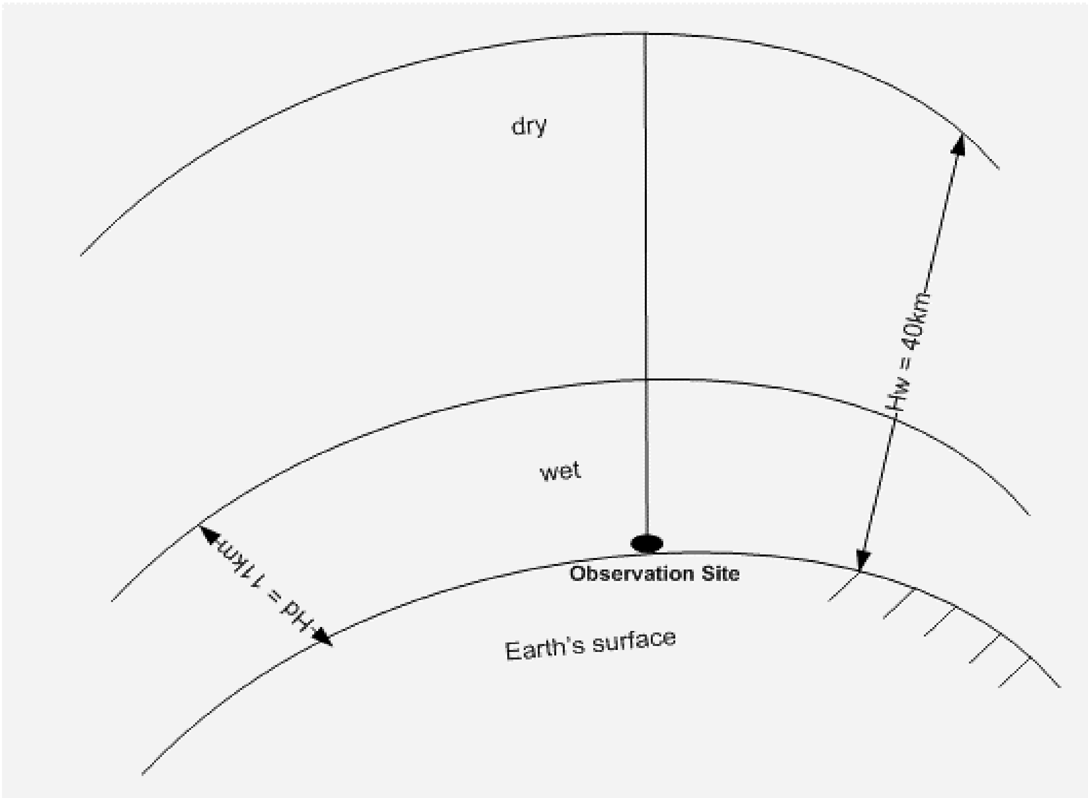


Figure 3.8: Thickness of wet and dry layers as defined in the Hopfield model (Source: Troposphere, 2014).

3.4.5 Multipath Error

Multipath error is the major error source, especially in weak signal environment like urban canyons or forests. Multipath error occurs when GPS signal arrives at receiver antenna through different paths. These paths can be direct line of sight signal and reflected signals from objects surrounding receiver antenna; thus it is very difficult to predict and to compensate by general mode, and also cannot be mitigated by differential processing. Therefore, effect of multipath error can hugely depend on reflecting geometry. Typically C/A code multipath errors are in order of 20 cm to several meters, depending on environmental conditions. Most multipath mitigation techniques are based on design of suitable antenna site selection, receiver design and error detection techniques for multipath minimization. For the code multipath mitigation, methods such as Narrow Correlator technique (Van Dierendonck et al., 1992), Storbe Correlator, or Multipath Estimation Delay Lock Loop (MEDLL) technology (Ray, 2000), are well used in receiver design. Figure 3.9 shows the multipath error in urban environment:

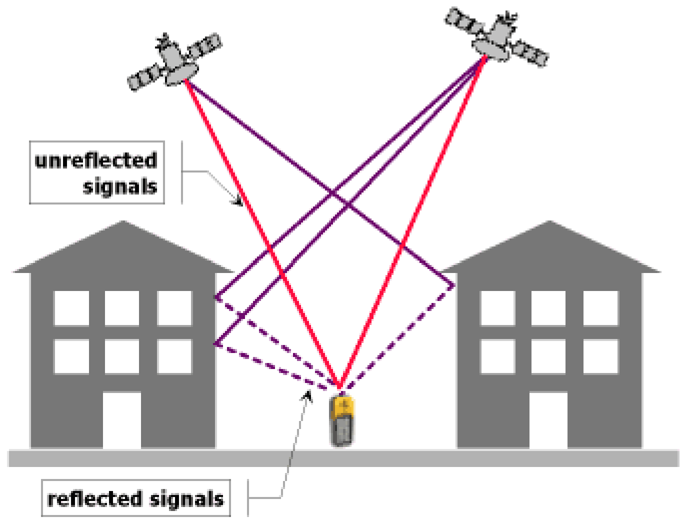


Figure 3.9: Multipath effect in urban environment (Source: Source of Errors in GPS, 2014)

3.4.6 Receiver Clock Error

GNSS receivers are equipped with quartz crystal oscillators. Advantages of these oscillators is that they are small, consume little power and are relatively inexpensive. Depending on the quality of oscillator used in GNSS receiver, the error could range from 200 ns up to a few ms, and measurement ranges could therefore vary from a few meters to a few thousand kilometers. By using single differencing between two satellites, this error can be eliminated. In absolute positioning, receiver clock offset has to be estimated as an unknown parameter in the navigation solution which estimates receiver position and receiver clock at the same time. Receiver clock offset can be estimated within 1 µs or better (Leick, 1995). In this thesis, receiver clock error is treated as an unknown parameter in position computations. Hence, the equation (3.4) can be expressed as:

$$\rho_i = r_i + c.t_u + \varepsilon_i \qquad (3.21)$$

where ε_i is the composite of errors produced by atmospheric delay, multipath and satellite ephemeris errors.

3.5 Conclusion

Above sections summarized that till now GPS or GLONASS are not only GNSS but it is more comprehensive system. Full GNSS includes the concept of global satellite navigation system like GPS, GLONASS, Galileo and Beidou II, regional satellite navigation system like QZSS, IRNSS and Beidou I, augmentation systems like GBAS and SBAS. More than hundreds of GNSS satellites are available user can choose many augmentation system, till the date. High performance of accuracy, integrity and availability provided by GNSS and GNSS augmentation systems gives GNSS the chance to be an important component in business, government and transport sectors.

GNSS has been used in many application in recent time. Vehicles are using GNSS to determine their locations, speed, direction and display them on moving maps. To navigate in lakes, seas and oceans boats and ships are using GNSS receivers. For en-route navigation, approach, landing or departure of flights, the aviation industry is using GNSS and GNSS augmentation system. GNSS is also used in surveying and mapping. Successful applications of GNSS on safety-critical aviation navigation and maritime applications, suggests a prospect of applying it for railway safety-critical applications (Kiss, 2000; Prasad and Ruggieri; Kaplan and Hegarty). However, compared with traditional train location system, GNSS has the benefits like lower initial cost, less maintenance and potentially increasing the capability of railway lines for both freight and passenger trains due to the high accuracy of GNSS. In Europe some projects have been demonstrated like APOLO, LOCO, DemoOrt, GADEROS, RUNE, INTEGRAIL, SOCRATEC etc.

Chapter 4

Work Plan and Architecture

4.1 Introduction

This chapter describes Work Plan and General Architecture of Knowledge Based Train Navigation System. Work Plan defines the step by step process of developing and designing of complex hardware and software, it also shows how this system is different from other systems used by different countries and Indian railway. Architecture of this system defines how a sensor network communicate with remote server. Section 4.2 describes satellite based train navigation and control system. Research planning is described in section 4.3 and the developed system architecture is illustrated in the section 4.4.

4.2 Satellite Based Train Navigation and Control Systems

With regard to the train navigation and control system, railway industry mainly concern with safety of life, capacity, flexibility and cost of operational system. Although, ABS system guarantees a safe distance between trains and provide flexibility to change the schedule, capacity of the system is not enough and cost of operation of this system is very high. As above section mentioned, all blocks in ABS system are fixed block, which means length of blocks are fixed. A long block is needed, to run high speed trains because a long safe stopping distance is needed. ABS system performance is decreases because trains are kept apart than the minimum safe stopping distance. This happened because of positions of trains are not known precisely in block. Further, cost of ABS system, including installing and maintenance cost, is also high. ABS system is suffering from another big problem which is vandalism. Repair of vandalism is expensive and also causes safety problems. Therefore satellite based train navigation and control system can be a potential replacement for current navigation and control system or at least be an attractive complementary system (Marais, et al., 2000; Kiss, 2000; Prasad and Ruggieri, 2005; Thomas et al., 2007). Systems developed by various countries, described in Chapter 2 which are integrated and maintenance of these systems equipment's is very difficult and expensive task. Systems developed by Indian railway are not satisfying the need of the nation's railway. The developed Knowledge Based Train Navigation System is in between, it is a cheaper solution then oversees solutions and it is satisfying the need of Indian railway.

GNSS can determine train position with an accuracy down to meter level due to high accuracy performance. Therefore, trains can be separated by minimum safe stop distance, and the capacity of railway line is increased. GNSS has lower initial cost and less maintenance, that could give a big benefit for railway industry. In India two projects have been demonstrated which are ACD and SIMRAN. Some research projects have been demonstrated in Europe also, e.g. DEMOORT (Hartwig et al., 2005), SOCRATEC (Fraile and GmbH, 2000), APOLO (Alcouffe et al., 2001), LOCOLOC/LOCOPROL (Mertens et al., 2003; Simsky et al., 2004), RUNE (Genghi et al., 2003), DEMOORT (Hartwig et al., 2006), ECORAIL, INTEGRAIL (Bredrich and Muncheberg, 2004) and GADEROS (Urech et al., 2002).

4.3 Research Planning

Knowledge based Train Navigation System plan is a guideline for the system to provide Navigational services, Controlling and Management services, with specific components such as phases, tasks, methods, techniques and tools. Research plan refers to how the research was done and its logical sequence. Important factors in concept plan are as follows:

The developed system mainly consists of five modules, first is train module, second is database and web server, third is controller module, fourth is asset management module and fifth is level crossing module. System development is certainly a complex procedure that is shown here in planning diagram Figure 4.1. The developed system provides following services:

- Navigation.
- Tracking.
- Live updates.
- Asset Management.
- Safety at level crossing.

In complete development life cycle, all procedures that are followed starting with literature survey to successful simulation are presented as step by step in planning diagram shown in Figure 4.1. This diagram not only create a quick view of development approach but also help to understand what sort of data, methods and technologies that are responsible for development of a knowledge based train navigation system.

4.3.1 Description of Research Plan

Entire research plan used in Knowledge Based Train Navigation System is divided into four phases:

In first phase of development, an Asset Management System is developed which helps administrator to take better decision. The system follows the Client Server Architecture. For Client side an Android based application is developed which can run into two modes, first mode is online mode, in this mode asset location information is calculated by integrated GNSS, second mode is offline mode, In this mode user can calculate Asset Location Information by touching the screen over Google maps without going to field. All the information about asset is transmitted to remote server by web service. On server, PostgreSQL and PostGIS is used to manage Asset Location Information.

In second phase a Knowledge Based Train Module is developed for android platform which uses SOAP interface to communicate with Remote Server. A Knowledge Based approach is used to develop this module by which it can take decisions while approaching to signals, level crossings, stations and maintenance segments. Developed module is a navigation and tracking module which navigate using voice commands along with tracking facility and current location of train is transmitted to Remote Server by this module.

In third phase a Web Server is developed which contain a Web Service and a Web Application to track trains over the web. Developed Web Service uses the concept of SOAP which is a communication protocol. Train module calls the developed Web Service and save current train location and speed information in Server Database. Developed Web Application shows train location over the web on a map. Web application having three types of users, first is Administrator who can manage, control trains and users, second is Station Master and third is General User who can view train location on the map.

In last phase, another value added application is developed named as Trip Navigation and Analysis System. This is a Desktop Based Application which can log GNSS receiver data and provide facility to analyze trip information into tabular form or interactive graph.

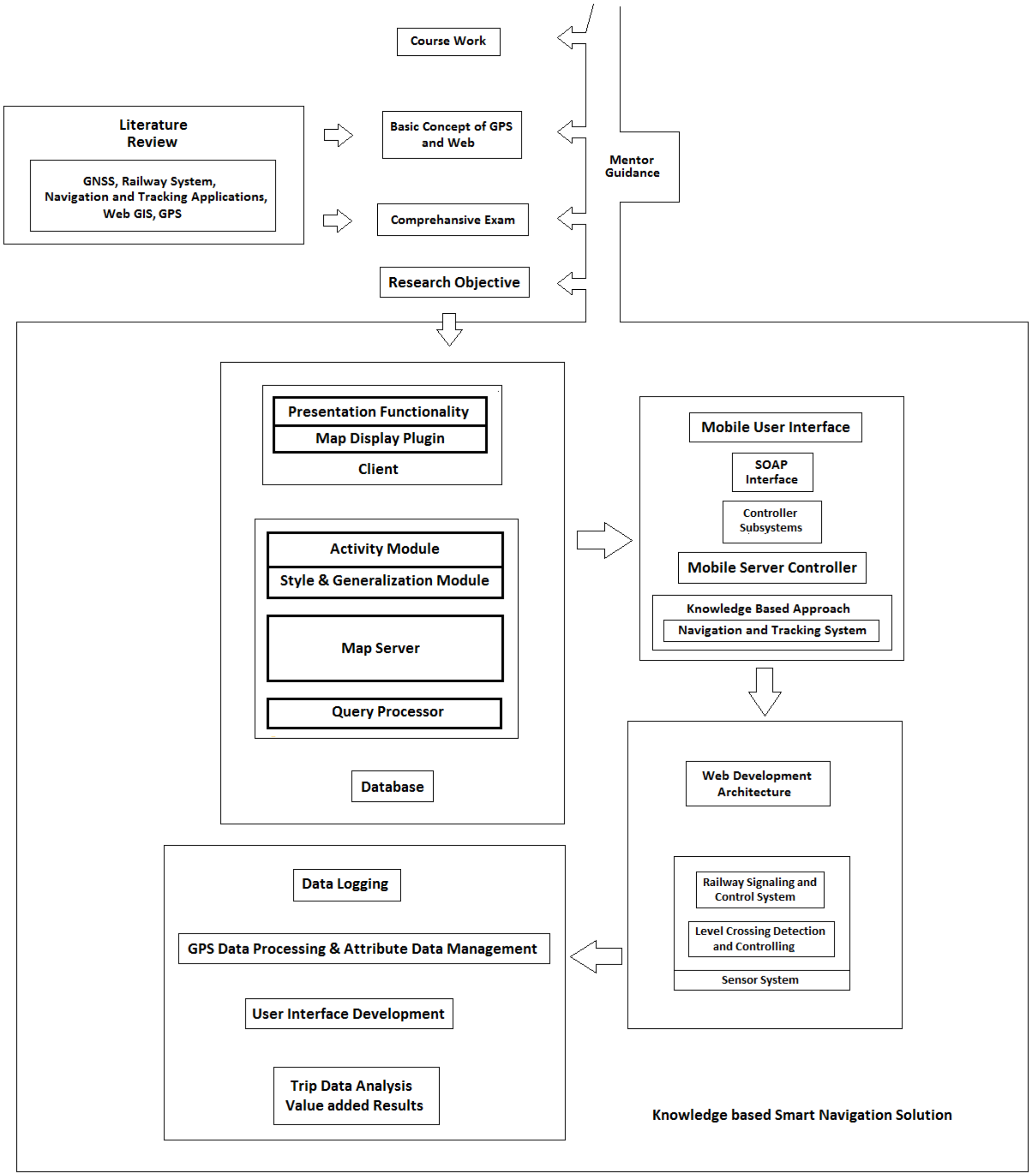


Figure 4.1: Research Plan of Knowledge Based Train Navigation System.

4.4 Architecture

Architecture of a system defines its broad outlines and precise mechanisms used. Architecture is a term applied to both process and outcome of planning and specifying overall structure, logical components, and logical interrelationships. It is extremely important with a well-crafted architecture for an application system's complete life cycle from development to implementation and operation (Johng et al., 2002).

Architecture is inherently about structure, but it's also about vision and creating sufficient foundations to deliver a set of requirements, regardless of whether those requirements are related to a physical building or a software system.

4.4.1 Architecture of Knowledge Based Train Navigation System

Developed system is a combination of software and hardware. Software is a combination of Mobile Applications, Web Applications and Desktop Applications. Software follows Client Server Architecture but the word Knowledge Based gives it a new meaning that extends its behavior form a simple client to an extended one with some extra capabilities and functionalities. Server is also not limited to simple Web Server with a specific feature of invoking desired HTML/AJAX based services but it is developed to have interfaces for Google Map/Earth APIs, GIS functionally and some newly defined services with a database interface. GIS can be defined as a computer based system for capturing, storing, checking, and manipulating data that are spatially referenced (Panigrahi, 2009; Pathak and Dikshit, 2010; Behera et al., 2011; Panigrahi, 2014)

Hardware consists of Train Module, Level Crossing Module and Signal Module. These modules have some extra capabilities and functionality for controlling, navigation and tracking of trains. Train module consists of GPS to get position of train and GSM/GPRS to communicate with server. Level Crossing and Signal Module consists GSM/GPRS module to send status of Level Crossing and Signal, or to get commands from/to server. Architecture of developed system is shown in figure 4.2 and consist three tier, defined as:

4.4.1.1 User Tier

The User Tier consists of administrators and end users who interact with Identity Manager through one of the user interfaces. Main task of this tier is to translate tasks and results to something the user can understand. This involves the use of Graphical User Interface for smart client interaction, and Web based technologies for browser-based interaction.

This tier is further divided into two parts:

4.4.1.1.1 User Interface:

This part shows what are different possible views of developed system available to different user. This further categorized into three groups:

- **UI Presentation:** Simple HTML web site interface for user interaction with system. This part demonstrate what are the different options available to users, among these, user can select any of the available option for further processing. HTML & CSS platform is used in developing this.
- **Map Display:** This system is a combination of Web Based and Desktop Based System, it uses Google Maps as background map for displaying real time Train Location. Another use of Google maps is in asset management to show the object location on the map. According to user's activities, map is updated and JavaScript based query system is used to develop this.
- **UI Behavior:** This phase is a collation of different functions responsible for specific user behavior. JavaScript and XML Script is govern these function and regularly update the server on the basis of user request.

4.4.1.1.2 Application Communication Protocol:

Application communication Protocol is divided into two communication protocols, HTML Interface (Defined for simple HTTP request and HTML response) and AJAX Engine (Defined for updated HTML pages as per the requirement of user defined in the form of various input parameters set for Map Display and User Behavior).

4.4.1.2 Logic Tier

Logic tier consists a web server. It is a program that uses client/server model and different web technologies like Hypertext Transfer Protocol (HTTP), JavaScript, JSON, and AJAX serves the files whose request is made from Web pages of users.

Logic Tier Web Server have two server applications and a Google App Engine:

4.4.1.2.1 Mobile Server Controller:

Mobile Server Controller handle the request/response to/from remote devices like Train Module, Signal Module, Level Crossing Module and Asset Management Application. SOAP interface is used to exchange structured information between different modules and web server and a data processor is used to process data and store into a database.

4.4.1.2.2 Application Server:

Application Server uses the following technologies:

- Active Server Pages
- ActiveX Contents
- JavaScript
- VB Script
- HTML Application Page

Beyond these technologies a Request-Response Handler is also used to handle real time client request and to entertain these with a certain set of services. This Request-Response Handler is broadly categorized into two specific set.

- HTML Response Handler
- AJAX Response Handler

AJAX Response Handler is responsible for all interactive function calls with Google maps rendering request. Its work is categorized into three major parts as:

- Map/Google Earth runtime Rendering
- 3rd party Data Fetching
- Invoke an HTML Application Page

4.4.1.2.3 Google App Engine

Google App Engine is a unique hosting platform that lets us build applications and run these in Google's data centers using the massive global infrastructure. App Engine offers a development environment that uses Java & Python and provides a powerful and robust set of APIs to users while maintaining security and independence from other apps.

- **Google Maps API:** Google Maps API is the smart bits of Google technology that helps user to use the power of Google Maps and set it directly on client site (Google Maps APIs, 2013). It lets us add relevant content that is useful to visitors and customize the look and feel of the map to fit with style of site. Almost 150,000 sites are already using the Google Maps API.

- **Google Earth API:** Google Earth API enables developers to embed Google Earth applications into web pages with JavaScript code. With Google Earth API plug-in installed, these applications run interactively in web browsers. The API display place marks, lines, polygons, overlays, and 3D models on the imagery, just as standalone versions of Google Earth does. The plug-in supports several of the Google Earth layers, including terrain, roads, borders, and buildings.

4.4.1.3 Data Tier

A data-tier in web application is a Logical Database Management entity that defines all of the SQL Server objects - like tables, views, and instance objects, including logins which are associated with a user's database (Data Tier Application, 2014). This tier consists two databases, simple sql database for Train Positioning Information and another database (PostgreSQL) of Asset Management System. There are three component of Asset Management Database which are as follows:

4.4.1.3.1 PosrgreSQL

PostgreSQL is an Object-Relational Database Management system with an emphasis on extensibility and standards-compliance. PostgreSQL is cross-platform and runs on many Operating Systems including Linux, FreeBSD, Solaris, and Microsoft Windows. Mac OS X, starting with OS X 10.7 Lion, has the server as its standard default database in the server edition, and PostgreSQL client tools in the desktop edition (PostgreSQL, 2014).

4.4.1.3.2 PostGIS

PostGIS is a Spatial Database Extender for PostgreSQL Object-Relational Database. It adds support for geographic objects allowing location queries to be run in SQL (PostGIS, 2014). Some features which are supported by PostGIS are illustrated as follows:

- Geometry types for points, line strings, polygons, multi points, multiline strings, multi polygons and geometry collections.
- Spatial predicates for determining the interactions of geometries using the 3x3 DE-9IM.
- Spatial operators for determining geospatial measurements like area, distance, length and perimeter.
- Spatial operators for determining geospatial set operations, like union, difference, symmetric difference and buffers.
- R-tree-over-GiST (Generalized Search Tree) spatial indexes for high speed spatial querying.
- Index selectivity support, to provide high performance query plans for mixed spatial/non-spatial queries.
- For raster data, PostGIS WKT Raster (PostGIS, 2014).

4.4.1.3.3 Data Directory

This is a group of definitions, rules and advisories of data, designed to be used as a guide or reference with the data warehouse. The directory includes data layers, data files, definitions, examples, relations, functions and equivalents in other environments (Data Directory, 2014).

Four modules are developed to achieve the objectives, starting with Asset Management System, Train Module, Web Based Train Navigation and Tracking and Trip Analysis System. These all modules are discussed in further chapters.

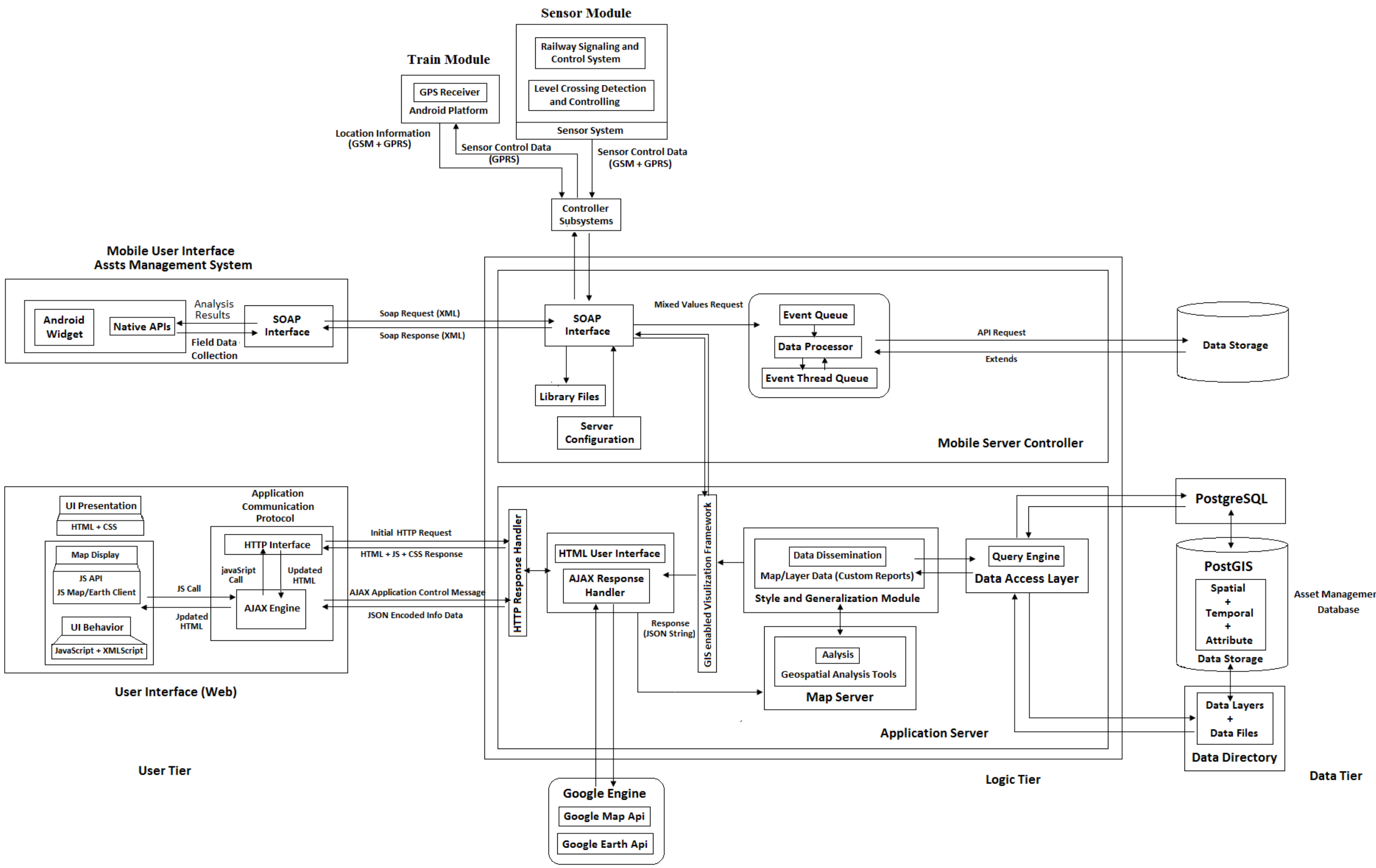


Figure 4.2: Architecture of Knowledge Based Train Navigation System

Chapter 5

Location Based Asset Management System for Railway: AMS-R

5.1 Introduction

Fundamentally Asset Management for railway infrastructure is about delivering the outputs valued by customers, funding partners and other key stakeholders, in a sustainable way, for lowest whole life cost. In order to build an efficient Asset Management System, large amount of data is required, in which location of assets plays key role. In current scenario various types of Location Based Services are available, so using the concept of Location Based Services, an efficient and reliable Asset Management System for railway is developed. In this chapter the developed system is presented. Section 5.2 describes the asset management system. Location based asset management system and its architecture and methodology is illustrated in section 5.3. In section 5.4, benefits of developed system is described. Results of the system is discussed in section 5.5 and section 5.6 concluded the system.

5.2 Asset Management System

Asset management systems are used by companies to keep track of their field installations and inventories (Cheng and Wei, 2009). Asset Management involves the balancing of costs, opportunities and risks against the desired performance of assets, to achieve the organizational objectives. Many definitions of Asset Management are used in different sectors. The most quoted definition of Asset Management is provided in PAS 55-1 which is as follows:

Systematic and coordinated activities and practices through an organization optimally manage its assets and their associated performance, risk and expenditures over their lifecycle for the purpose of delivering the organization's business objectives (BSI, 2008).

Scope of Asset Management in railways can be categorized in to two categories, which are as follows:

- The physical assets to which the asset management process applies.
- Activities, decisions and processes for the infrastructure.

Physical assets of railway infrastructure consisting the following items:

- Ground area.
- Track.
- Engineering structures: tunnels, bridges, culverts and other overpasses etc.
- Level crossing.
- Superstructures: rails, grooved rails, sleepers, ballast etc.
- Access way for passengers and goods.
- Safety, signaling and telecommunication installations.
- Lighting installations for traffic.
- Electric power plant.

5.2.1 Asset Management Framework

Asset Management framework consists of key components of Asset Management System, which falls into three categories and is shown in figure 5.1:

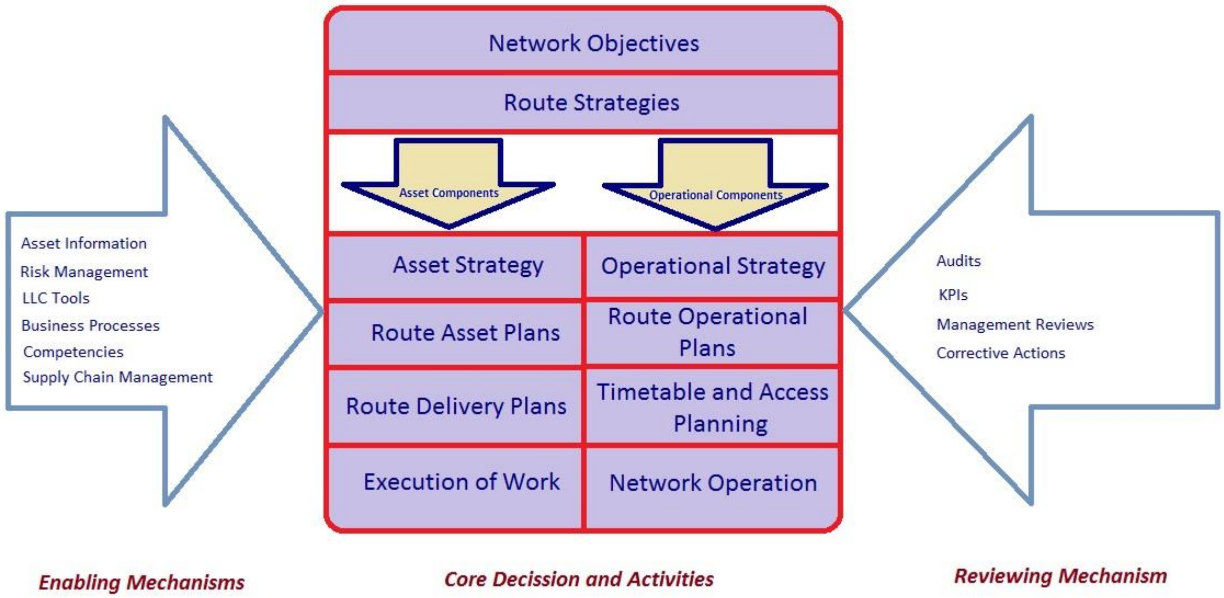


Figure 5.1: Asset Management Framework (UIC, 2010).

5.2.1.1 Core Activities and Decisions

This is the spine of Asset Management Framework which defines the decisions and activities that link strategy to the delivery of work, including both work on infrastructure and operation of network.

5.2.1.2 Enabling Mechanism

The effectiveness of core activities and decisions is influenced by many support mechanisms like, lifecycle of costing tools, asset information, business processes etc.

5.2.1.3 Reviewing Mechanism

To monitor and improve the effectiveness of asset management system, reviewing mechanisms are required. These mechanisms deliver sustainable infrastructure outputs for level of committed funds. These mechanisms provide continuous feedback for continuous improvement of asset management system (UIC, 2010).

5.3 Location Based Asset Management System for Railway

Location, which is the most essential context of an object, can be used to provide context aware services to users, which is called location based services (LBS). LBS is the recent concept in which applications integrates geographic location information with general notation of services. The concept of LBS presents many challenges in terms of research and industrial concerns. Location services are mainly used in three areas: emergency services, commercial sectors, and military and government industries (Schiller and Voisard, 2004).

LBS requires five basic components:

- Software application from service provider.
- To transmit data and requests for service, a mobile network is required.
- To supply the end user with geo-specific information, a content provider is required.
- A positioning component.
- End user's mobile device.

According to law, LBS should be permission based. That means the end user must opt-in to the service in order to use it. In most cases, this means that installing the LBS application and accepting a request to allow the service to know device's location. LBS rely on mobile platforms upon which multiple sensors and measurement systems have been integrated to provide continuous, three-dimensional positioning and orientation (Kealy et al., 2007). From the release of Apple's 3G iPhone and Google's LBS-enabled Android operating system, however, has allowed developers to introduce millions of consumers to LBS (Location Based Services, 2014). Due to rapid development of smartphone market, smartphone based positioning technologies are playing a more and more important role in location-based service industries (Bai et al., 2014).

Railway organizations have massive amount of assets which have to be managed, reinstall, renovate and maintain properly. To accomplish these tasks an asset management system is required which provide necessary information about desired asset. Location is the key component of asset information. To obtain this location information about an asset and send this information to a central server, an Android based application is developed. Complete system is the combination of two applications one is server side application and second is remote device application. By using remote device application user can save location information of assets to external storage as well as in central server. If user wants to take photograph of an asset, user need to touch Ok button when alert ask to take picture while saving location information and feature details. The developed application geotag captured picture of an asset and save it to an appropriate folder. When user touch any marker, line or polygon the related information is displayed in the information window and user can view picture of that asset.

5.3.1 System Architecture

Architecture of the developed system follows the client-server architecture. Client application is installed into an android based device which transmit location information of an asset to central server. Architecture of the system is illustrated in figure 5.2:

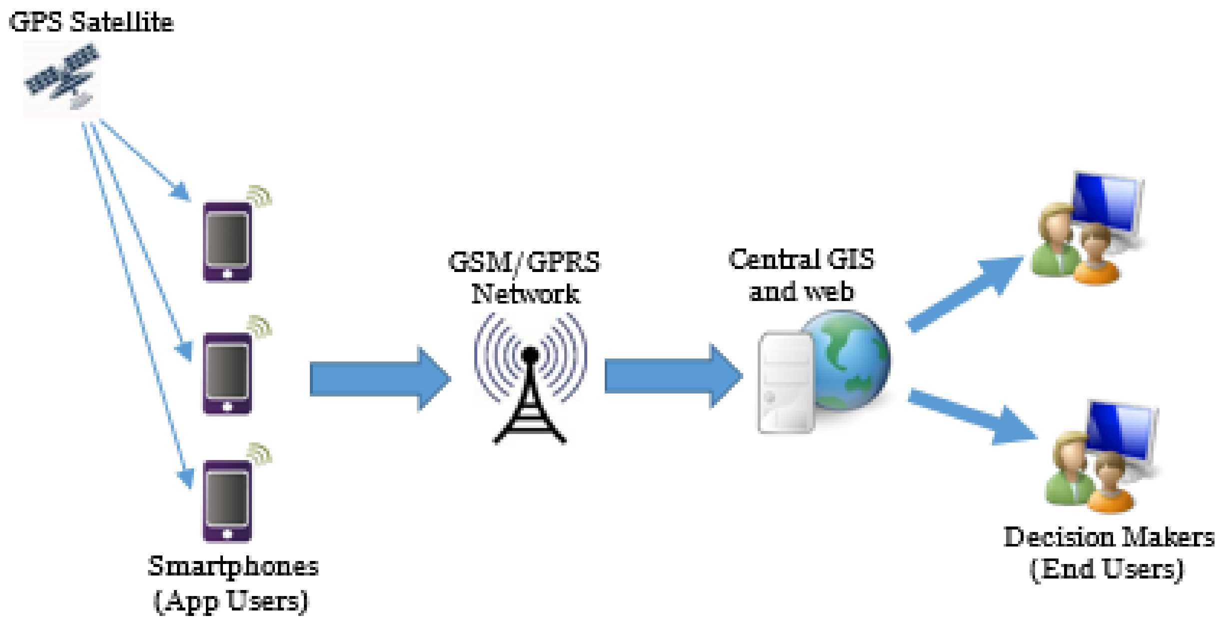


Figure 5.2: Architecture of Asset Management System for Railway.

Client application works in two mode, first is offline and second is online. In offline mode, application doesn't use GPS receiver but in online mode it does. Server application is the combination of database and GIS server.

5.3.2 Methodology and Development

Methodology of developed application is illustrated in Figure 5.3.

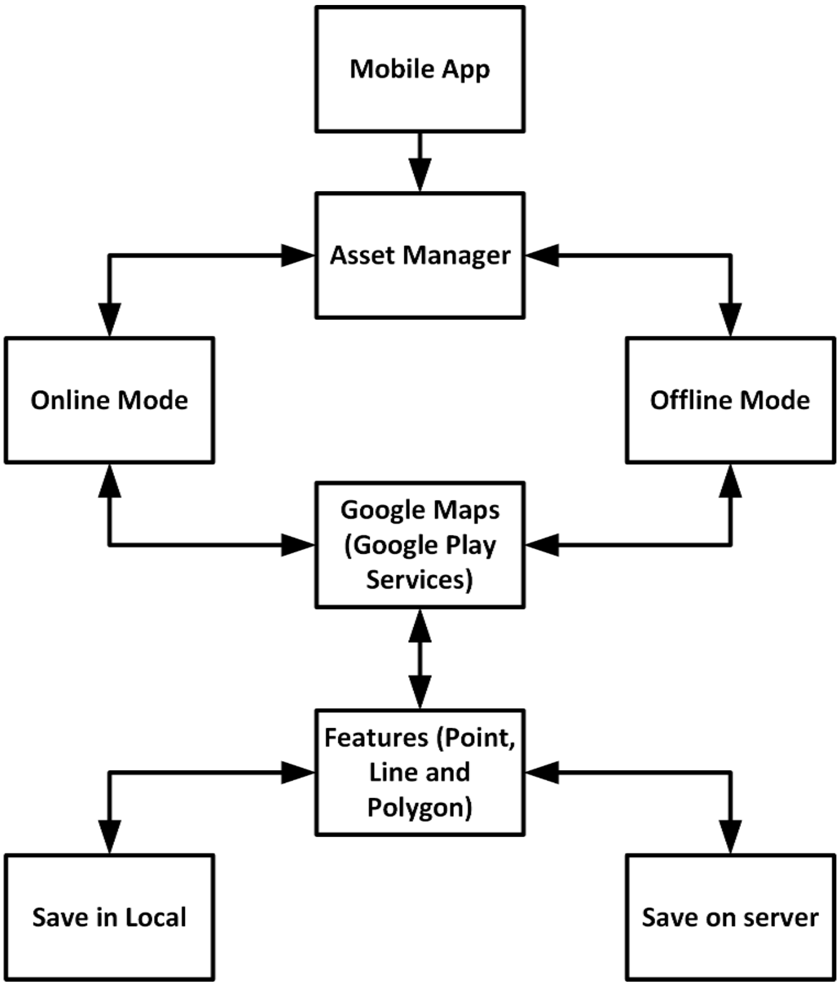


Figure 5.3: Methodology of AMS-R.

As mention above, the system consists two applications one is client application and another is server application. Client applications is an android based application called AMS-R, which can be installed in any android based device like phone, tablet etc. Eclipse IDE is used to develop client side application. Eclipse contains a base workspace and an extensible plug-in system for customizing the environment. By means of various plug-ins, Eclipse may also be used to develop applications in various programming languages like: Ada, ABAP, C, C++, COBOL, FORTRAN, Haskell, JavaScript, Lasso, Natural, Perl, PHP, Python, R, Ruby, Scala, Clojure, Groovy, Scheme and Erlang (Eclipse, 2014).

AMS-R is configured to run on android versions between 4.1 and 4.4. Google Maps API v2 is used to integrate Google Maps with the developed application. Google Maps API is integrated using Google Play Services. Google Play Services provide easy access to Google Services. For this, Client Libraries are provided by Google for each service that let user implement the functionality. Client Library contains the interfaces to individual Google services and allows user to obtain authorization from users to gain access to these services with their credentials (Google Play Services, 2014).

The developed remote application consists three main activities: DashboardActivity, AMSActivity and AMSOfflineActivity, other two activities: CameraActivity and ImageActivity are used to take picture when saving feature details to external storage and view desired picture respectively. Dashboard contains the main configuration functions of the application. User can create new project, open, edit and delete existing projects. User can also configure project settings, location setting from this activity. After configuring the project user can start collecting data in two modes: Online and Offline. Figure 5.4a and 5.4b shows the dashboard activity and it's menu.

When user touch Online mapping button, AMS activity is launched and GPS is enabled, so user can collect assets location information using GPS. AMS activity is illustrated figure 5.5.

Before taking feature location information user need to select feature from menu and give attributes to selected feature like: id, name, feature code, description. After giving attribute information user can collect location information about an asset. Figure 5.6a and 5.6b shows menu option and feature details dialog respectively. When user select appropriate option and save the asset information by touching save button on menu bar, a dialog popup and ask to capture a picture of the asset. If user touch ok button in take picture dialog, CameraActivity is launched and take picture of asset and geotag the picture with asset (See figure 5.7a and 5.7b).

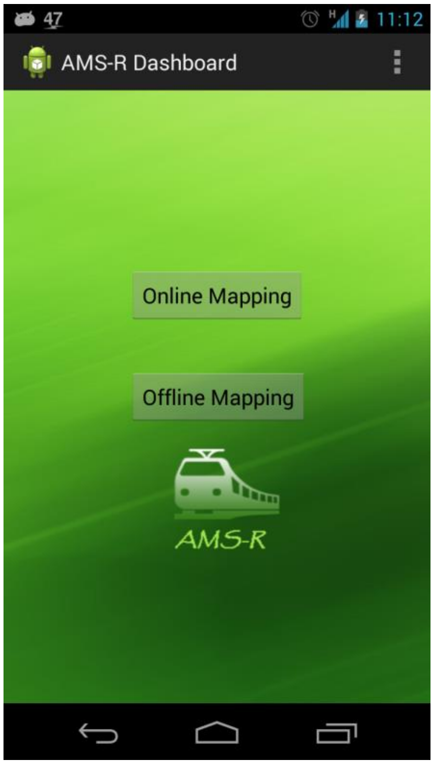


Figure 5.4 a: Dashboard Activity

Figure 5.4 b: Dashboard with it's menu

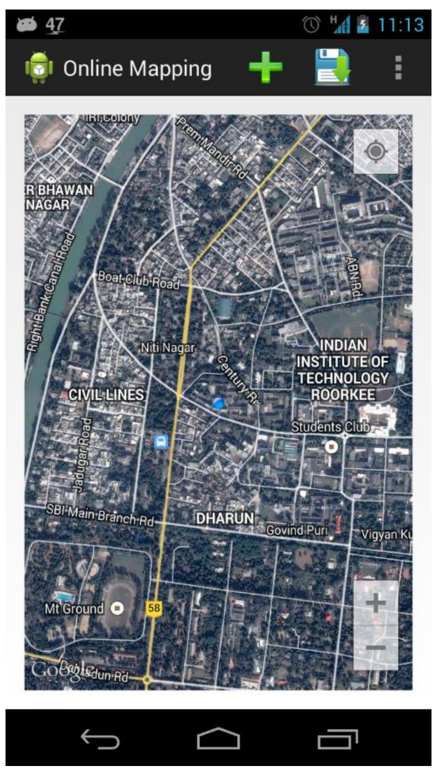


Figure 5.5: AMS-R Online Activity.

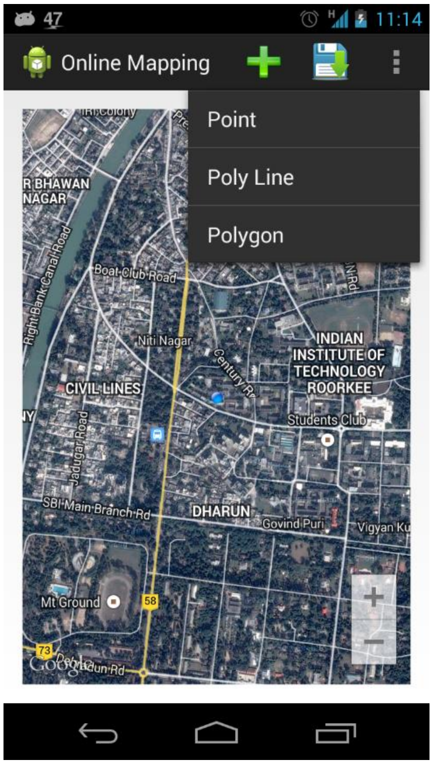


Figure 5.6 a: AMS-R Online Activity with it's Menu

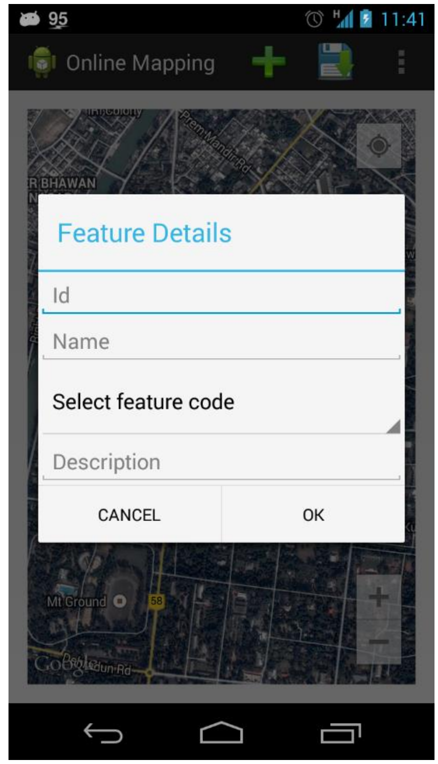


Figure 5.6 b: AMS-R Online Activity with feature details

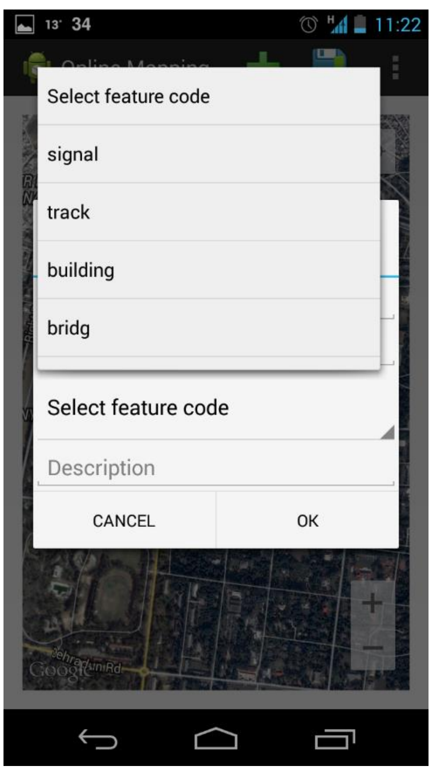


Figure 5.7 a: Feature Codes when saving Asset Information

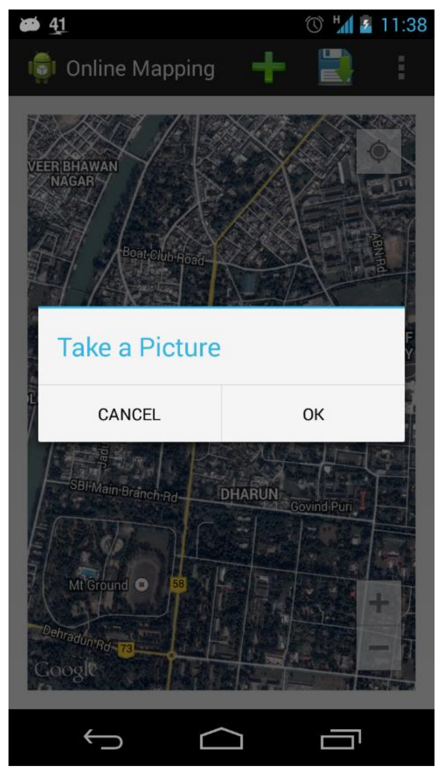


Figure 5.7 b: Take Picture Dialog when saving Asset Information

When user touch Offline Mapping button in dashboard activity, AMS Offline activity is launched. In this activity GPS is disabled so user can collect asset location information by touching the map. User also have to select feature from menu and give attributes like AMS Online activity. Figure 5.8 illustrate the AMS Offline activity.

Figure 5.8: AMS-R Offline Activity.

After completing the data collection, user have to tap on sync option in menu to sync collected data with server (See figure 5.4b).

On server side PostGIS is used for database. PostGIS is a Spatial Database Extender for PostgreSQL Object-Relational Database. It adds support for Geographic Objects allowing location queries to be run in SQL (PostGIS, 2014). For Map Service, GeoServer is used which allows user to display Users Spatial Information to the world. Implementing the Web Map Service (WMS) standard, GeoServer can create maps in a variety of output formats. This is a Java-based server software that allows users to view and edit geospatial data. This allows excessive flexibility in map creation and data sharing by using open standards set forth by the Open Geospatial Consortium (OGC) (GeoServer, 2014). To publish maps and spatial information over the web Apache was used.

5.4 Benefits of AMS-R

Location is the most vital information about an object and Location-Based Services (LBS) is a predominant term used to describe applications or services that identify location of a person or object in order to provide some useful information. So in Asset Management System, location play a key role. Some benefits of Location Based Asset Management System are as follows:

- Location information about an asset can be updated to central server remotely.
- User can view all Asset Location Information in mobile device.
- Staking is easy of an asset.
- Real time location synchronization of an asset.
- Cost effective.
- Very less training required.
- User can take pictures of a asset.

5.5 Results and Discussion

A field survey was conducted to collect the location information about roads, buildings, bridges, signals etc. Developed AMS-R application is used with Samsung Galaxy Nexus i9250 smartphone, which is running on Android 4.3.3 (Jelly Bean). Railway stations at Roorkee, Dhandera and Landhaura was selected as a study area. Figure 5.9 shows field data collection.

Figure 5.10 shows collected Railway Asset Information from Roorkee to Laksar railway stations. The collected data was upload to a central server by selecting Sync option in menu of Dashboard activity (See figure 5.4b).

Figure 5.11 a, b and c shows stations (blue line area), track (sky blue, yellow and red lines) and signals (markers) at various stations. In figure 5.12 a and b, signals at Roorkee and Dhandera stations are shown by markers. Figure 5.13 a, b and c shows various assets like canal bridge, road over bridge and level crossing.

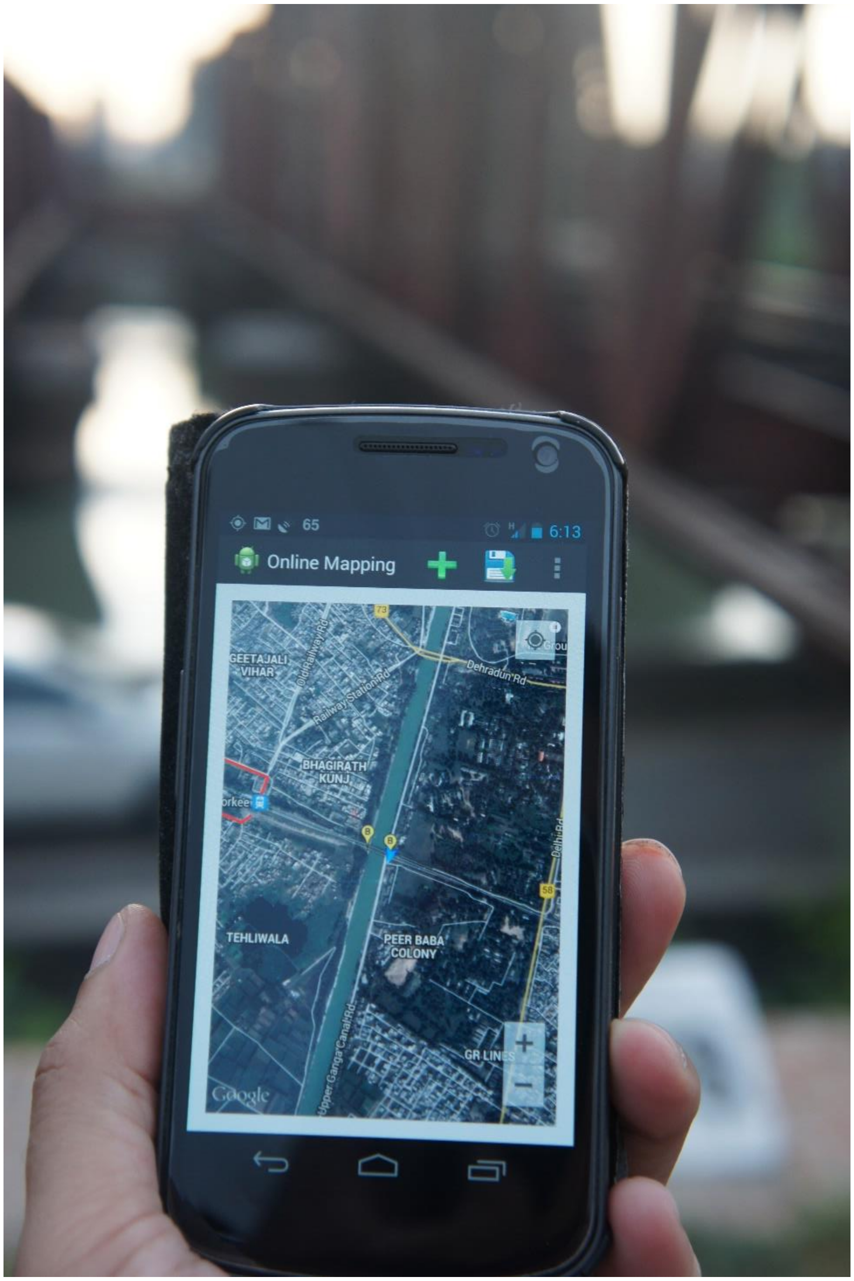


Figure 5.9: Field data collection using Google Nexus i9250.

All the collected assets information is stored in the external storage as well as in central server also. After data collection if user wants to send collected data to central server, user need to select Sync option from menu of dashboard activity otherwise data remains in external storage of device.

5.6 Conclusion

In context of Asset Management System, Location Information is the most essential part of asset information. Railway have massive amount of assets so the developed application is suitable option for collecting location information of an asset. Android Smartphones and devices are cost effective due to Open Source License of this software. So using developed application with Android powered smartphones or devices could be the cost effective solution for Asset Management System in railway industry. Previous studies shows that horizontal difference between smartphone and dedicated handheld GPS is 1 to 5 meter (Shoab et al., 2012), so where less accuracy is required, the inbuilt GPS receiver of smartphone can be used to get Asset Location Information. Offline mapping feature of developed application makes it differ from other location based applications. If a user is unable to reach near the asset, user can identify that asset on background map and digitize manually. This application have the capability of bringing field and office activities into collaborative environment that can improve productivity and reduce cost.

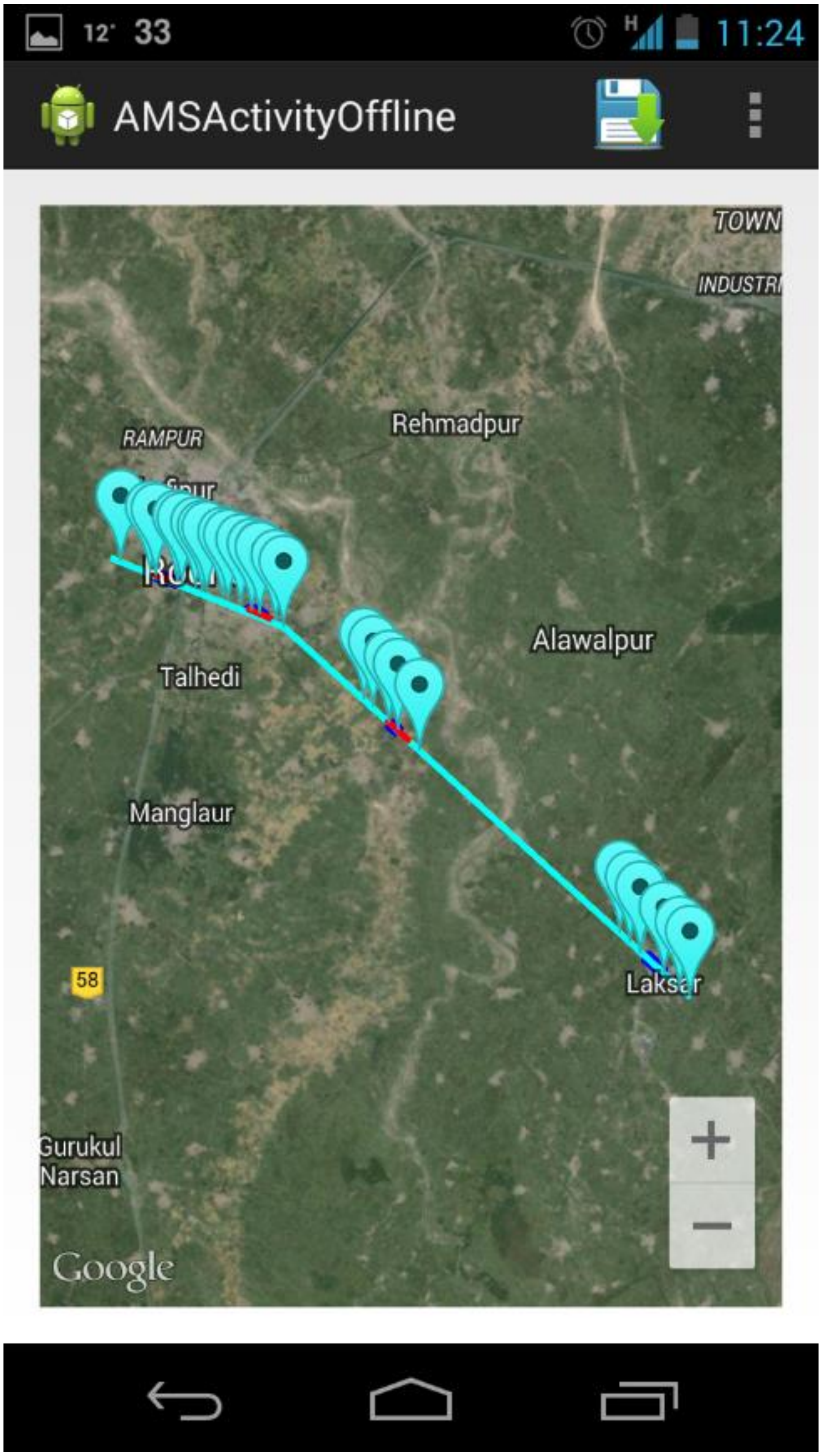
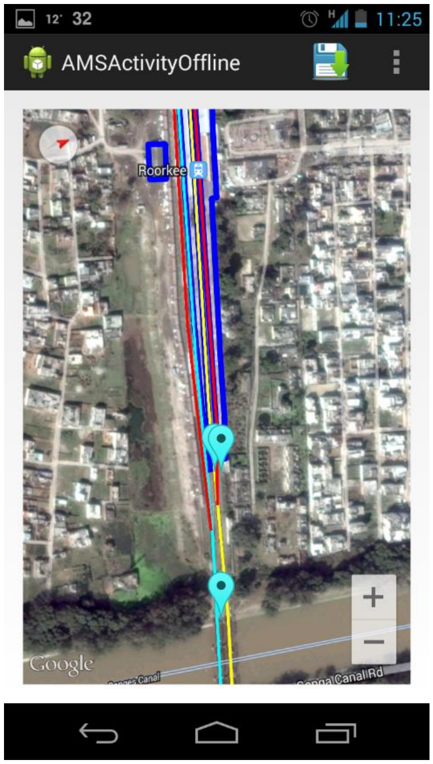
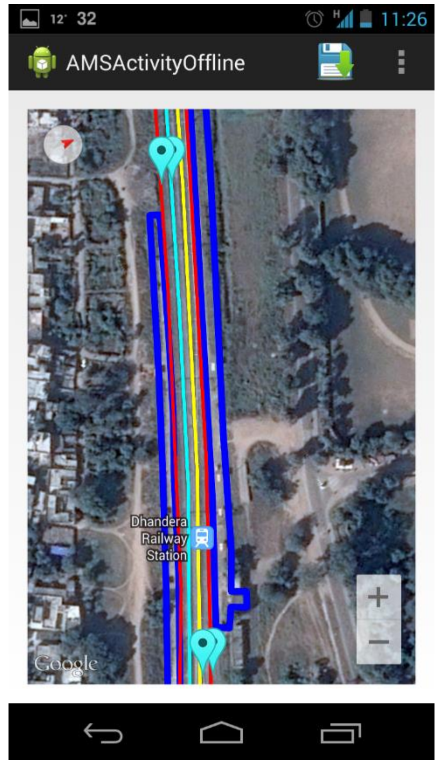


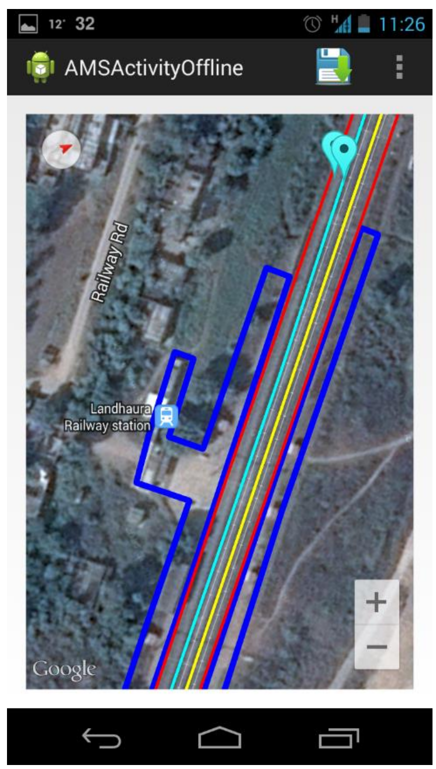
Figure 5.10: Collected assets data from Roorkee to Laksar.



(a)

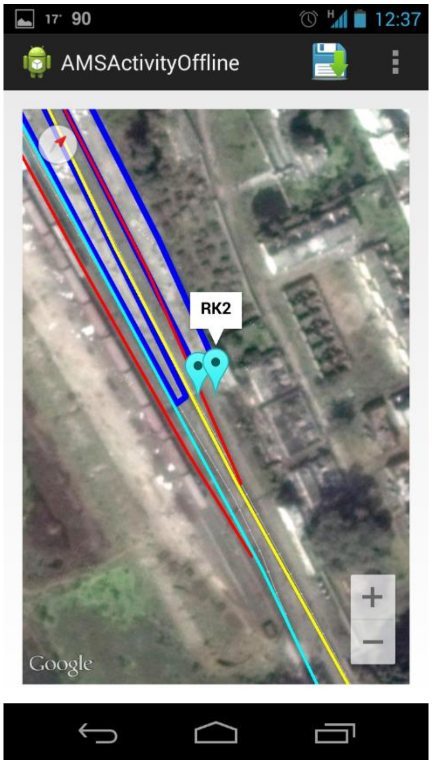


(b)

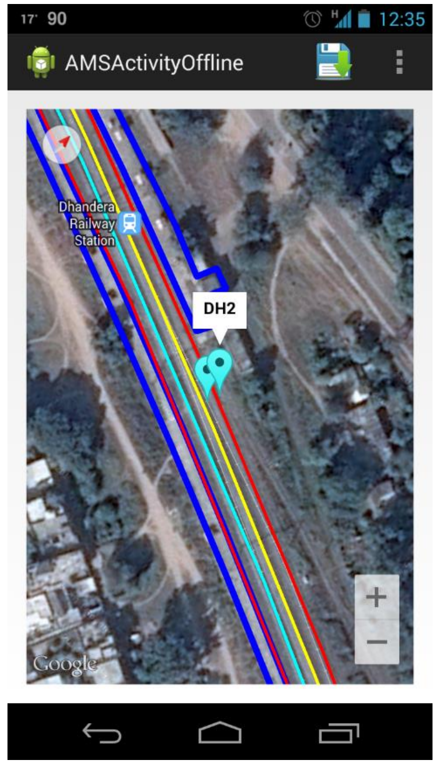


(c)

Figure 5.11: Figure a, b and c shows various assets data at various stations.

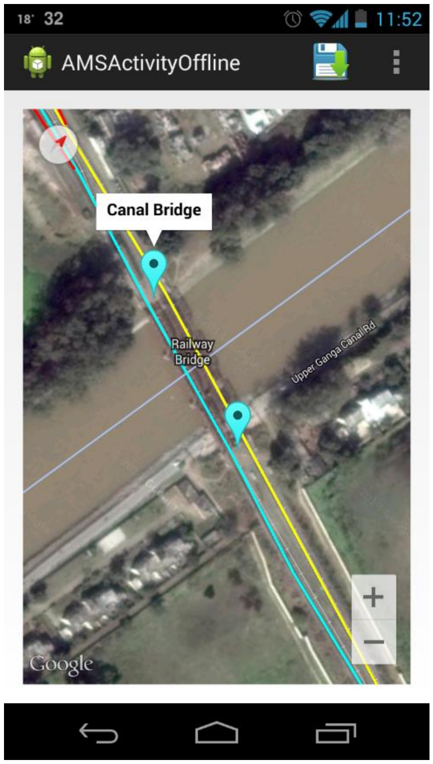


(a)

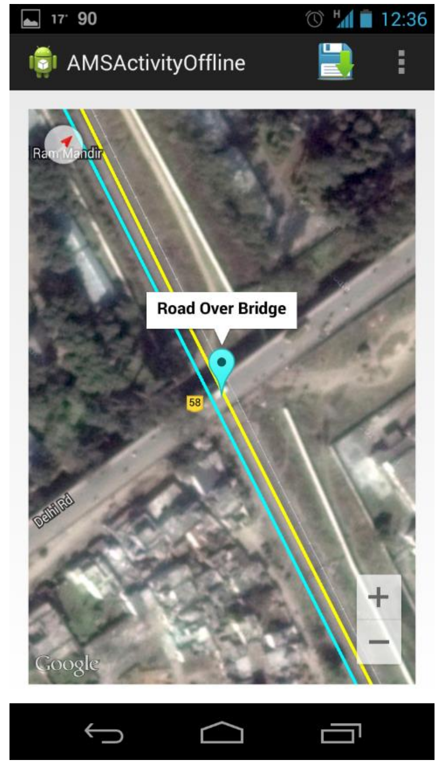


(b)

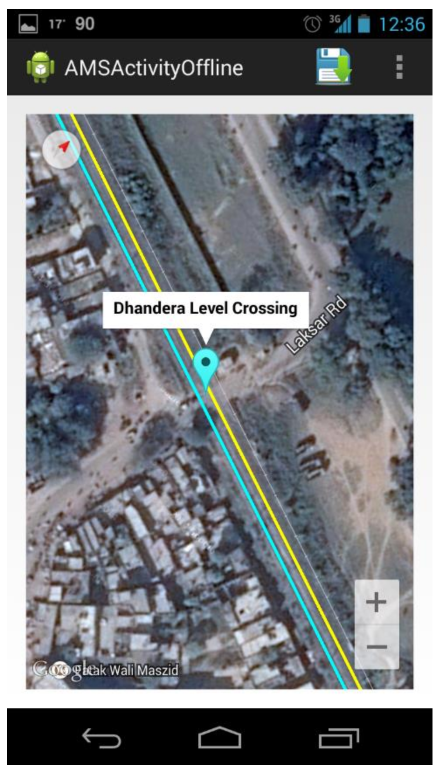
Figure 5.12: Signals at Roorkee and Dhandera stations.



(a)



(b)



(c)

Figure 5.13: Figure a, b and c shows canal bridge, road over bridge and level crossing.

Chapter 6

Knowledge Based Train Operator Module

6.1 Introduction

In this chapter, developed Train Operator Module is illustrated. An android based device is used as a train operator module which contain an application called Train Navigator and Tracker (TNT). To develop this application, Knowledge Based Approach is followed. Section 6.2 describes Knowledge Based System. Applications of Knowledge Based Systems in railway are illustrated in section 6.3. In section 6.4, developed train module is described. The integration of Track Maintenance Updates is discussed in section 6.5 and section 6.6 discusses results obtained during test. At last in section 6.7, whole system is concluded.

6.2 Knowledge Based System

Among all members of Artificial Intelligence (AI) family, Knowledge Based System (KBS) is the major family member. With availability of advance computing facilities, attention is now turning to more demanding tasks that might require intelligence. To solve complex problems, society and industry are becoming knowledge oriented and relying on different expert decision making abilities (Akerkar and Sajja, 2010; Bhattacharya and Ghosh, 2008). KBS software can be developed for any problem that involves a selection from among a definable group of choices where decision is based on logical steps (Ghosh and Bhattacharya, 2009).

Knowledge Based System could be a software that uses artificial intelligence or expert system techniques in problem solving processes. It incorporates a store (database) of expert knowledge with couplings and linkages designed to facilitate its retrieval in response to specific queries, or to transfer expertise from one domain of knowledge to another (Knowledge Based System, 2014).

6.2.1 Rule-based Knowledge Based System

Rule-Based Knowledge Systems are known as a kind of Expert System since they are anticipated to replicate the interpretation process of a human expert. An Expert System permits updating, maintenance, and reusability of knowledge, using context-dependent knowledge to obtain useful solutions to problems, and providing explanation-subsystems to support how or why explanations (Haq et al., 2014). A rule-based expert system is mainly composed of two parts: the Knowledge Base Knowledge Representation and the Inference Engine, for evaluating conclusions based on knowledge base using a logical reasoning process. Domain knowledge in the knowledge base is usually articulated as qualitative.

IF…THEN… rules:

IF <condition> THEN <conclusion>

The conclusion part is also known as action.

The inference engine has three main tasks: (1) collecting rules whose conditions in the IF parts can match the available FACTS, (2) performing actions in the 'THEN' parts in rules that are executed and (3) using a conflict resolution to make sure that only one rule will be fired when more than one rules conditions are matched.

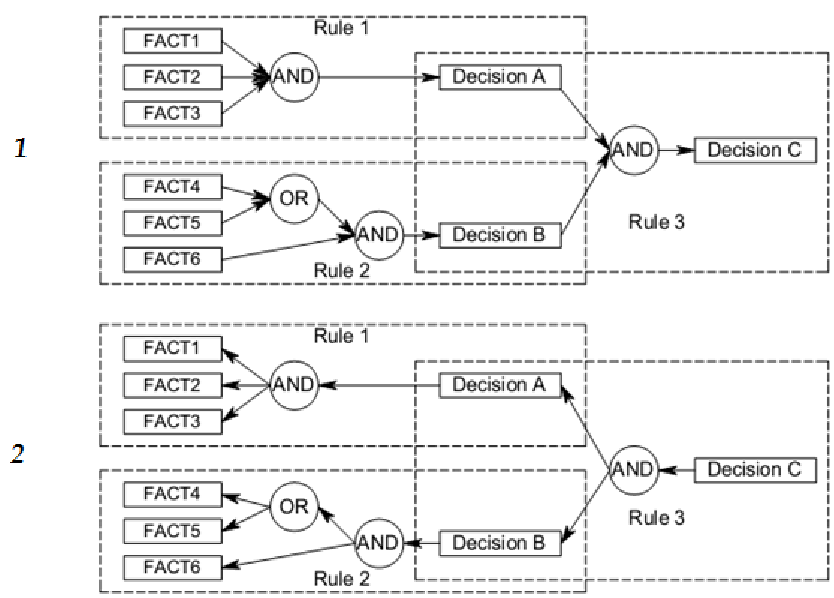


Figure 6.1: (1) forward chaining **(2)** backward chaining

There are two strategies for evaluating rules: forward chaining, and backward chaining (see Figure 6.1). Forward chaining is also known as data-driven inference, and backward chaining as goal-driven inference (Russell and Norvig, 1995; Hopgood, 2001). In the forward-chaining strategy, the rules are fired whenever the facts can satisfy the IF parts of these rules (e.g., in Figure 6.1 (1), rules 1 and 2 fire first, and then rule 3). In the backward chaining strategy, the inference engine looks steps to activate rules whose preconditions are not yet met. A set of explicit goals are required that consist of statements about which rules need to be used in the next step. The rules are fired only when they can potentially satisfy a goal. When more information is needed, new sub-goals are automatically created to fire additional relevant rules until the goal is satisfied or is determined to be non-satisfiable (Winston, 1993; Arora et al., 2000; Haq, 2013).

Knowledge based systems or expert systems have been applied in railway for various purposes like, decision support, analysis etc. In previous studies, Chang, (1988) develop a train scheduling expert system for AC electrification. Atamuradov et al., (2009) uses expert system for failure diagnostic for railway point machines. Li et al., (2011) applied an expert system to high speed railway track circuit coding. Starešinčić, (1997) analyze the potential advantages of expert systems in railway traffic planning. Mor-Yaroslavtsev and Levchenkov, (2011) present a model to integrate expert systems into railway electric transport safety control.

6.3 Applications of Knowledge Based Systems in Railway

It is widely recognized that Knowledge is one of the most important asset of any industry. So a KBS or Expert System is also required to get benefits from that knowledge (Ghosh et al., 2012). Various KBS or Expert Systems are used in various industries. Railway is a significant part of the backbone of transport system, as it is a major service provider for passenger traffic and freight transportation, in most countries. So KBSs are also applied in railway industries in various manner. Some of the areas, in which KBS or expert systems are applied in railway industry:

- Railway traffic scheduling and controlling.
- Diagnosis and maintenance.
- Decision support.

6.3.1 Railway Traffic Scheduling and Controlling

Modern Train Traffic Systems have to fulfill high requirements on service reliability and availability. Railway Traffic Scheduling and Controlling is often considered a difficult problem primarily due to its complexity regarding size and substantial interdependencies between trains. In many countries, the traffic is diverse with trains carrying different types of cargo (commuters, long-distance passengers with connections, express freight, bulk goods, etc.) with different preferences, destinations and speed functions. All these specific attributes make the trains highly inter-reliant and their interplay complex to plan, overview and execute. In addition, in different countries the organizations of Railway Traffic Management differs. The challenge is thus to comply with relevant preferences based on the available capacity to achieve and execute a robust and attractive timetable. (Törnquist, 2005).

To overcome the above problem, various KBS or Expert systems is applied to schedule and control railway traffic. In 1988, Chang, develop a Train Scheduling Expert System for AC railway electrification. To develop this expert system for train scheduling, the following steps were taken:

- Parameter adjustment of train drive heuristics models.
- Formation/modification of train time-tables.
- Train control knowledge acquisition system.
- Configuration design and expert system tool selection.

Mor-Yaroslavtsev and Levchenkov, (2011) modeled an integration of expert systems into railway electric transport safety control. An additional embedded module M which collects data from the sensors S_E, S_W etc. about the technical state of the engine E, wheels W and other critical parts will possessed by each vehicle T in the train control system. The incoming data, or antigens, will be presented to the antibody set to recognize dangerous situations and make a decision whether it's possible to start or continue movement regardless of driver's actions or traffic lights' signals (see Fig. 6.2).

The agents in the system I interact with knowledge database *Db* via expert system's use interface and, if necessary, send a signal to stop the engine via the controller. In this case the incoming data from the sensors is the set of antigens. The data includes, but it is not limited to speed, acceleration, voltage, rotation, temperature, and presence of smoke.

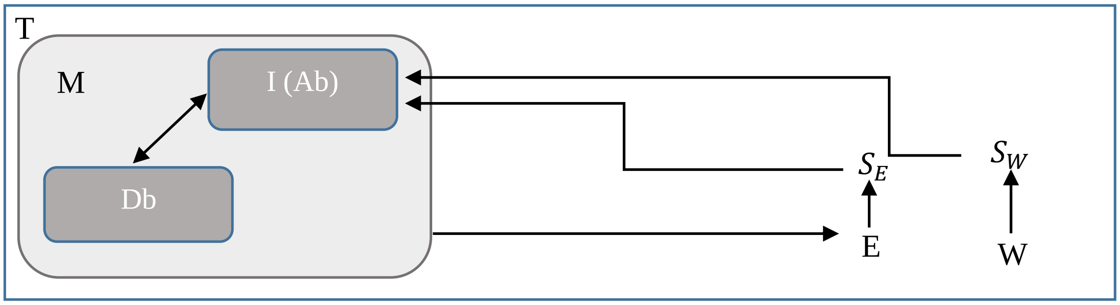


Figure 6.2: Generic railway electric transport control system design (Source: Mor-Yaroslavtsev and Levchenkov, 2011).

Fay, (2000) develop a fuzzy knowledge-based system for railway traffic control. It contains expert knowledge in fuzzy rules of the "IF-THEN" type. Fay proposed a Fuzzy Petri Net notion that combines the graphical power of Petri Nets and the capabilities of Fuzzy Sets to model rule-based expert knowledge in railway traffic control. Assistance provided by the system consists of:

- Simulation of the traffic development in the near future.
- Detection of conflicts.
- Display of relevant information.
- Prediction of certain dispatching measures' impacts.
- Proposal of adequate dispatching actions based on accumulated expert knowledge.

Geng and Li, (2001) develop and integrate a KBS in existing railway information system for scheduling railway fright cars. The system architecture is shown in figure 6.3. This system is developed using prolog and helps the managers in allocating train resources. The system have following features:

- It presents and provides easy access to relevant information. Such as orders to be scheduled, the goods to be loaded, alternative processing, alternative equipment, the load capacity of resources.
- It visualize the current state of the problem solving and let users monitor the effect of the decision.
- It supports the interactive generation or revision of the schedule by operation such as selection, insertion, deletion, relocation and substitution for resource allocation.
- It provides a consistent check on the feasibility of alternatives.

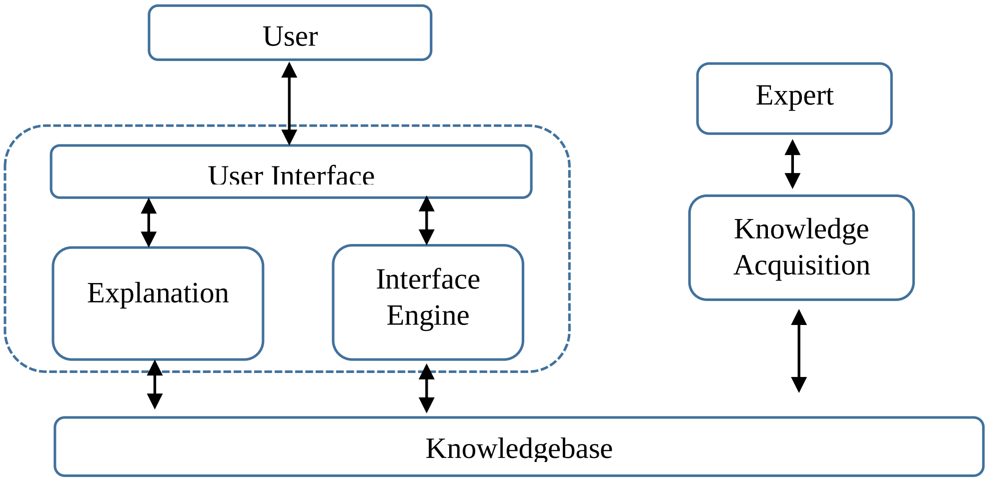


Figure 6.3: KBS architecture for scheduling of railway fright cars (Source: Geng and Li, 2001).

6.3.2 Diagnosis and Maintenance

It is now a requirement to improve reliability, availability and safety of railway systems in order to accommodate increasing passenger and cargo transportation with higher speed, grater load and increased service frequency. It is clear that, this demand increase cannot be satisfied with only building new tracks, the efficiency of new track and existing track should be increased. This could be achieved by increasing the availability of railways within minimum cost, which is directly related with repair and maintenance frequency cost (Atamuradov et al., 2009).

In 2009, Atamuradov et al., proposed an expert system for failure diagnosis for railway point mechanics when failure modes are not easily separable. This system diagnose the failure of railway turnout system. Railway turnout system allows trains to change their tracks by moving the rail before the train passes. The modeling structure of this system consists three sub models: preprocessing, time series analysis and expert system. The modeling is illustrated in figure 6.4.

Figure 6.4: Modeling structure for failure diagnosis of railway turnout system (Source: Atamuradov et al., 2009).

When a failure occurs, the time series data will move away from normal signature. So the similarity between observed time series and control signal give information about health of the turnout system. The expert system gives two failure mode and a healthy turnout mode (Atamuradov et al., 2009).

Dell'Orco et al., (2003) proposed an expert system for optimal planning of rail track maintenance. A fuzzy logic approach is used maintenance planning and the expert system is based on a set of *if-then* rules to help the maintenance manager in analyzing the system and choosing the best maintenance policy. Building up this expert system, it is apparent that two groups of data incorporate the main factors influencing the human experts' decision:

- Data related to the geometric quality, like alignment, longitudinal level, cross-level, gauge, rail wear and rail corrugation.
- Information related to the structural quality and resulting from experience, simple visual inspections conditions and assembly of single rail components.

By this expert system a decision maker can take decision of maintenance planning through a set of a linguistic propositions like:

IF x is s THEN y is t

Where x and y are linguistic variables, whilst s e t are their possible values.

Decision is taken on the basis of the Standard Deviation (SD) of data, putting one or more precise thresholds for each data.

Li et al., (2011) applied an expert system to high speed railway track circuit coding. This expert system is a computer software system which contains a large number of authority knowledge, where knowledge can be applied to solve the time problem in specific region through reasoning and analysis process. The knowledge database consists of rule database and case library. The rule database is used to save track circuit coding regulation, and case library is used to save different cases where lines, routes or locations vary, therefore, it is convenient to extend the knowledge case. Reasoning machine is responsible to analyze and reason the needed data and make a conclusion at last, forward reasoning is selected in this system.

6.3.3 Decision Support

Expert system stores knowledge of how a particular type of problem is solved and uses knowledge to conclude a solution. Conventional programs are designed to solve problems for which all the factors used in decision-making process can be completely analyzed (Ho and Wang, 2001). So expert systems or KBS are widely used in decision making process.

In the process of decision making for railway traffic scheduling and management, expert systems are extensively used. Fay and Schnieder, (1999) develop a knowledge based decision support system for real time train traffic control. The challenge of increasing train speeds, tight time schedules and higher traveler demands force train operators to improve the punctuality and reliability of their train services, so a dispatching decision support system is developed. Knowledge of expert dispatchers, collected over many years and shortened to rules-of-thumb, forms a valuable resource for dispatching problem solving. Hence, the approach followed in this dispatching support system is to acquire this knowledge in cooperation with dispatchers and to derive a rule base from this knowledge which can automatically be used for development of dispatching possibilities.

Conflicts are first classified by a diagnostic tool. Then, knowledge base is scanned for rules which are suitable for undertaking or resolving the conflict with regard to overall traffic objectives and strategies. By application of the appropriate rules to the conflict situation, a set of promising dispatching actions is derived. The resulting strategies are checked for satisfying the hard constraints (e. g. for overtaking, the parallel track has to be long enough). Only, strategies that satisfy all hard constraints are considered further (Fay and Schnieder, 1999).

LITRA, 2014 proposes a methodological framework for the use of a decision support system to assist in operative management of Romanian railway traffic. In Romanian railway system, traffic management activity is applied by a pyramidal organizational structure, in which there are four levels of decision hierarchy.

- Central level: represented by central dispatcher driving the movement, called Central Railway Traffic Management (BCCTF).
- Regional level: consists of leading regional dispatch movement called Regional Traffic Controllers (RCR).
- Zonal level: represented by the dispatch area driving traffic controllers called Circulation (RC).

- Station level: the railway network is 994 railway stations. In terms of traffic management, each station is uniquely subject of traffic rules.

Dell'Orco et al., (2003) proposed an intelligent decision support tool for optimal planning of rail track maintenance. This system is described above, under section 6.3.2.

6.4 Developed Knowledge Based Train Operator Module

To navigate and control train, a rule based knowledge based system is developed which is applied in train operator module. A train operator module consists three parts: Android based device, GNSS receiver and GSM module. The developed system is installed in android based device which get location information from GNSS receiver and send this location information to central server via GSM module. Some information about upcoming point of interest (POI, like: signal, level crossing etc.) also transferred from server to train operator module via GSM. These information is used in knowledge based system to take decision at various POIs. Figure 6.5 shows train operator module which consists a development board, GNSS receiver and antenna, GSM/GPRS module.

Figure 6.5: Development board, GNSS receiver, Antenna and GSM modem.

To assist this module, another system is developed to get status of level crossing and signal and update this status to central server. This system mainly consists three parts:

a. Microcontroller
b. GSM Modem
c. Level crossing switch/signal console

For level crossing, when a man close/open level crossing gate the switch change it's status to on/off and the developed system update this status to central server by sending an SMS. When station master or signal man change status of signal (Red, Green or Yellow), the developed system update this information to central server by sending an SMS.

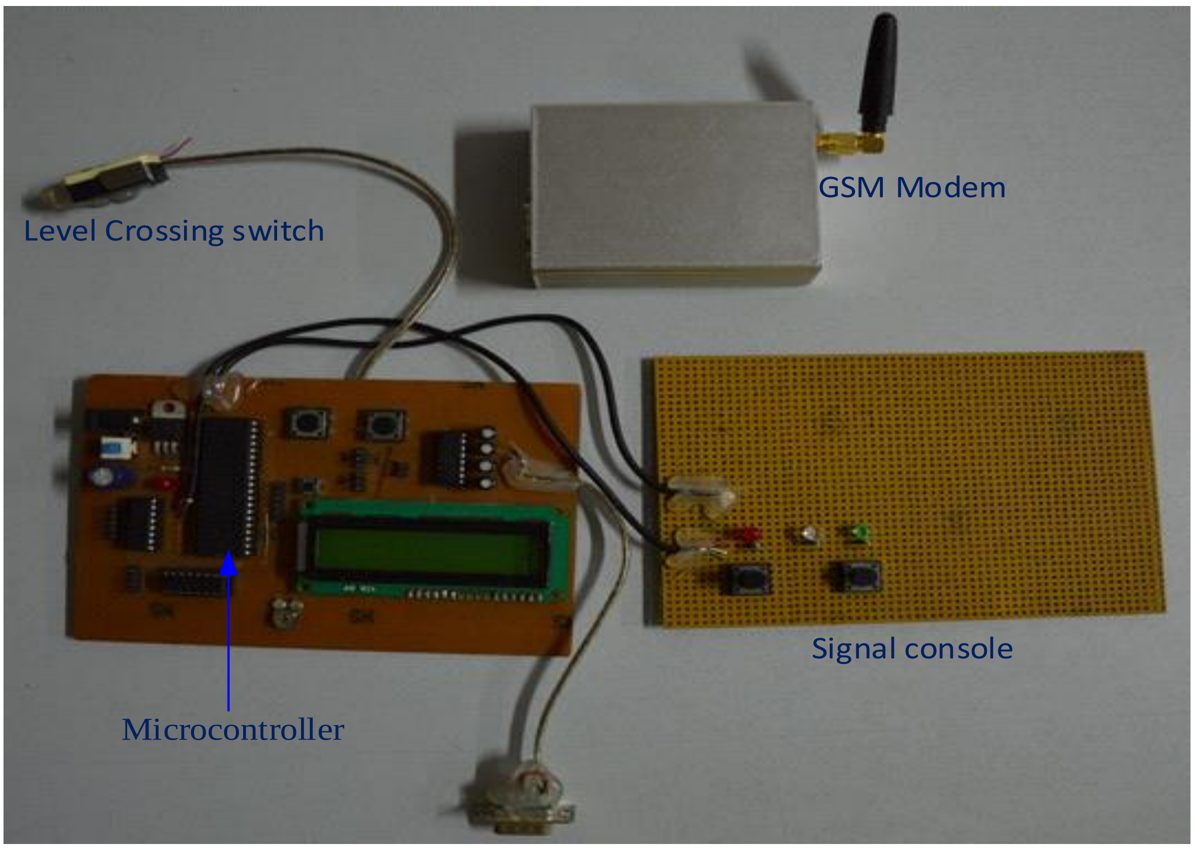


Figure 6.6: Level crossing and signal console.

Rules of this system are as follows:

Rule 1: Signal rule

When train approaching to a signal, developed system communicates with server and gets status of signal (Green, Orange and Red) at a distance of 2 km from signal. If it gets status of upcoming signal green, system will not apply any kind of speed restriction condition and train will go at same speed. If status of signal is orange then system will apply proceed slow condition and generate warning. If status of signal is red system will apply stop condition and stop train before signal and wait until signal becomes green.

```
IF Signal_status = Green
    then
            proceed_without_slowdown
    else If Signal_status = Orange
            then
                    proceed_with_slowspeed
    else
            stop
```

Rule 2: Level crossing rule

When train is approaching to a level crossing (LC), developed system communicates with central server and gets status of LC (Close or Open) at a particular distance from signal like in rule 1. If it gets status of upcoming LC is close, system will not apply any kind of speed restriction condition and train will go at same speed. If it get status open, system will send SMS to station master and generate a warning for loco pilot.

```
IF LC_status = Close
    then
            proceed_with_samespeed
    else
            send_sms
```

Rule 3: Station rule

When train approaching to a station the developed system generates a warning for driver, if train driver does not slow down, the system applies speed restriction condition and generate warning for loco pilot at a distance of 1 km from station.

```
IF Station_distance <= Threshold_distance
    then
            generate_warning

    else IF Speed >= Threshold_speed
            proceed_with_slowspeed
```

Rule 4: Track maintenance rule

Several accidents occurs while maintenance of a track is in progress due to lack of information sharing. Track maintenance rule prevent this type of accidents. When train approaching to the zone where maintenance is in progress, developed system slow down the speed of train at a given limit. After crossing maintenance zone train can take its normal speed.

```
IF Zone_distance <= Threshold_distance
    then
            generate_warning

            IF Speed > Threshold_speed
                    proceed_with_slowspeed
    else
            proceed_with_normal_speed
```

6.5 Integration of Track Maintenance Updates with Train Module

Track requires to be maintained periodically with the object of keeping it to best running condition, consistent with its maintainability. Periodicity of maintaining is depends on several factors, such as type of track structure, volume of traffic, its age, rate of track deterioration, maximum permissible speed, system of traction, condition of formation etc. Irrespective of the system of track maintenance adopted, it is obligatory to overhaul specified lengths of gang beat annually. The length of the section to be overhauled shall be such that complete overhauling of track will be accomplished within a specific period (normally 3 to 5 years) (The Maintenance of Permanent Way, 2014).

Sometimes, maintenance causes the fatal accident with the maintenance workers due to lack of information sharing. Sometimes train driver doesn't know segment on which the maintenance work is going on and passes that segment on high speed, so some fatal accident occur due to this. The developed knowledge based train module can prevent this kind of accidents. Track maintenance updates are available for train driver through this module.

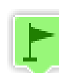
6.5.1 Working

When train starts it's journey, it download its latest route file from central server, this route file is latest updated by the administrator. The file contains whole route information like: signals, level crossings, bridges and the track segments which have to be maintained. When train reaches to a threshold distance from the maintenance segment, the train module follow the rule number 4 and warns the train driver to slow down the train speed at a given speed limit. After passing the maintenance segment, train module generates a warning for train driver to gain normal speed and proceed.

6.6 Results

In this Knowledge Based Train Operator module, different POI's are denoted by different symbols, which are as follows:

Trains:  (Own train)  (Nearby trains)

Signal:  (Red)  (Yellow)  (Green)

Level Crossing:  (Open)  (Close)

Bridges:  (Canal/River, ROB, RUB etc.)

Maintenance Segment:  (Start)  (End)

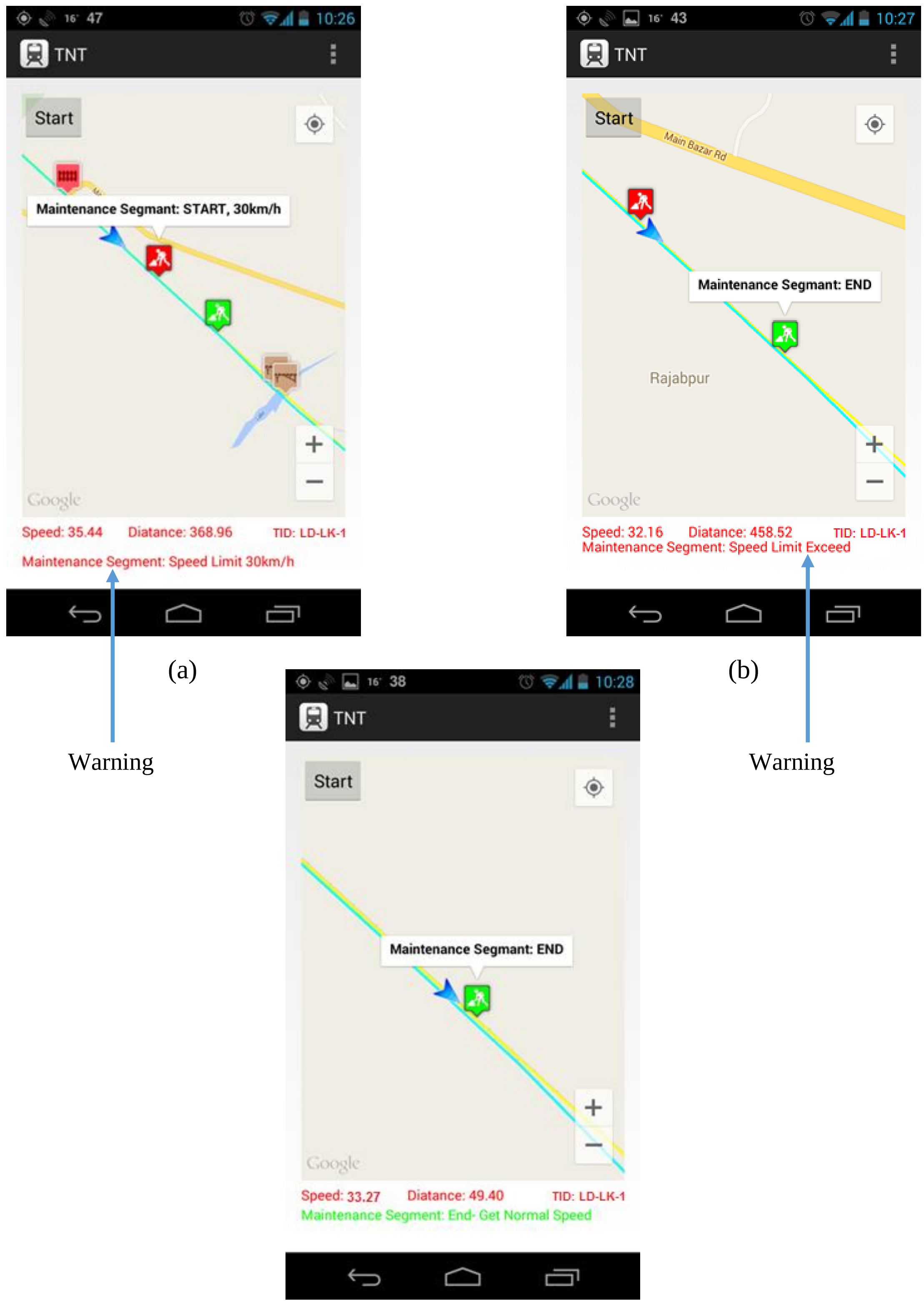
In developed module, text "Distance" shows train distance from upcoming POI and text "TID" shows Track Id on which train is running.

During test journey from Roorkee to Laksar, figure 6.7 shows signal rule at Roorkee railway station. When signal RK2 was red, train was not moving and the signal marker color and POI text was also red (see figure 6.7 a). After yellow signal, train moves with caution speed and corresponding signal marker color and POI text was yellow (see figure 6.7 b). When signal RK1-2 was green, train was getting it's normal speed (see figure 6.7 c).

Figure 6.8 a, b and c shows status of different level crossing with appropriate color. Results of the maintenance rule are shown in figure 6.9 a, b and c. Figure 6.10 a, b and c shows results while train was approaching to various bridges and a signal. Figure 6.11 shows result of station rule while train was approaching to Dhandera station. While train was approaching to another tain and the distance between both trains is less than or equal to 4 km, the module check track id's of both trains and generate appropriate warning (see figure 6.12).

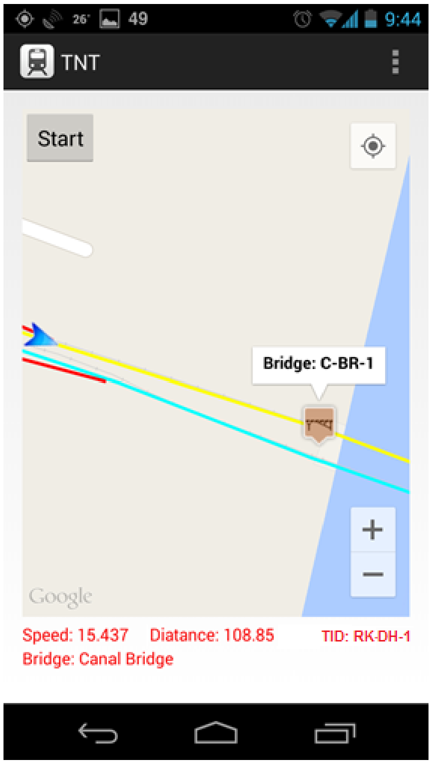
Figure 6.7: Results of signal rule.

Figure 6.8: Results of level crossing rule.

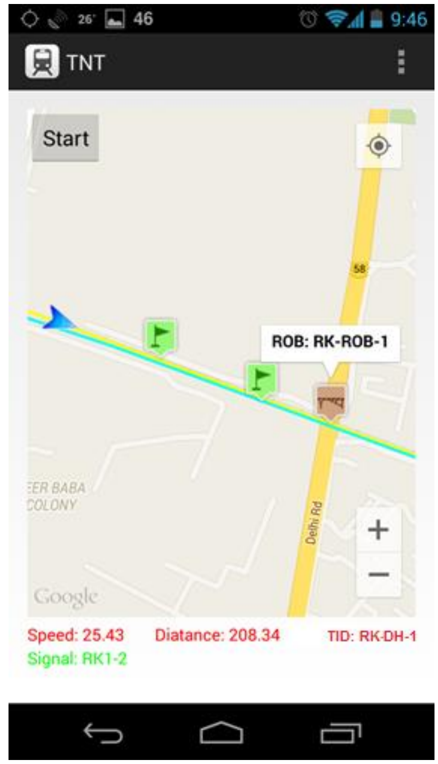


(c)

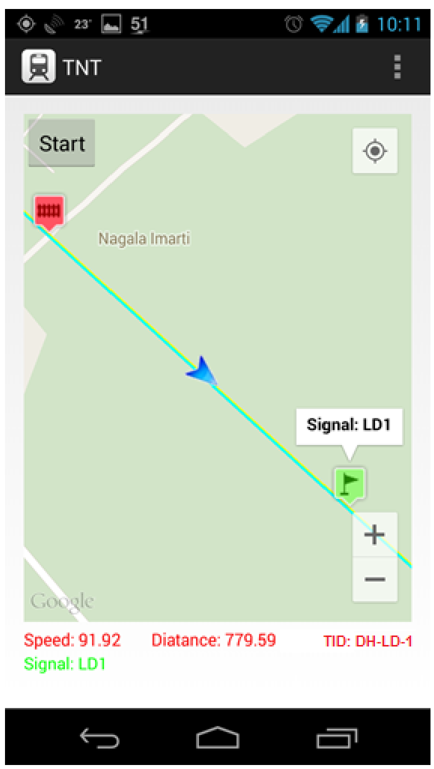
Figure 6.9: Results of maintenance rule.



(a)



(b)



(c)

Figure 6.10: Results at various bridges and signal.

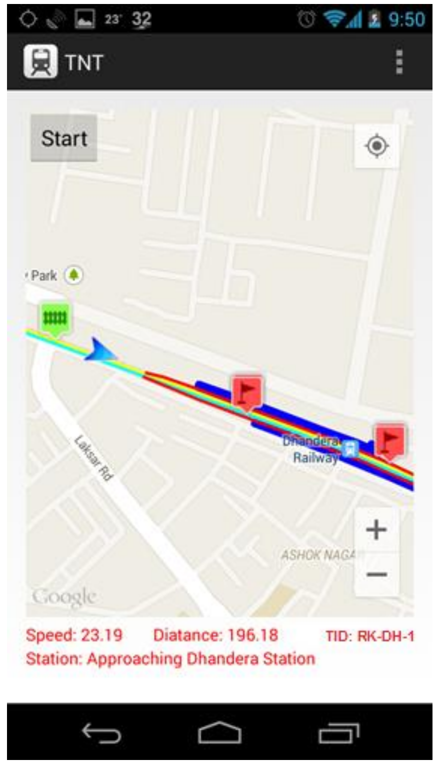


Figure 6.11: Results of station rule while train approaching to Dhandera station.

Message, while two trains are approaching to each other, Green color shows that both trains are on different track (If red, both train are on same

Figure 6.12: Two trains are approaching to each other.

6.7 Conclusion

Above section summarized the knowledge based approach for train operator module. This module consists Android Development Board, GNSS receiver with antenna and GSM module. For Signal and LC status, another microcontroller based module is also developed which uses GSM module to send status of signals and LC to central server. A rule based approach is applied to control and navigate the train using this module. Four rules are applied to solve complex problems while approaching Signals, LCs, Stations and Track Maintenance Segments. Other rules can be included in database. Different symbols are used for different POIs. Near POIs, results shows that in all conditions the system performance is satisfactory. The system is able to generate warnings for train driver while approaching POIs.

Chapter 7

Web Based Train Navigation and Tracking System

7.1 Introduction

In this chapter, the developed Web Based Train Navigation and Tracking System is illustrated. Section 7.2 describes the advantages of web technology in railway industry. Web GIS and its features are illustrated in section 7.3. In section 7.4, integration of Web GIS and GNSS with railway operations is described. The developed web based train navigation and tracking system is discussed in section 7.5 and at last in section 7.6, whole system is concluded.

7.2 Web Technology

Web technology relates to the interface between web servers and their clients. It includes programming interfaces, markup languages and standards for document identification and display (What is Web Technology, 2014).

In 1989 Tim Berners-Lee invented the World Wide Web. After about 24 years, the first connection was established, today it is known as the Internet. At that time, Tim was a software engineer at CERN, the large particle physics laboratory near Geneva, Switzerland. Scientists were eager to exchange data and results, but had difficulties in doing so. Tim understood this need, and realized potential of millions of computers connected together through Internet. Tim had specified three fundamental technologies by October of 1990, which remain the foundation of today's Web.

- HTML (Hyper Text Markup Language).
- URI (Uniform Resource Identifier).
- HTTP (Hypertext Transfer Protocol).

First Web page editor/browser (World Wide Web) and first Web server (httpd) was also written by Tim. First Web page was served by the end of 1990 and people outside of CERN joined the new Web community by 1991. Tim founded the World Wide Web Consortium (W3C) in 1994 as a place for stakeholders to reach consensus around the specification and guidelines to ensure that the Web works for everyone and that it evolves in a responsible manner (History of the Web, 2014).

Web browsers and web servers are communicating client-server computer programs for distributing documents and information which is called web data, over Internet. For presentation and interaction with people in web browsers, web data are marked up in the HTML language. For identification each web server uses an IP address or domain name as well as a port number. HTTP protocol is used to send data request to a web server and the web servers running on server computers either retrieve the requested data from local disks or generate the data on-the-fly, mark up the data in HTML, and send the resulting HTML files back to the web browsers to render. Apache, Tomcat and IIS are popular web server programs, and IE and Firefox are popular web browsers (Mandla and Jain, 2006; Tao, 2010).

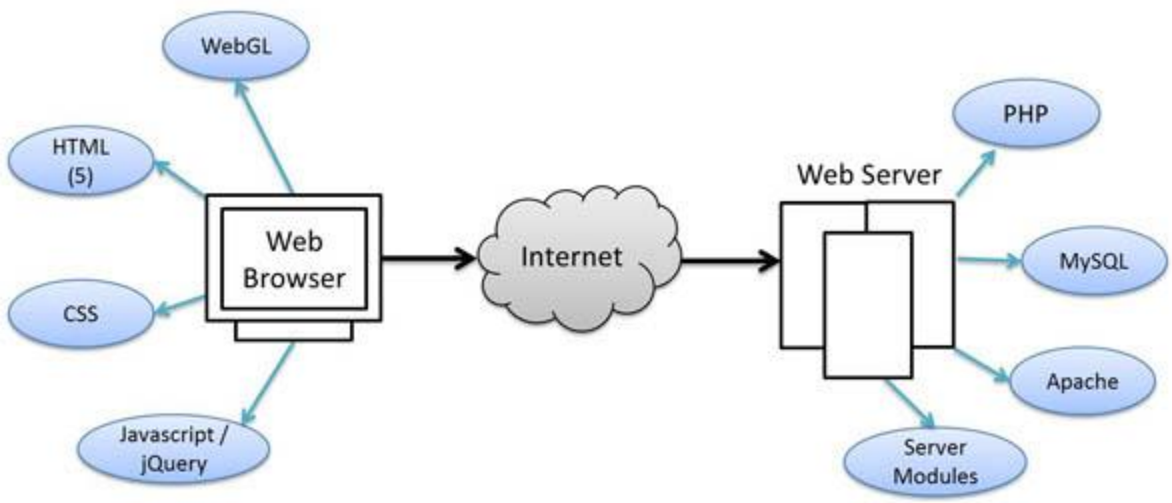


Figure 7.1: Web architecture of developed system.

7.3 Advantages of Web Technology in Railway

With the rapid growth of Internet in last two decades, information technology is seeping into every part of human life and everything is getting digitized. Web technology is the integral part of information technology which plays a major role in most of the industries, and railway industry is one of theme which is taking benefits of web technology. Some web applications and their advantages are as follows:

7.3.1 Online Reservation

In 21st century, technology has transformed many aspect of life including the way of making train reservation in India. To make ticketing more convenient for travelers, Indian railway started online reservation system, which helps people in ticket booking. While this is convenient for most people, it has made things particularly easier for people residing in remote locations. Some of the advantages of online reservation system are as follows:

- Convenient.
- Save time and effort.
- Towards a greener planet.

In India, Ministry of Railway and Indian Railway Catering & Tourism Corporation LTD. (IRCTC) developed a reservation system for advance booking of rail tickets through internet. IRCTC launched internet ticketing system on 3rd August, 2002 in collaboration with CRIS, the Centre for Railway Information Systems. Tickets for rail journey in India can be booked on the web site www.irctc.co.in by any user after registering at the site. Payments of tickets can be made by Debit/Credit Cards, direct debit to user's accounts, IMPS (Immediate Payment Service) and cash cards. Passenger can cancel ticket before preparation of reservation chart of the train by logging in his/her User ID and password. IRCTC follows three tier architecture, which are as follows:

- Presentation layer.
- Application layer.
- Database layer.

Entire system is protected by Trend Micro Interscan Messaging and Symantec Antivirus systems (Aggarwal, 2007).

7.3.2 Web Based Railway Risk Assessment Information Management System

Korean government sponsor a project, called Risk Assessment Information Management System which has been conducted by Korea Railroad Research Institute (KRRI). The purpose of RAIMS is to generate key risk assessment results that can be used for railway safety management. Information generated by RAIMS is based on risk models and assessment techniques, tailored for railway application in Korea from general risk assessment methodology (Wang et al., 2008). This system mainly focused on:

- Classification of railway accident type and hazards.
- Primary hazard analysis.
- Evaluation of hazard frequency.
- Evaluation of hazard severity.
- Evaluation of risk.
- Cause of critical hazards.
- Safety requirement management.
- Cost benefit analysis for safety policy.

RAIMS is basically web based system in which several users are registered in the system and only admitted users can access to system. Users are categorized in three category for this system, general users, analyst and system manager. Figure 7.2 illustrate the functional diagram of this system.

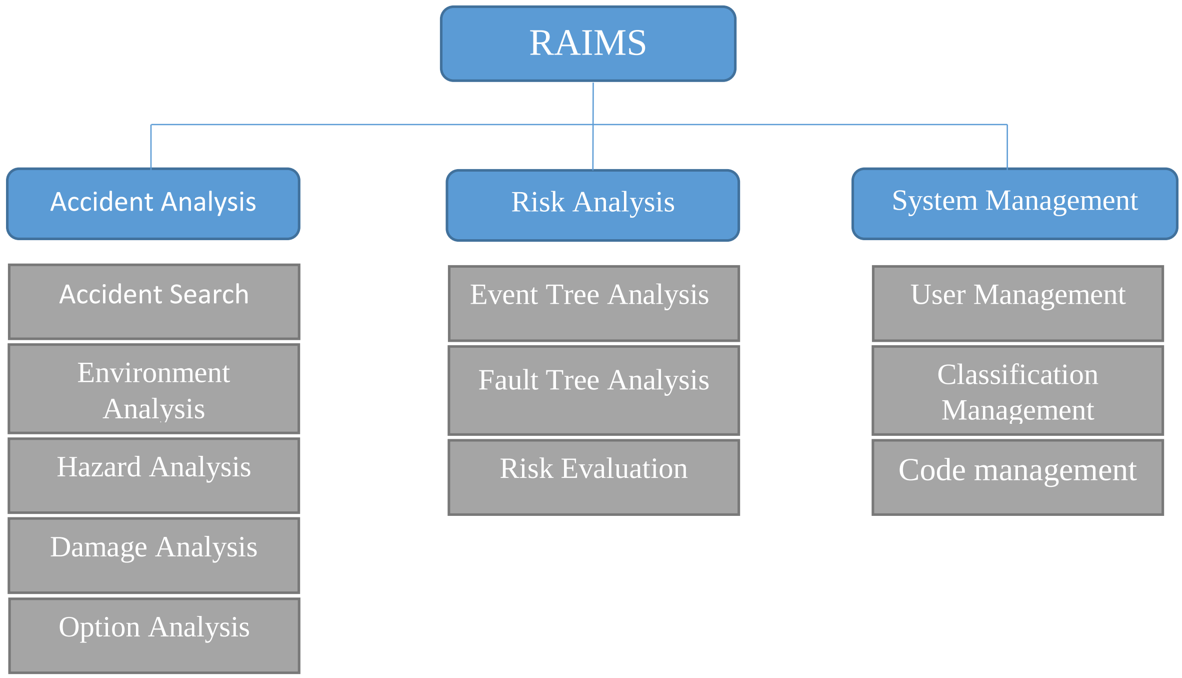


Figure 7.2: Functional diagram of RAIMS.

RAIMS is a key part of railway safety management since it provides risk assessment results for Government, duty holders, or other authorities to make decision regarding railway safety management policy (Wang et al., 2008).

7.3.3 Railway Decision Support System Using Web

In steering the course of national and international economics and defense strategy, as well as, business activities and personal lives the ability to make decisions is a crucial process. Decision making involves searching for conditions that call for decisions, and then designing and choosing actions. The quality of decision-making depends on both the decision makers and any Decision Support System (DSS) used (Simon et al., 1987; Turban, 1990).

Xi et al., (2005) proposed a study on Intelligent Decision Support System of Railway Empty Wagon Distribution (REWD-IDSS) in china. General target of this study is, under the environment of Train Movement Information System (TMIS) network and Fright traffic Management Operation System (FMOS) data source is to provide the Intelligent Decision Support System for the timely distribution of empty wagon and assurance of loading job being finished, meeting the needs of transport adequately to realize the efficient exercise of whole railway wagon in China. Although, this system is not a pure web based decision support system but the system structure is composed of client/server architecture. The browser is used to release information and browse and download to related departments (Xi et al., 2005).

Sheng et al., (2010) also developed a web based distributed group decision support system for railway construction organization, which is called RCDSS. Using computer-aided compiling of construction plan, RCDSS provides train schedule influence analysis, railway technical operation influence analysis, railway macro-network operation influence analysis and multi-criteria comprehensive evaluation for further decision support. RCDSS has been implemented in Shenyang Railway Administration in China in a Web-based environment and is accessible by authorized decision makers without geographical constraints (Sheng et al., 2010).

In 2001, Berners-Lee et al. developed the idea of the Semantic Web to aid with Web semantic interoperability. Lu et al., (2006) proposed a study on the application of semantic web technologies for railway decision support system. Ontology is the core of the Semantic Web that makes the web machine processable. It covers both vocabularies of concepts and relations and axioms of constraints and rules. To show functions of inference, visualization, query, etc. a Semantic Web ontology for vehicle and tracking system integration is presented in this study.

7.3.4 Web GIS in Railway

Web GIS allows users to view, edit and manipulate spatial data over the web but Web GIS is more than just GIS over the Web. Web GIS enables the communication of all components through web, enabling diverse data, analysis algorithms, users and visualization techniques that may be hosted at any location on the web. Some advantages of Web GIS is illustrated below:

- Web GIS brings GIS into the hands of people i.e. maps that work everywhere.
- Web GIS reduces the need to create custom application.
- It gives platform for integrating GIS with other business system.
- Cross organizational collaboration is enabled using Web GIS.
- Web GIS enables access to vast collections of ready to use maps like base maps, demographic, and terrain maps, etc. and GIS services, including geocoding, routing etc.

- Web GIS is a map-centric content management system, which helps organize, secure, and facilitate access to geographic information products (What is Web GIS and why does it matter to me?, 2014).

Due to vast functionality of Web GIS, various transportation industries is taking benefits from this. Lu, (2006) develop and investigate a distributed Web GIS based intelligent transportation systems with Web Service technology, which is based on the Open GIS Consortium (OGC) GIS Web Service framework and SOA architecture. Web Services are software components that are well defined, self-contained, and does not depend on context or state of other services. OGC developed web-based geographic information and services accessible via Internet through OGC consensus process.

Another study was done by Liu et al. in 2008 on applications of Web GIS in high speed railway. They proposed four layer structure for high-speed railway, which includes client layer, webserver layer, map server layer (application layer) and database layer. MapXtreme for Java is chosen for map server. The graphical interface of client-side is provided by Java Applet and JavaScript technologies, and Java Servlet procedures are developed of the server-side by Java technology. Apache, Tomcat are chosen for web server to publish MapXtreme. On the basis of MapXtreme, system can provide high-speed railway GIS sketch map of various countries such as China, Japan, Italy etc. It also provides layer exhibition query of line, station, motor base, bridge and tunnel etc. and it can also query correlative literature, design and fundamental data.

7.4 Integration of Web GIS and GNSS with Railway Operation

Many railway organizations invest heavily in their track network and other related support infrastructure. These network supports movement of goods, passengers and other services and can often make a key difference in keeping regional and even national economics emulative. Countrywide, railway network is highly utilized and sometimes in downtime it may create serious spout, delays and safety issues.

Worldwide, many railway organizations brought GIS/Web GIS and GNSS into their information system suite to more efficiently manage their assets, maximize throughput and safety, and minimize delay. Integration of Web GIS and GNSS has been efficiently deployed in support of broad array of railway functions some of them including:

- Asset Management.
- Safety and security.
- Passenger Information System.
- Train Monitoring.

According to utilization of GNSS in railway sector, the applications of GNSS can be categorized into two categories safety critical and non-safety critical applications. Safety critical includes train control and signaling. Application of GNSS is to improve safety and accuracy for Remote electronic braking, train diagnostics and train/wagon location monitoring. Rail track surveying is another area where accurate positioning data provided by GNSS can be used. Some countries running car body tilt trains that uses GNSS data to assist car body tilt control, which permits tilting trains to negotiate sharp curves at higher speed and with less centrifugal force inside a car (Salmi and Torkkeli, 2009).

Above integrated applications comes under non-safety critical applications. Here GNSS provides location information and these different applications uses this location information according to it's requirement. To improve the performance of passenger transportation, rain monitoring system play a vital role which uses GNSS technology. The essential part of better service is, proper dissemination of up-to-date information about arrival and departure times of trains, especially when there are delays. Location of railway assets can be display on web maps in Web GIS based asset management system. So a decision maker can view and make appropriate decision from anywhere.

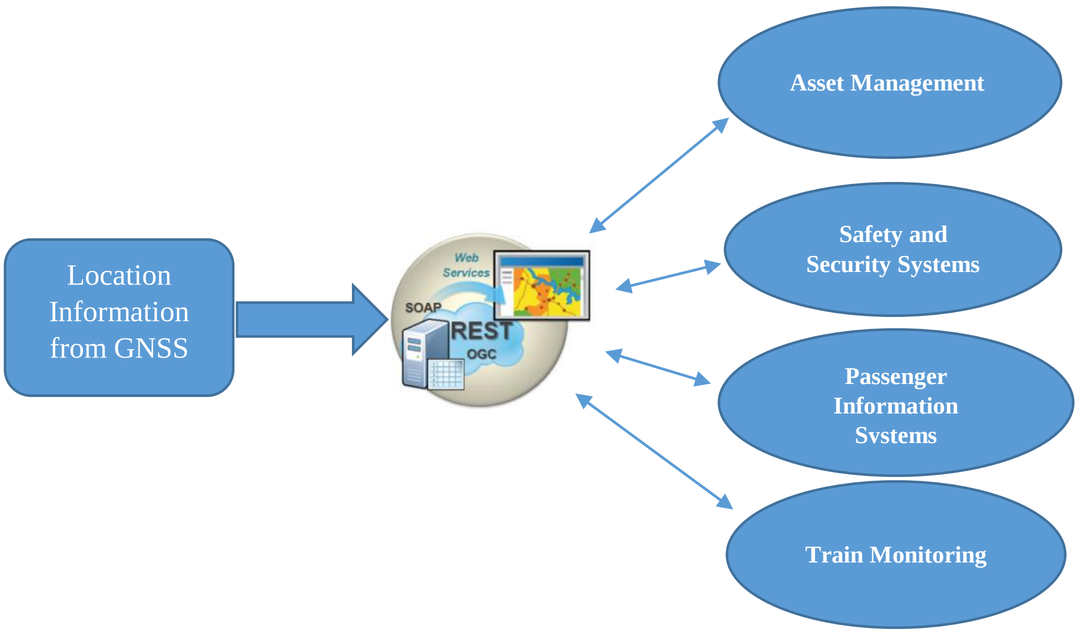


Figure 7.3: Web GIS and GNSS integrated systems.

7.5 Developed Web Based Train Navigation and Tracking System

The developed system is integration of Web GIS and GNSS to track a moving train. Web GIS is used for background maps and location information is obtained by remote GNSS device. Figure 7.4 illustrate the proposed system.

The system consists four parts:

- Remote GNSS Device.
- Communication Network.
- Central Server.
- Users.

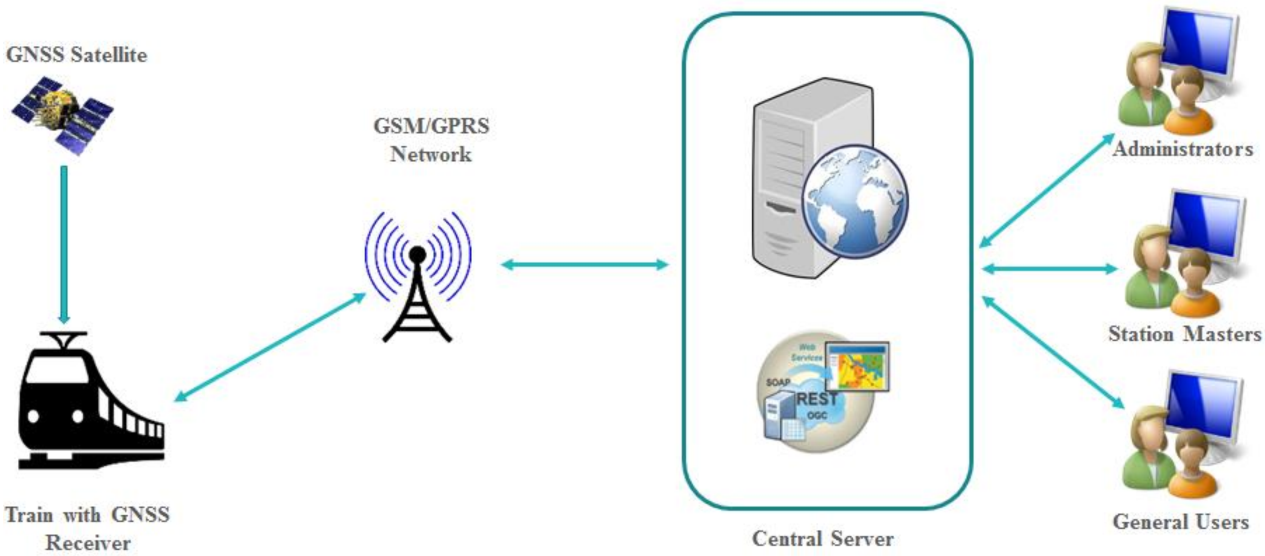


Figure 7.4: Web based train navigation and tracking system.

7.5.1 Remote GNSS Device

Remote GNSS device is located in train which contains GNSS antenna, receiver and GSM/GPRS modem to send train location information to central server. Remote GNSS device could be any Android based device and should contains two serial ports. A serial GNSS receiver is used to get train location information and a GSM/GPRS modem is used to connect device with internet. The developed Knowledge Based Application called TNT is installed in device. TNT gets location from GNSS receiver and send this information to a central server by calling a web service using internet. Remote device is Knowledge Based Train Operator Module which was discussed and shown in Chapter 6.

7.5.2 Communication Network

Communication network is essential part of any object tracking system. Here GSM/GPRS network is used for communication between remote GNSS device and central server. A serial interfaced GSM/GPRS module is used in the remote GNSS device to connect it with internet. General packet radio service (GPRS) is a packet oriented mobile data service on the 2G and 3G cellular communication system's called GSM. In 2G systems, GPRS provides data rates of 56 to114 kbps (General packet Radio Service, 2014).

7.5.3 Central Server

Central server is the major part of whole system which consist two types of servers, one is web server and second is GIS server. Central server manages all data and requests from users and remote devices. Web server publish the web service and web site over the internet for different kind of users. GIS server provides facility of raster and vector maps to web server which integrate these with web site. The developed web service and web site is hosted on the web server and the GIS maps is organized by the GIS server. Remote devices and users receive/send data from/to the central server.

7.5.4 Users

A person that has authority to use an equipment, application, facility, process, or system, or one who consumes or employs a service to obtain a benefit or to solve a problem, and who may or may not be the actual purchaser of the item.

Here, different kinds of users have different role in this system. Mainly three types of users are in the developed system, first Administrator, second Station Master and third are General Users. Administrator have all the rights to manage whole system like, add/edit or delete a train or a user. Station Master can see all running trains and manage signals/level crossings. At the last, the General Users can only track on train at a time.

To provide complete train navigation and tracking the developed system integrates all the above four parts. To accomplish defined objective, the developed application is designed and developed by using Html, Asp. Net (server side scripting language), JavaScript (client side scripting language), Google API's (providing spatial information), and VBA (Excel Macros) in Visual Studio 2010. Home Page for this system is shown in Figure 7.5 which consists login link for users to get into site. First users are required to register themselves with the web site to login into website. User registration form is shown in Figure 7.6.

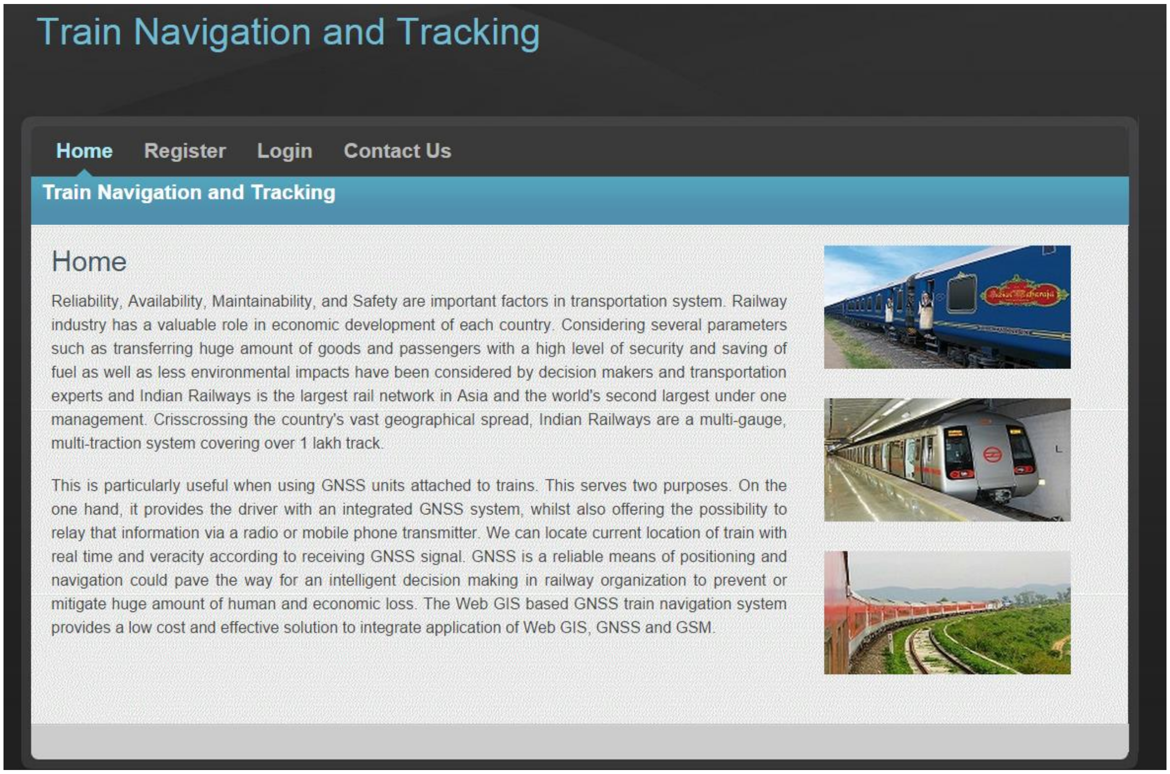


Figure 7.5: Home Page of Web based train navigation and tracking system.

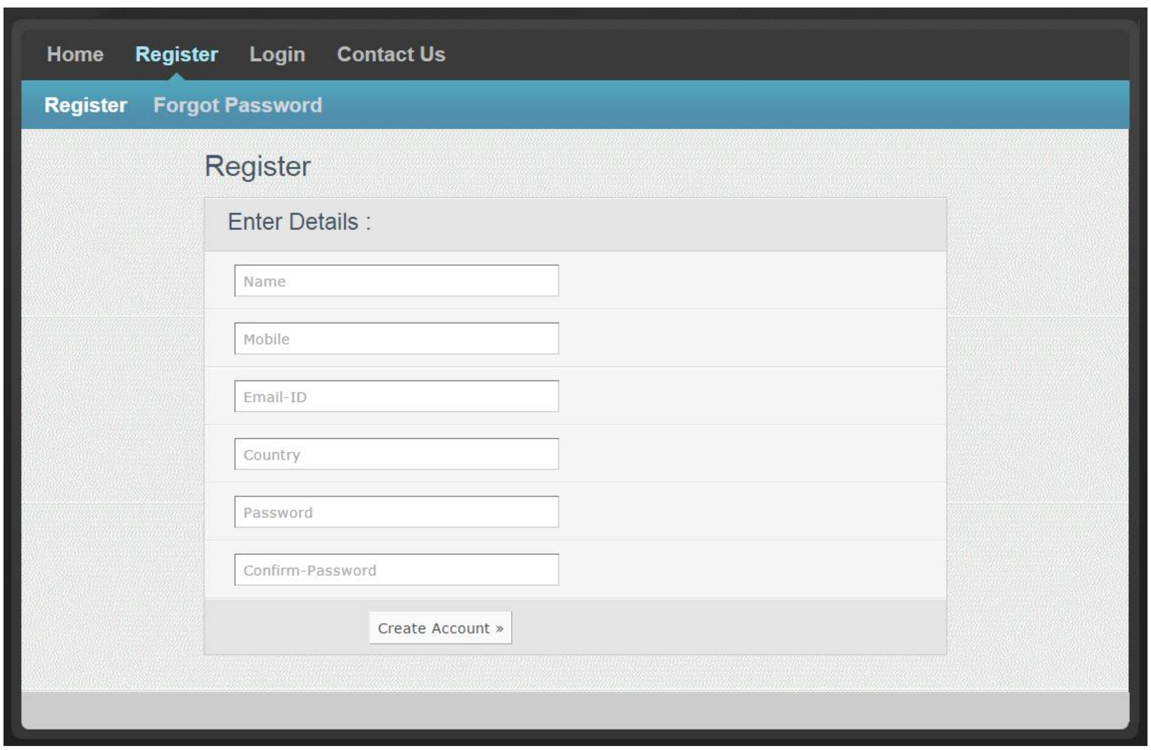


Figure 7.6: User registration form.

To track the train users are required to login in to the website. Login page is shown in Figure 7.7.

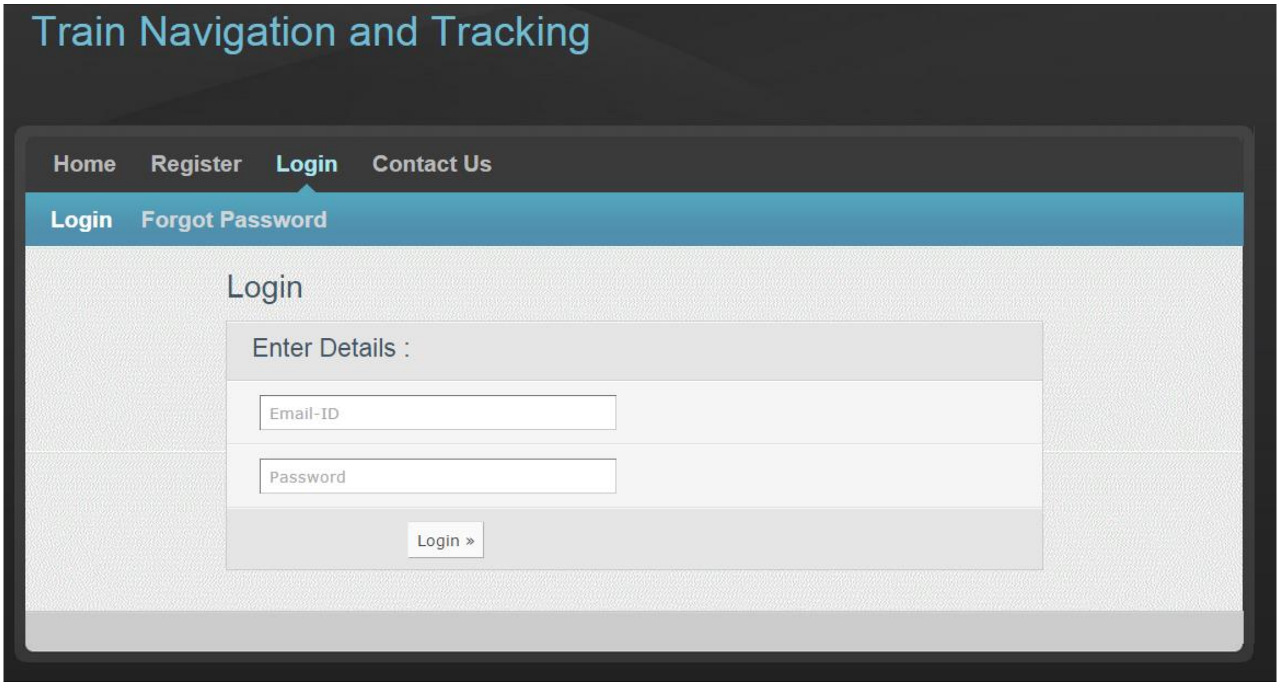


Figure 7.7: Login page.

Here are three types of user first is Administrator, second is Station Master and third is General User. Administrator can manage all users and add/edit/delete trains, Station Master can see all trains and General User can track only trains. Figure 7.8 and 7.9 shows the train list with administrator login and general login respectively.

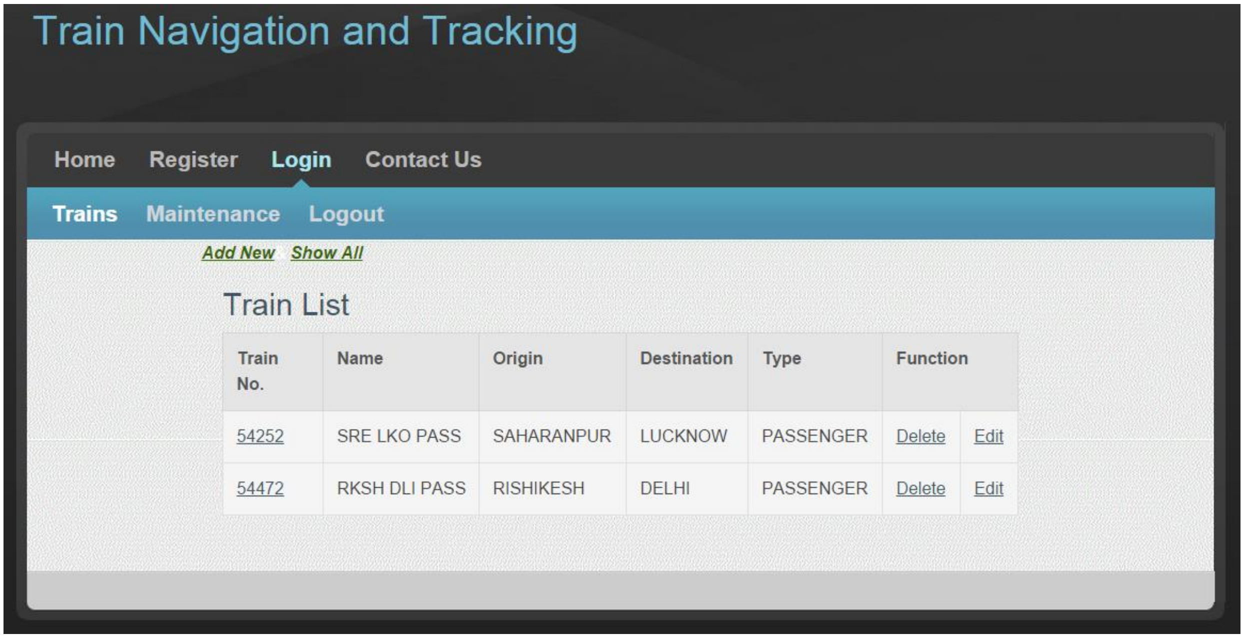


Figure 7.8: Train list with administrator login.

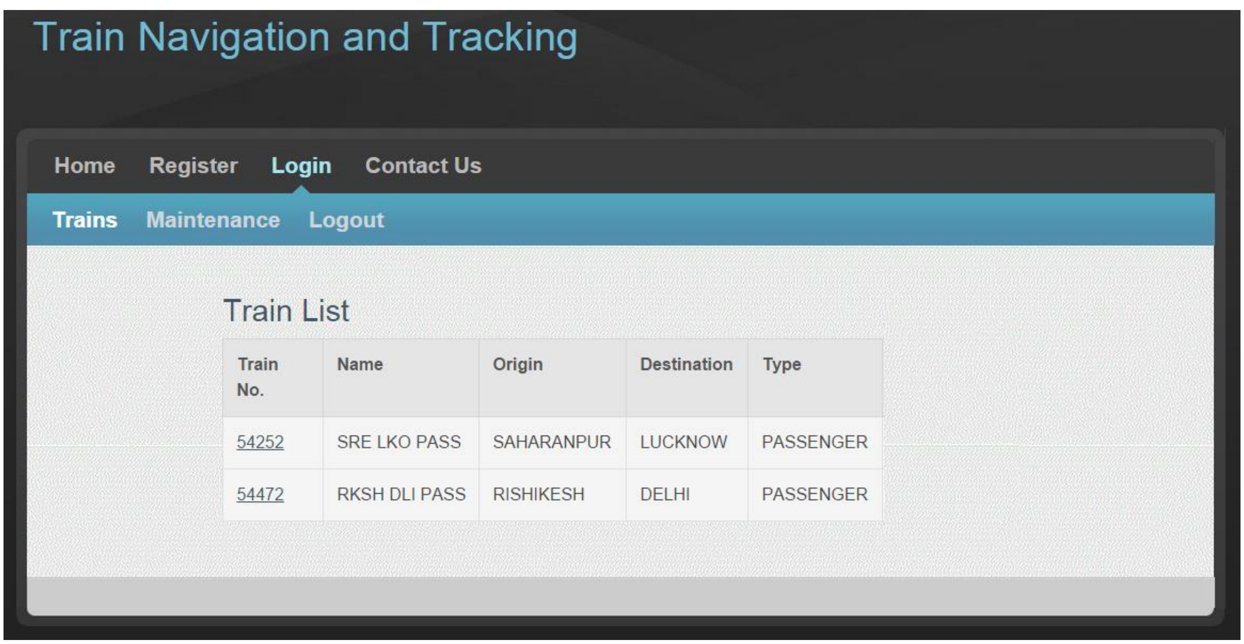


Figure 7.9: Train list with general user login.

To add a new train into train list, administrator can go to add train form by clicking on Add Train link on train list page (See Figure 7.8). Add train form is shown in figure 7.10.

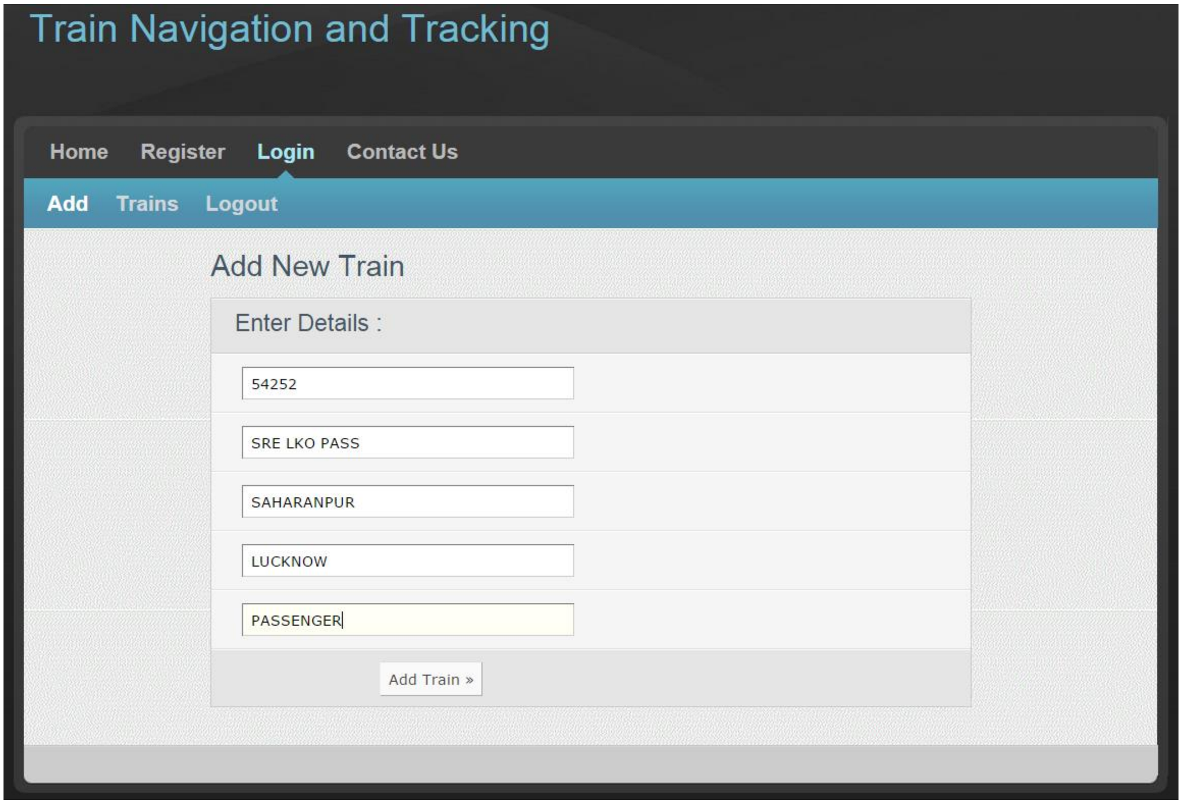


Figure 7.10: Add train form to add new train into the train list.

7.6 Results

To track the train user need to click on train number from train list (See Figure 7.8 or 7.9). General user can track only one train at a time by clicking on train number but administrator or station master can track single train or all trains at a time. A single train position and information on Google Maps is shown in Figure 7.11.

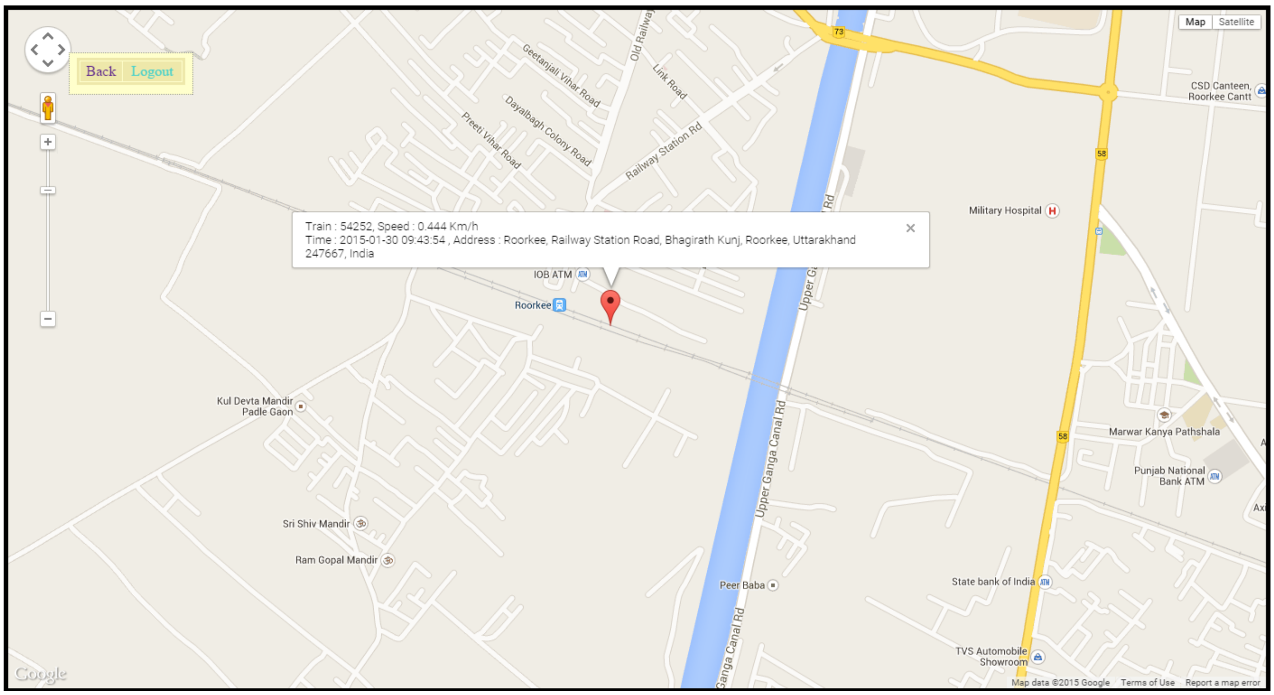


Figure 7.11: Train location and information is shown on Google Maps.

While station master is logged in, he/she can track all trains and can manage signals/level crossings. Here figures shows the results for test journey between Roorkee and Laksar Stations and different POI's are denoted by different symbols which were discussed in chapter 6 results. Figure 7.12 shows Roorkee station master window and whole study track.

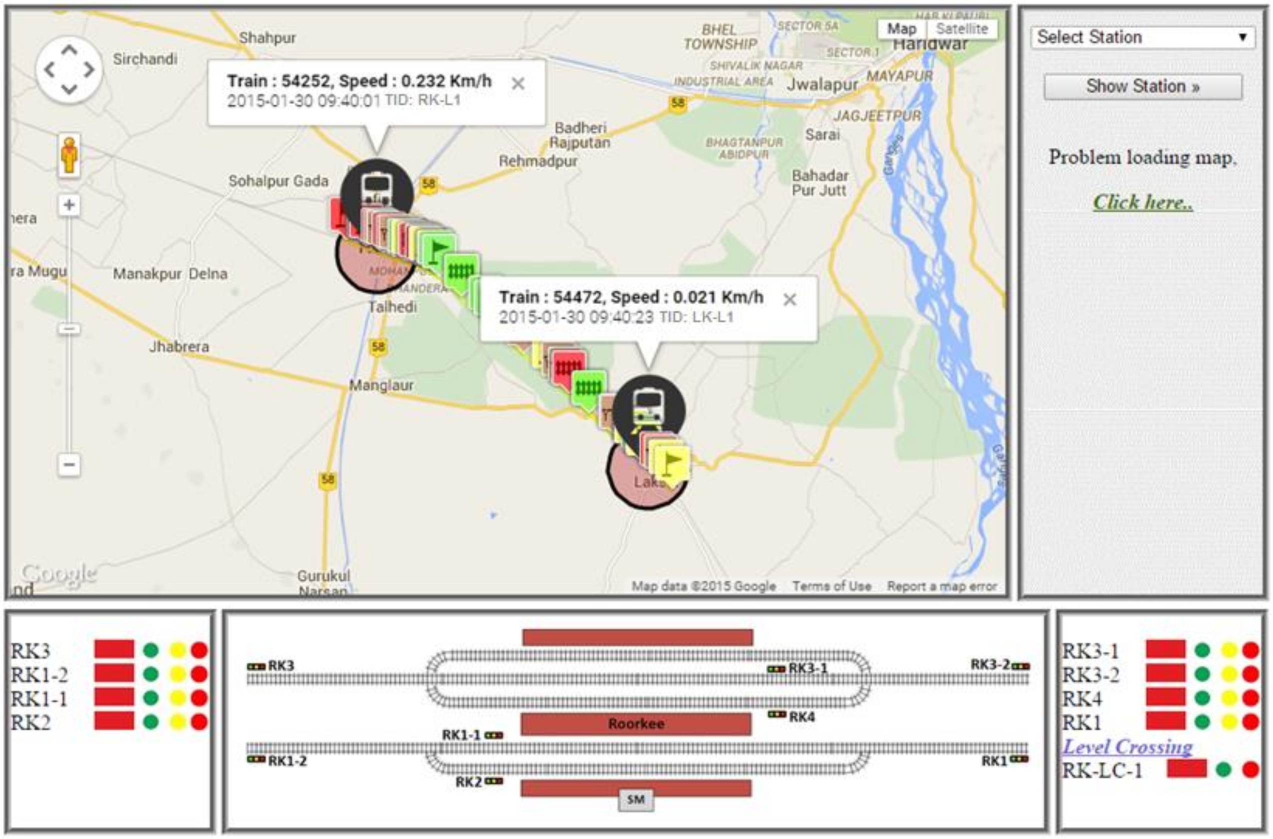


Figure 7.12: Both trains in Roorkee station master window.

RK1, RK1-1, RK1-2, RK2 etc. are signals and RK-LC-1 is level crossing, color in front of these are showing status of corresponding signal. If station master wants to change status of signals or level crossings, he/she needs to click on red, yellow or green radio button of corresponding signal.

Figure 7.13 shows when train stopped at Roorkee railway station and status of all signals are red.

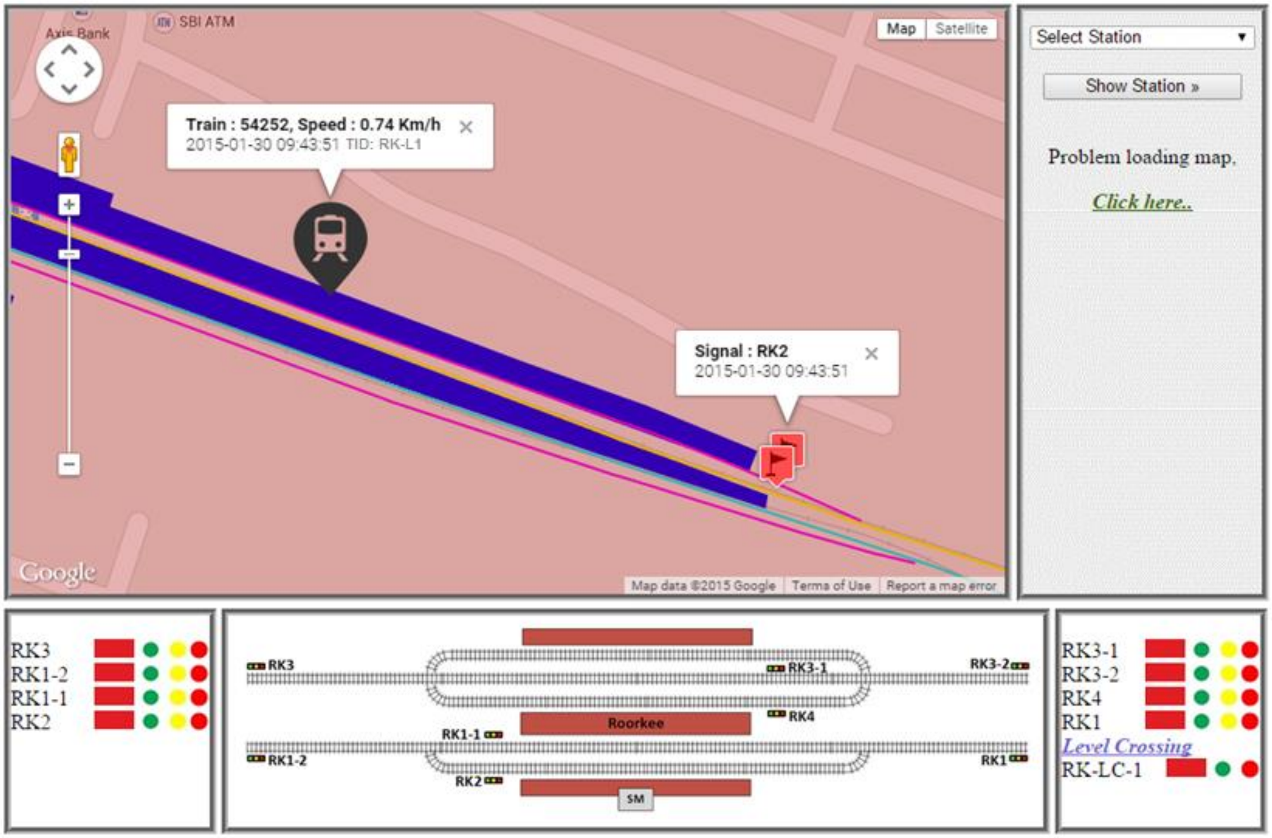


Figure 7.13: Roorkee railway station plan for station master and train at station.

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Train was on that track which was controlled by signal RK2. Figure 7.14 shows that signal RK2 status changed to yellow and trains moved under caution speed. Green signals RK3, RK3-1 and RK3-2 shows another train is entering to station on different track.

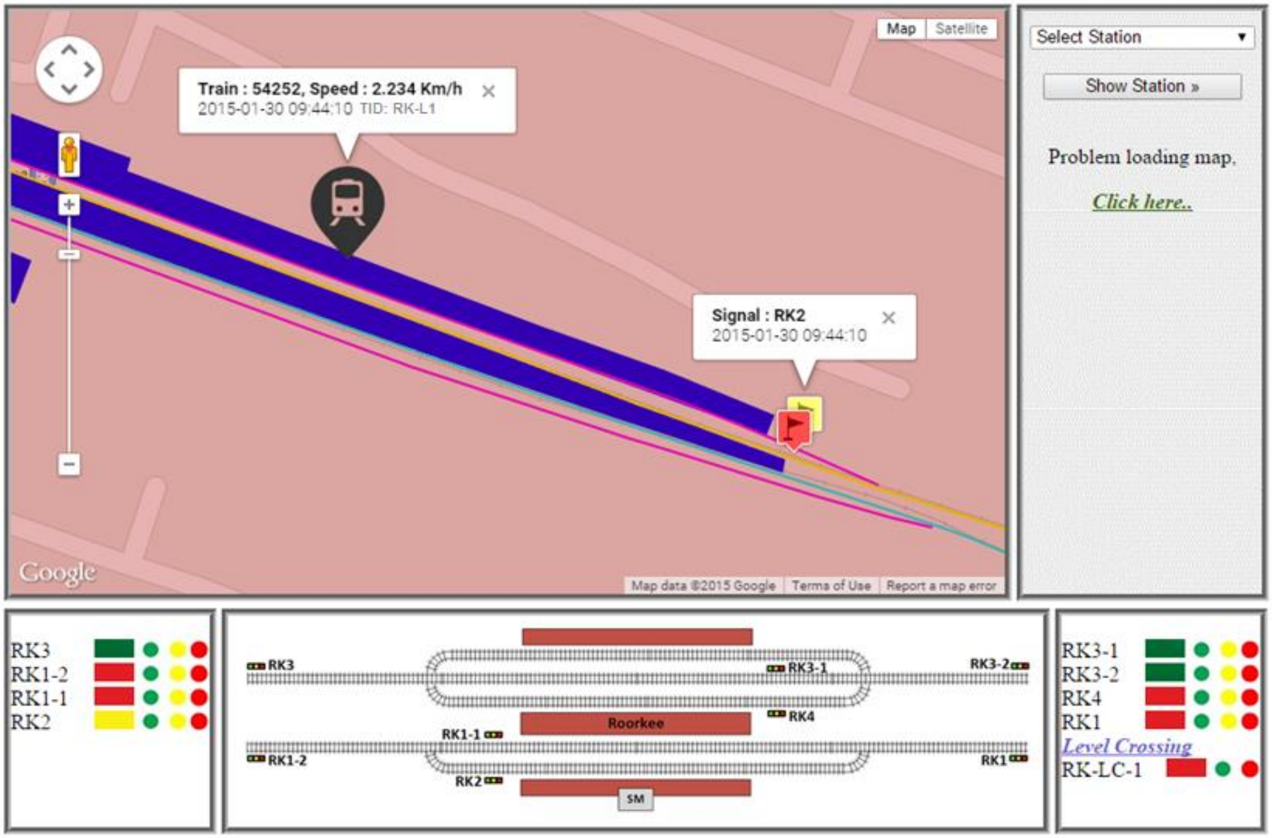

Figure 7.14: After changing signal RK2 color to yellow.

Figure 7.15 shows status of signal RK1-2 is green and train is moving with normal speed.

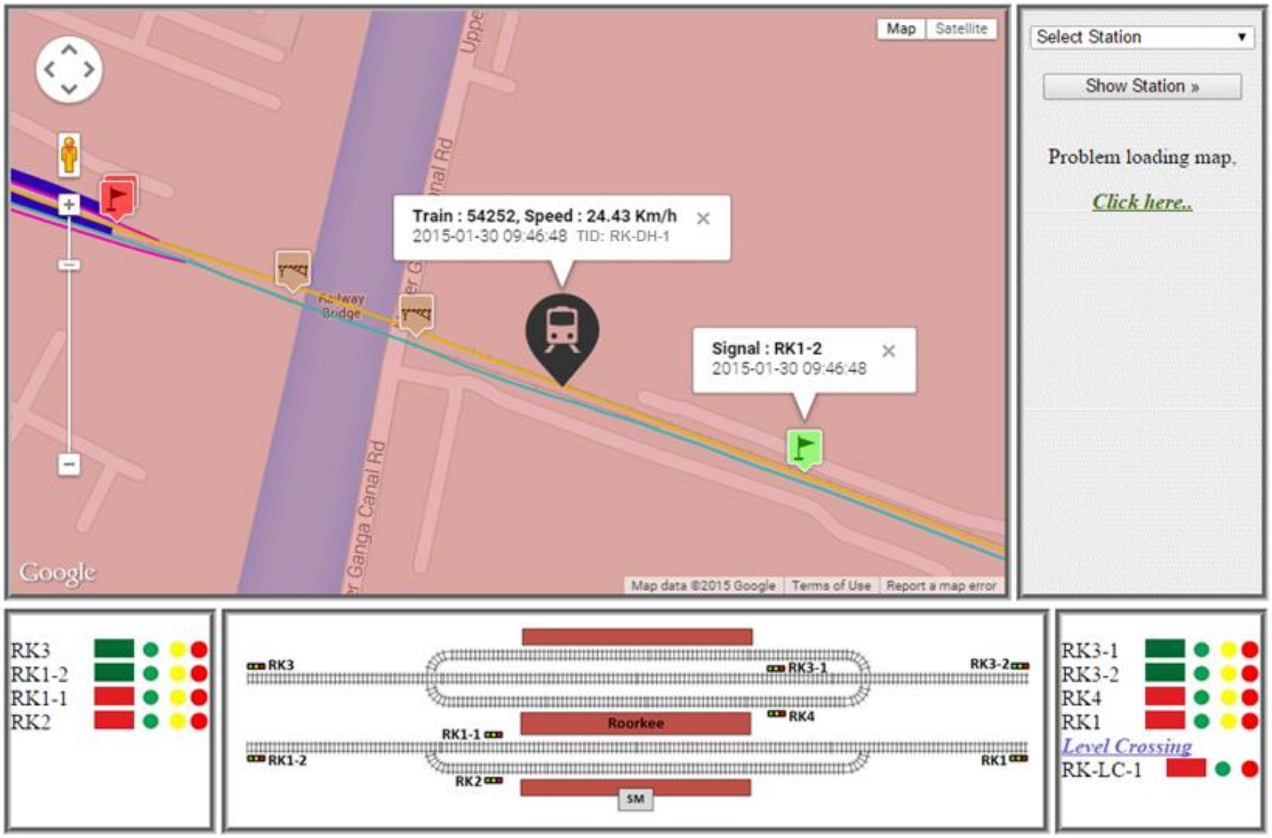

Figure 7.15: After changing signal RK1-2 color to green.

Figure 7.16 shows status of a level crossing while train was approaching to that near Dhandera station and status of that level crossing (DH-LC-1) was green, it means the level crossing was closed for road traffic.

Figure 7.16: While train was approaching to level crossing DH-LC-1.

Figure 7.17 shows train when it was at Dhandera station and status of signal shows that another train was passing through another track.

Figure 7.17: Train at Dhandera station.

Train leaving Dhandera station is shown in figure 7.18.

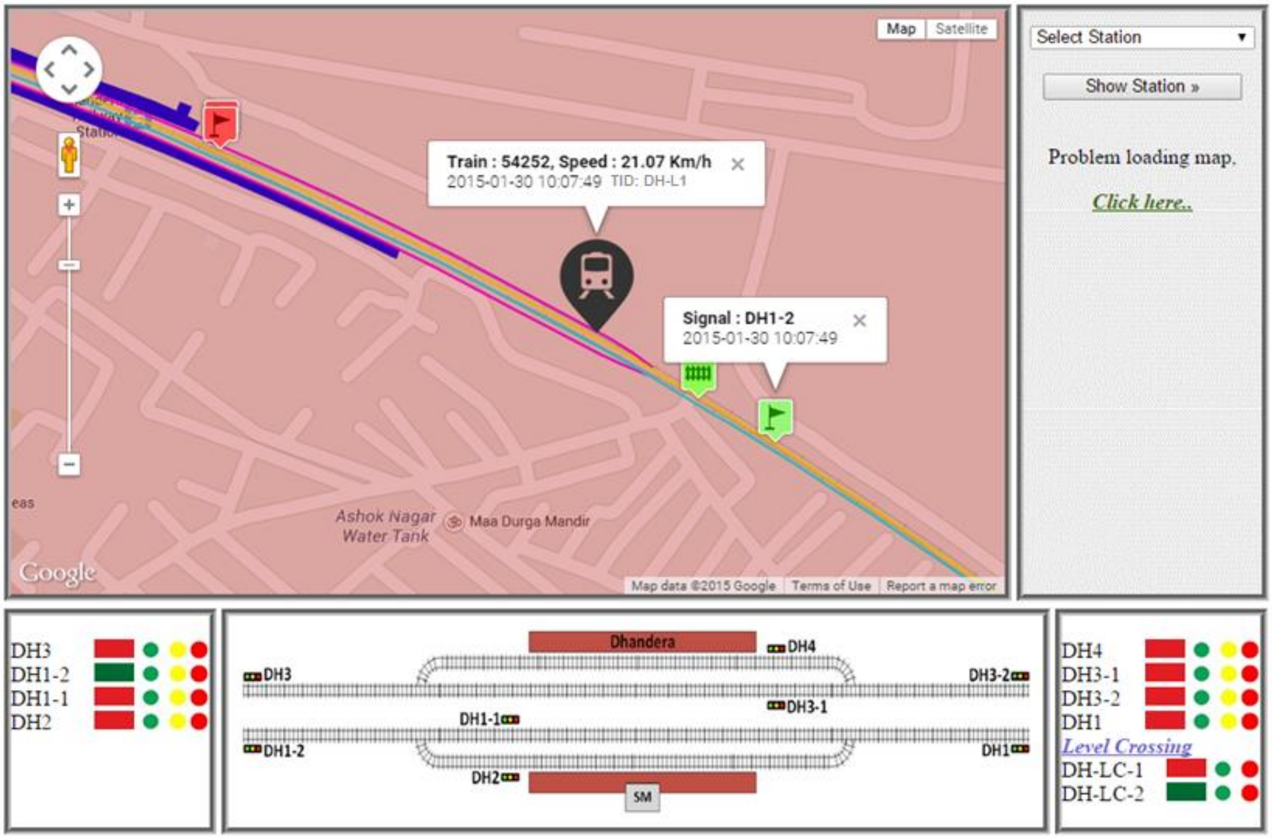

Figure 7.18: Train leaving Dhandera station.

Figure 7.19 shows speed of the train 92.78 km/h between Dhandera and Landhaura station.

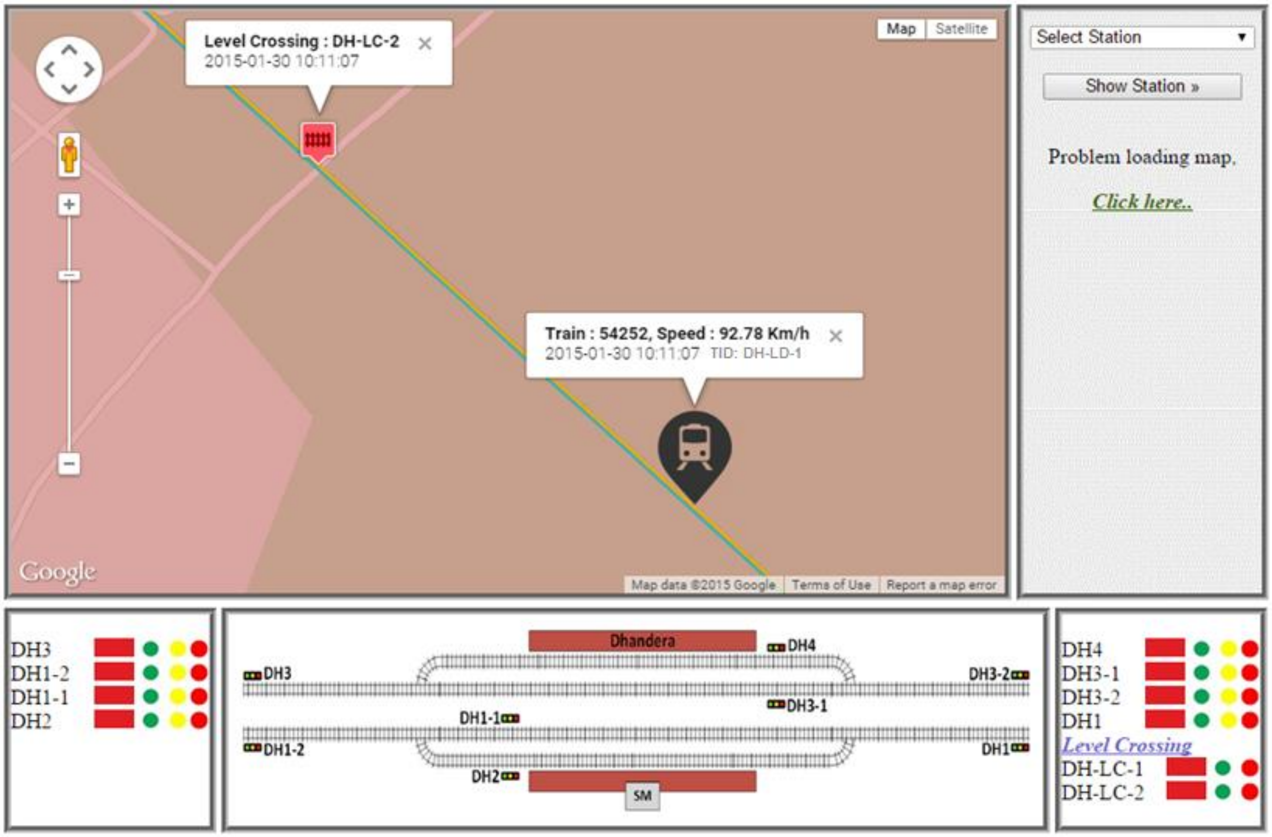

Figure 7.19: Train between Dhandera and Landhaura station.

Train at Landhura is shown in figure 7.20.

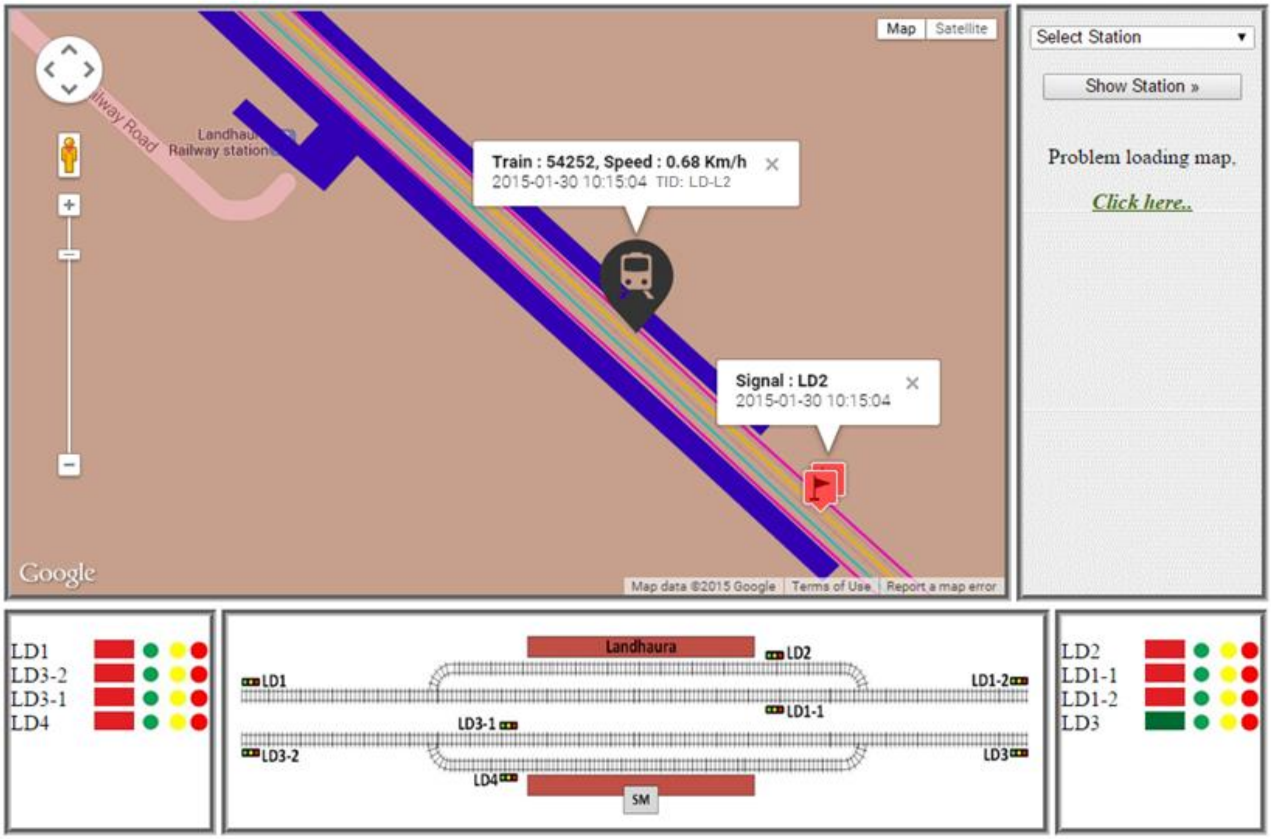

Figure 7.20: Train at Landhaura station.

Figure 7.21 shows that buffer of two trains is intersecting with each other when both trains are approaching to each other.

Figure 7.21: Trains approaching to each other between Landhaura and Laksar station.

7.7 Conclusion

This chapter describes the developed Web Based Train Navigation and Tracking System and illustrates potential of Web Technology in Railway. Web technology is widely used in various industries and railway industry is one of them which is taking benefits by this technology. In India, IRCTC Online Ticket Reservation System is the biggest example of implementation of Web Technology in Indian railway. Other Web based systems like Railway Risk Assessment Information Management System, Decision Support System and web GIS are used by various countries. The developed system consists, Remote GNSS Device (Knowledge Based Train Operator Module), Communication Network (GSM/GPRS), Central Server and Users. Three types of users (Administrator, Station Master and General User) can use this system. Administrator can manage whole website (Add/Edit/Delete Users/Trains) and can control trains, Station Master can see location of single/all trains with station layout and can control trains by changing status of signals and General Users can only see the location of selected train. Results of this system shows the behavior of trains at various POI's with status of signals and LC between Roorkee and Laksar Railway Station.

Chapter 8

Trip Navigation and Analysis System

8.1 Introduction

In this chapter, developed trip navigation and analysis system is illustrated. GNSS Navigation systems become more common now. Many organizations and people have now equipped vehicle with a GNSS device that continuously track the location of vehicle. GNSS is used to get location information for navigation. Section 8.2 describes the Trip Navigation and Analysis System. Architecture and development of the system is illustrated in section 8.3. In section 8.4, features of developed system is described. Requirements of this system are discussed in section 8.5 and at last in section 8.6, results are illustrated.

8.2 Trip Navigation and Analysis System (TNAS)

A system which aids in navigation, called navigation system. Navigation systems may be entirely on board a vehicle or they may be located elsewhere and communicate via radio or other signals with a vehicle (Navigation System, 2014). Currently GNSS based navigation systems are becoming more common (Kray and Kortuem, 2005). GNSS is already described in chapter 3.

India is a developing nation and people can appreciate the technology if cost effectiveness is followed. In the current scenario GNSS information cannot be analyzed in a way that it can be customized. In the current work GNSS information is customize in respect of Latitude, Longitude, and Elevation etc. in real time, therefore to minimize the gap of GPS information customization and analysis can be rectified in current work.

TNAS is a user interface for real time GPS data. In this system Google earth API is used to plot the position of GPS.

In this system user can navigate along with a provision of recording the trip in terms of GNSS data for a predefined time interval. A GNSS receiver is connected to laptop by Bluetooth. When GNSS receiver receives location information, it plot on Google earth and save it in a file. After the completion user can analyze the trip.

Trip analysis has three options:

- Halt Locations.
- Track.
- Speed vs. Clock time Graph.

On clicking Halt Locations button, it shows locations on Google earth where vehicle speed was below a threshold speed. On clicking Show Track button, it shows the selected trip on Google earth. On moving cursor over the graph, corresponding speed and location will be shown on the Google earth.

8.3 Architecture and Development

8.3.1 Architecture

Architecture of the system defines structure and precise mechanism which is used. Architecture is shown in figure 8.1 and divided into two segments:

8.3.1.1 Navigation and Data Logging Interface:

In this navigation process and communication between GNSS receiver and computer is defined. After establishment of communication the developed application gets NMEA data and process that for extracting location information, this information is logged into a defined file for further uses. Real time navigation is achieved by Google Earth API and shown on integrated Google Earth.

8.3.1.2 Analysis Interface

This interface defines the analysis process of logged data into tabular form and graph form. Analysis interface uses a native file handler to read data from logged file. After reading it generate result into tabular form and interactive graph form. Table shows position information, halt location, halt time etc. and the interactive graph shows the speed at a particular time. If user move curser over the graph the corresponding position is shown on integrated Google Earth.

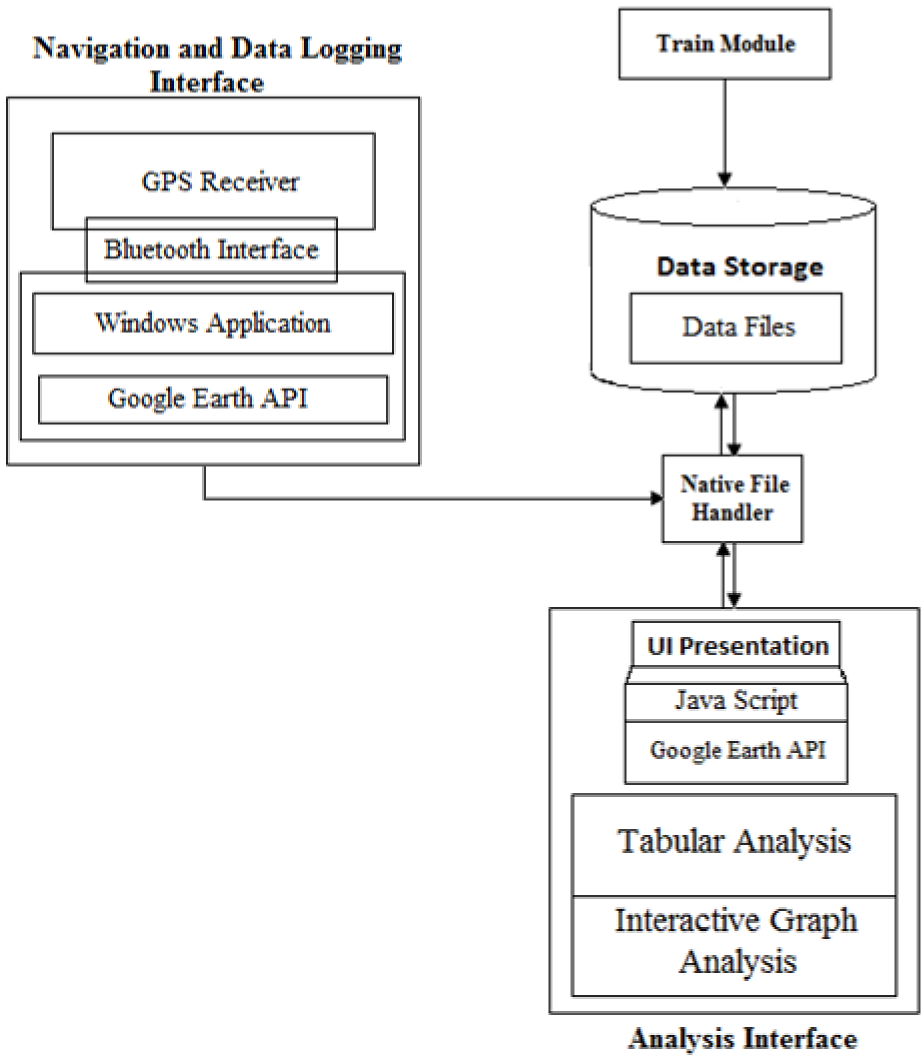

Figure 8.1: TNAS architecture.

8.3.2 Development

The system is window based and developed in VB.Net with integration of Google Earth API for background map. VB.Net is a multi-paradigm, high level programming language, implemented on the .Net Framework. Google Earth API enables developer to embed Google Earth applications into web pages with JavaScript code. With Google Earth API plug-in installed, these applications can run interactively in web browser. API can display place marks, lines, polygons, overlays, and 3D models on the imagery, just as standalone versions of Google Earth can. Plug-in supports several of the Google Earth layers, including terrain, roads, borders, and buildings.

The system consist of four panels: Record Trip, GPS Data, Trip Information, and Navigation on basic user interface (See figure 8.2). IIT Roorkee main building is the default location for Navigation panel, when user runs TNAS first time, Google earth is loaded with default location in Navigation panel. Function of above four panels are as follows:

Navigation: This panel shows real time location of vehicle on Google earth.

Record Trip: In this panel name can be setup for trip, user can select com port on which GNSS receiver is connected and then connect application with GNSS receiver for recording the data. In the end of trip disconnect GNSS receiver from system then it will auto save the trip.

GPS Data: When GNSS receiver is connected to application, text box shows real time GNSS data in NMEA format. Extracted information Latitude, Longitude, Speed, Elevation, Number of satellites and GPS Time in GMT format shown below the text box.

Trip Information: This panel shows trip information in tabular form. User can open recorded file then table shows time on which vehicle was not moving, Halt Time, Latitude, Longitude and Elevation when vehicle speed was below a threshold speed.

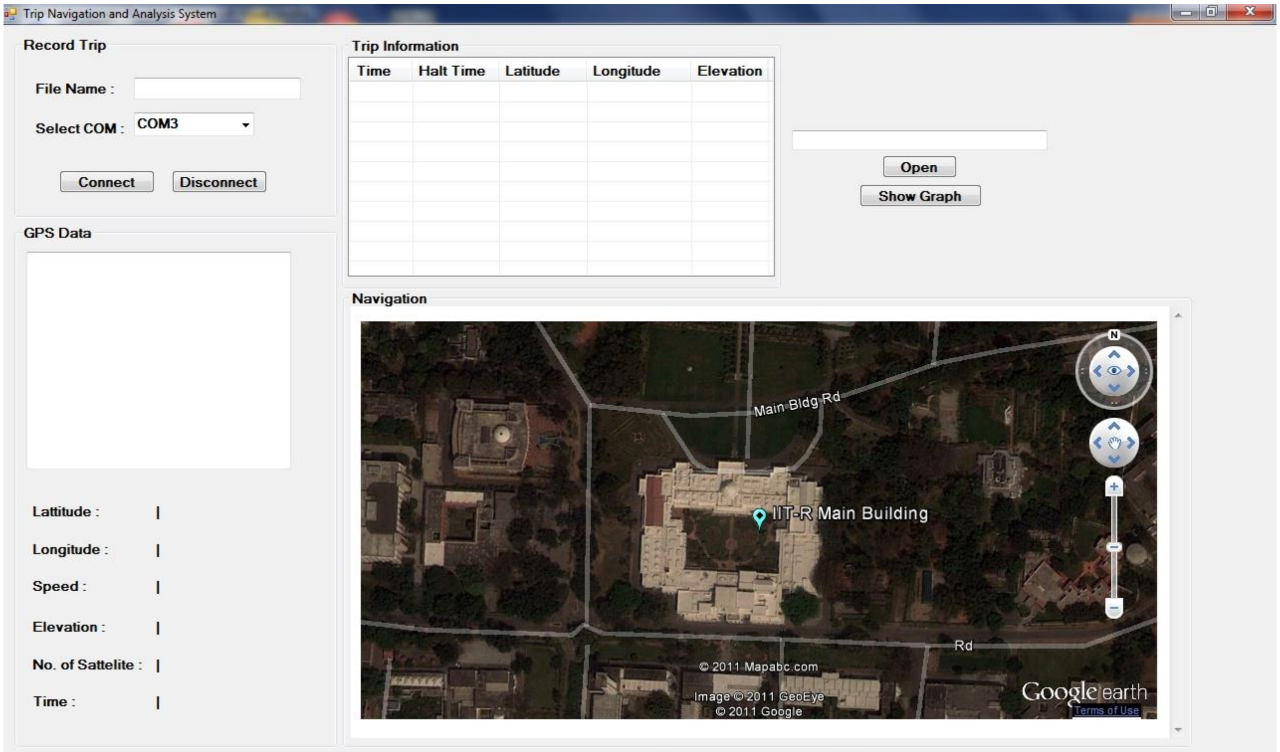

Figure 8.2: Basic user interface of TNAS.

8.4 Features

Biggest advantage of TNAS is cable free convenience. Bluetooth wireless technology provides a cable-free connection between receiver and field computer, no more snagging cables when moving through difficult terrain or getting in and out of a vehicle. Main features of TNAS are as follows:

- Vehicle navigation on Google earth.
- User can record trip.
- User can analyze trip in tabular form.
- User can analyze trip in Speed vs. Clock time graph.
- Wireless communication between GNSS and laptop.
- Shows halt locations on Google earth.
- Show trip on Google earth.

8.5 Hardware and Software Requirements

Basic hardware and software requirements of system are as follows:

- Bluetooth enabled laptop.
- Bluetooth enabled GNSS receiver.
- Internet (for navigation only).
- Operating System: Windows XP/ Windows 7.
- .Net framework 3.5 or more.

8.6 Results

To setup application for navigation and record a car trip, following steps should be performed:

- Enter Trip Name.
- Select COM Port.
- Press connect button.
- Enter passcode to connect Bluetooth GPS.

Bluetooth wireless technology provides a cable-free connection between receiver and field computer, no more snagging cables when moving through difficult terrain or getting in and out of a vehicle.

After performing the above steps the application is ready to navigate and record the trip information. GPS Data panel shows the real time location information in terms of Latitude, Longitude, Speed, Elevation, No. of Satellite and Time in UTC format. This panel also shows real time NMEA data also.

If user wants to analyze a train trip, user need to download train data from the central server into a text file which can be open into TNAS to analyze train trip.

Enter the trip name and select COM port on which GNSS receiver is connected (See figure 8.3).

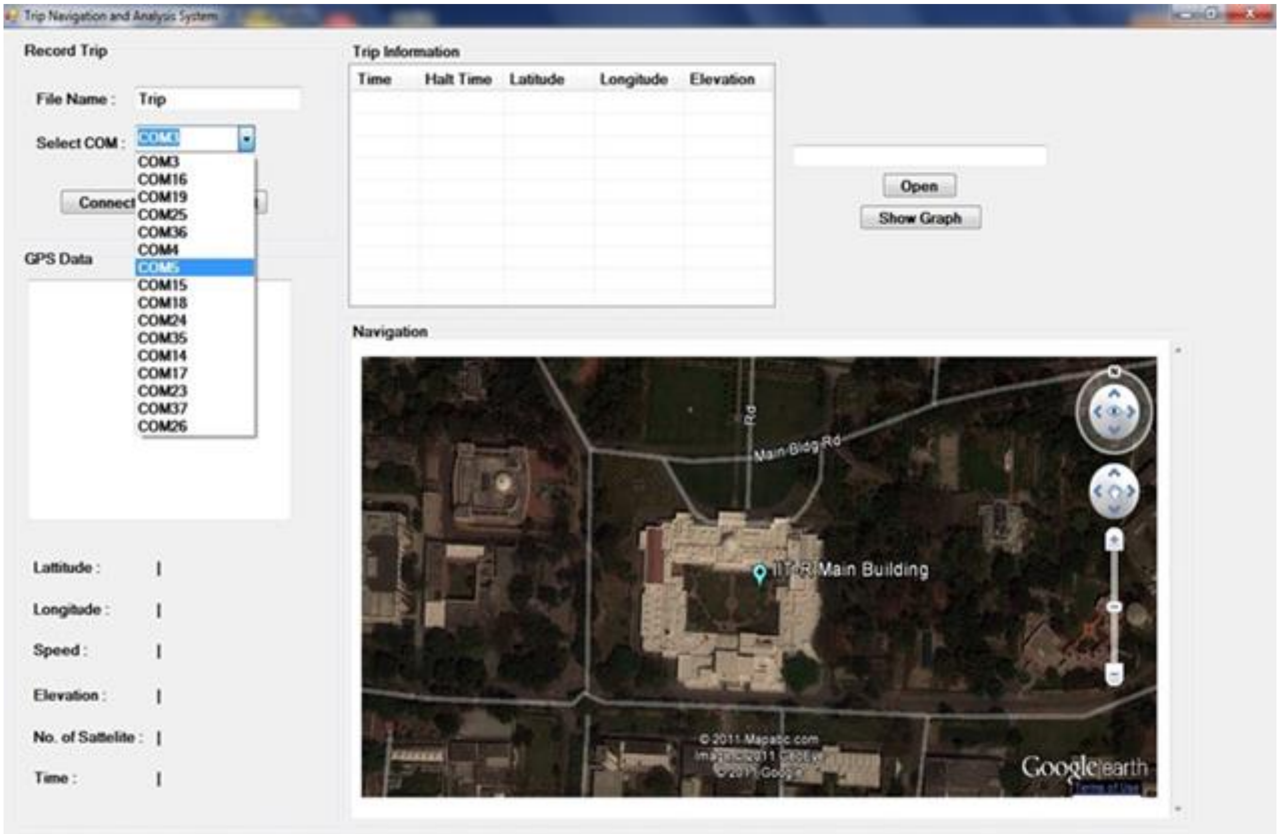

Figure 8.3: Selecting COM port and enter trip name.

Enter device passcode to establish the communication link between Bluetooth GNSS receiver and TNAS (See figure 8.4).

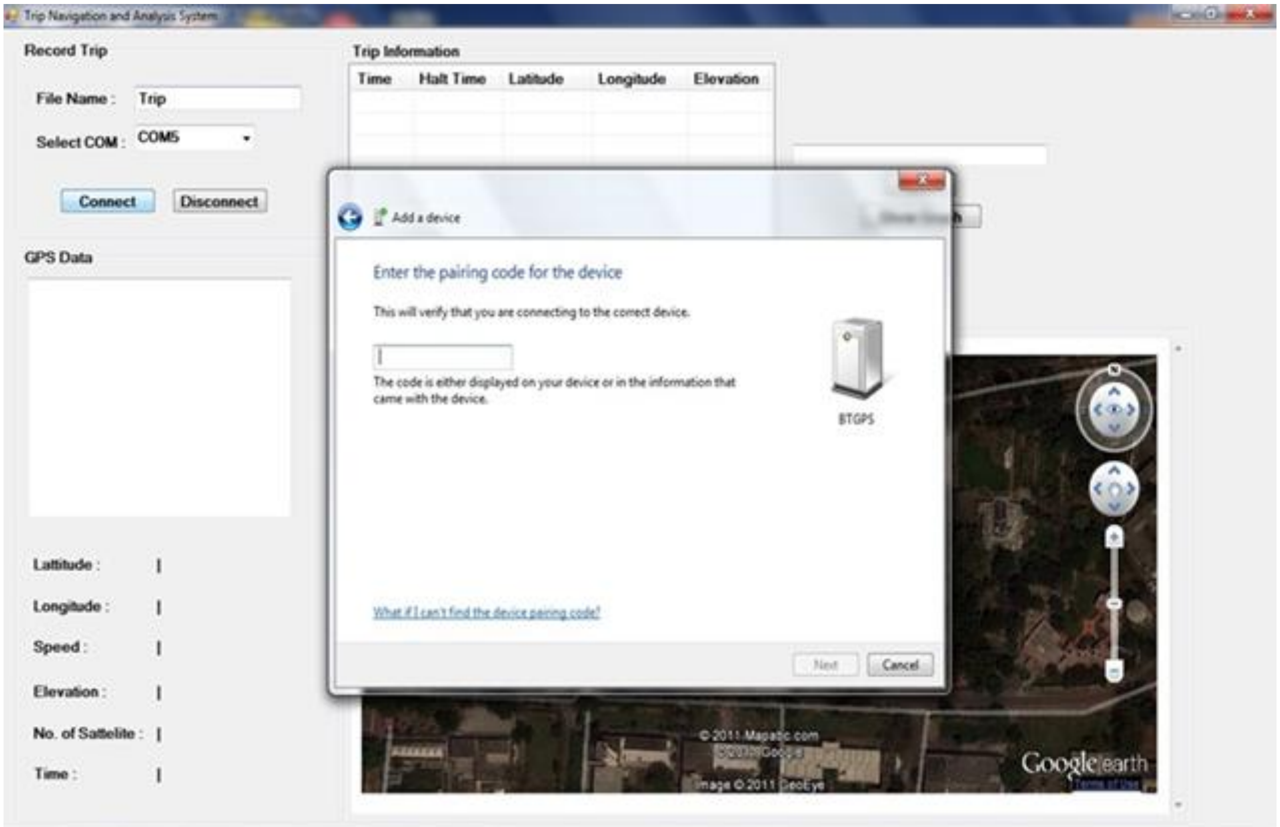

Figure 8.4: Required passcode to connect GNSS receiver with application.

A message will be popped up when GPS is connected and retrieve location information (See figure 8.5).

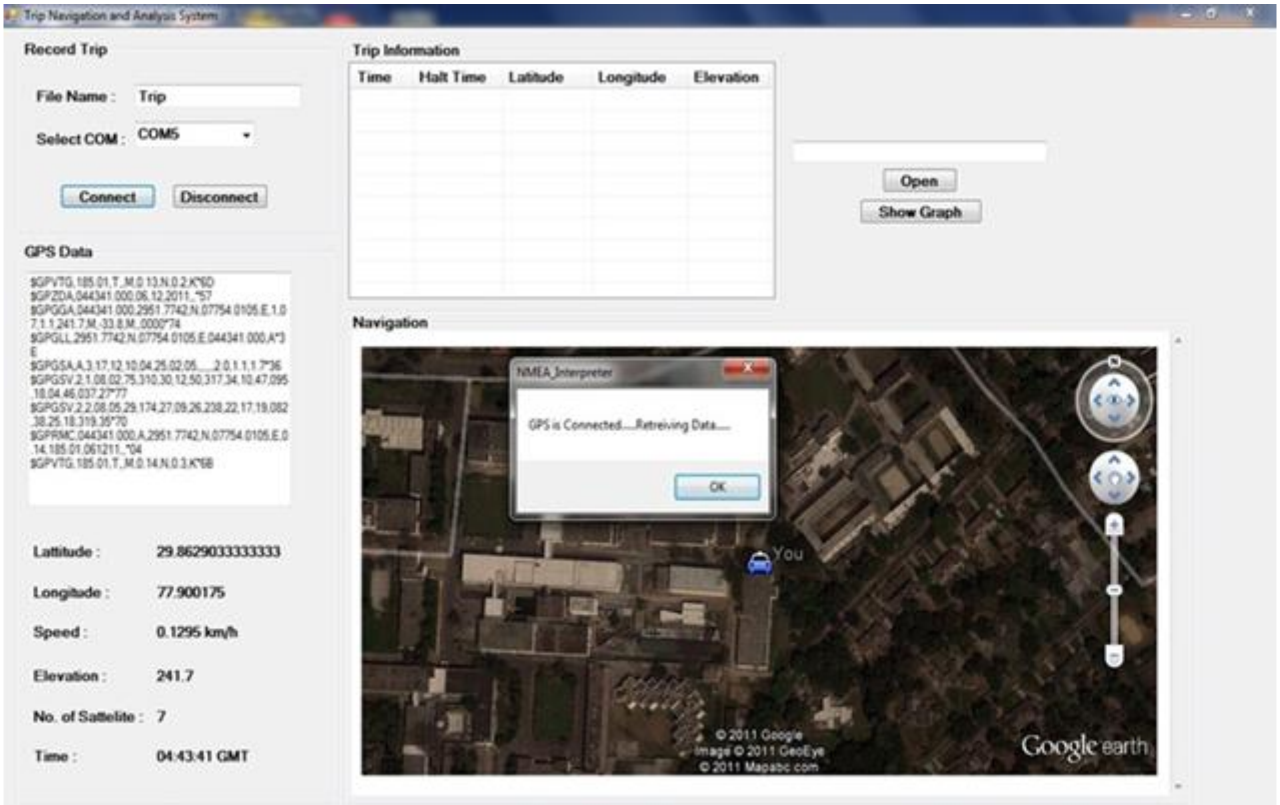

Figure 8.5: Application is connected with GNSS receiver.

After connecting with GPS, real time location of vehicle will be shown on Google earth and start trip recording (See figure 8.6).

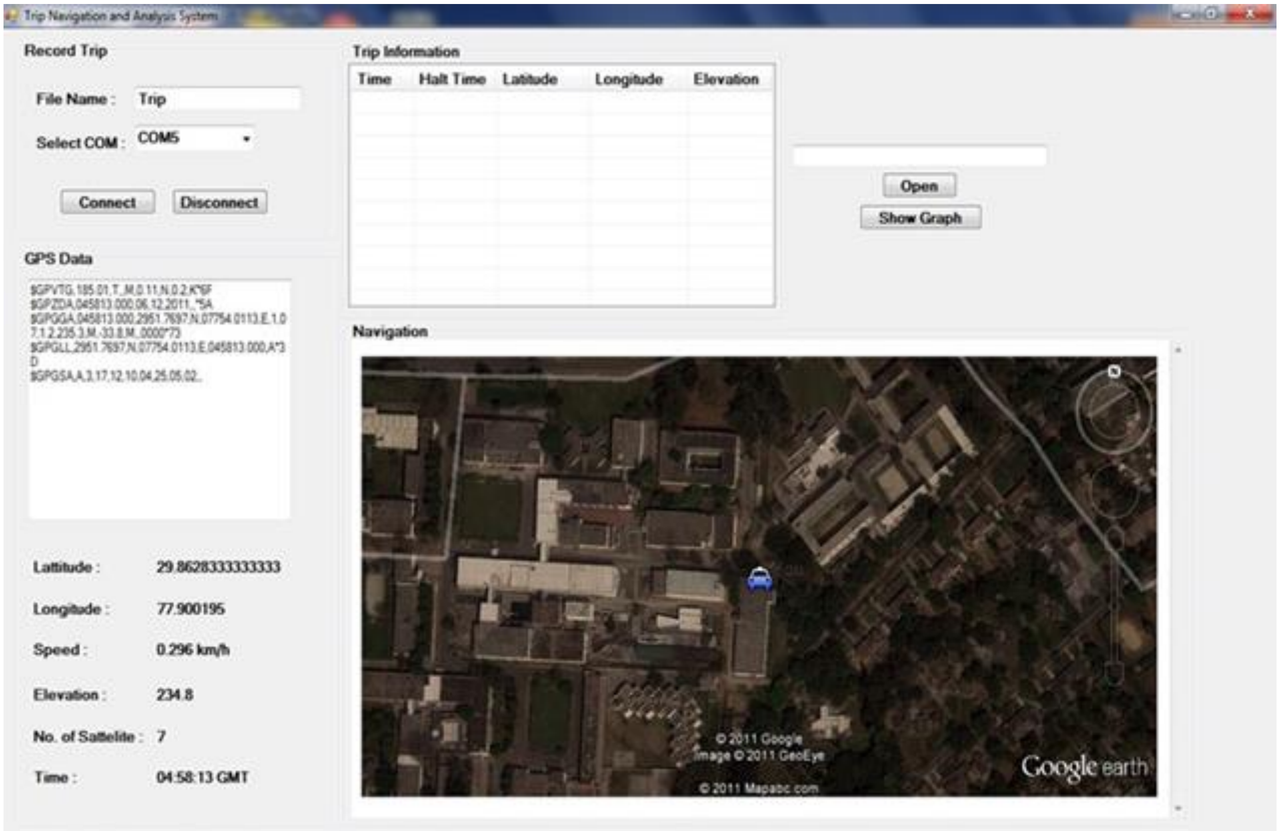

Figure 8.6: Real time vehicle location on Google Earth.

In the end of trip, press disconnect button to stop recording. A message popped up on screen and trip will save automatically (See figure 8.7).

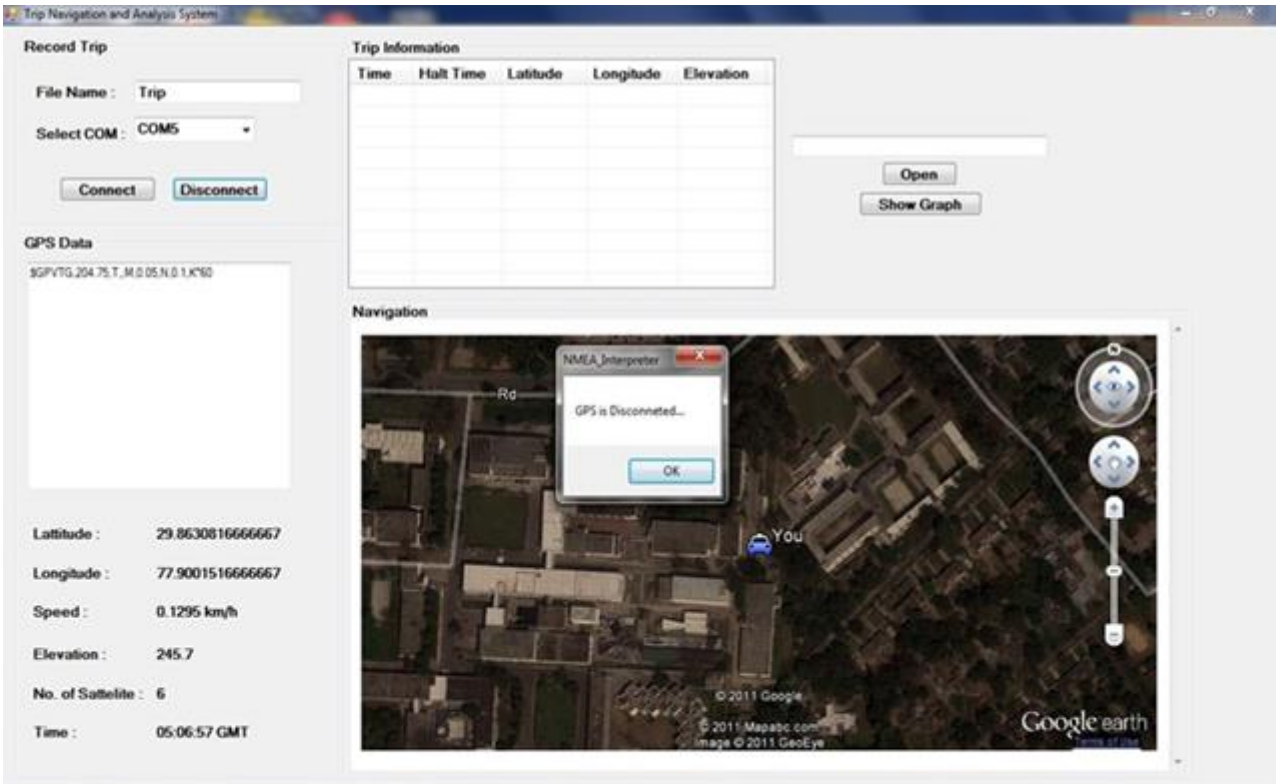

Figure 8.7: Disconnecting GNSS receiver.

User can analyze recorded trip in two modes:

- In Tabular form.
- In Graphical form.

If user wants to analyze trip in tabular form then run TNAS and open a trip file. Information regarding to congestion and halt will be shown in Trip Information table and Navigation panel shows default location.

Table shows Time, Halt Time, Latitude, Longitude and Elevation when vehicle speed was below a threshold speed (See figure 8.8a and b).

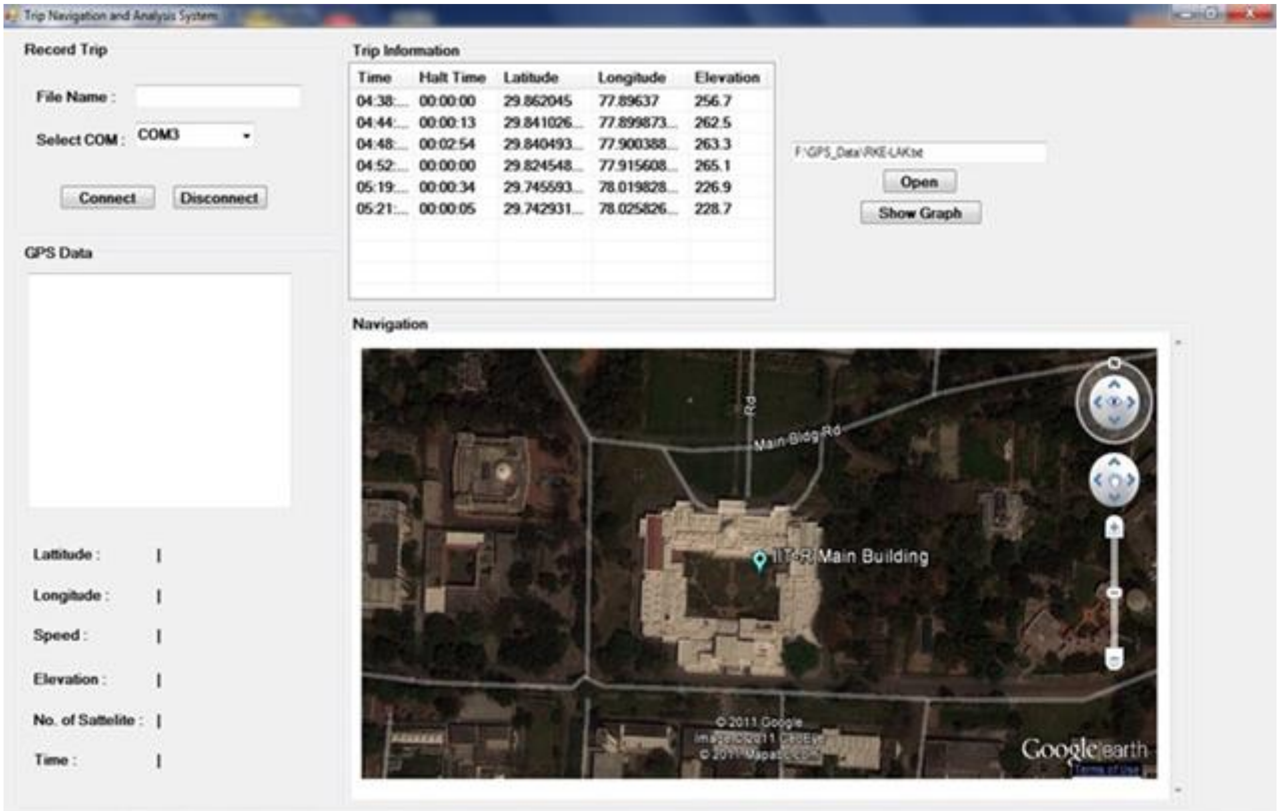

Figure 8.8 (a): Car trip information in tabular form.

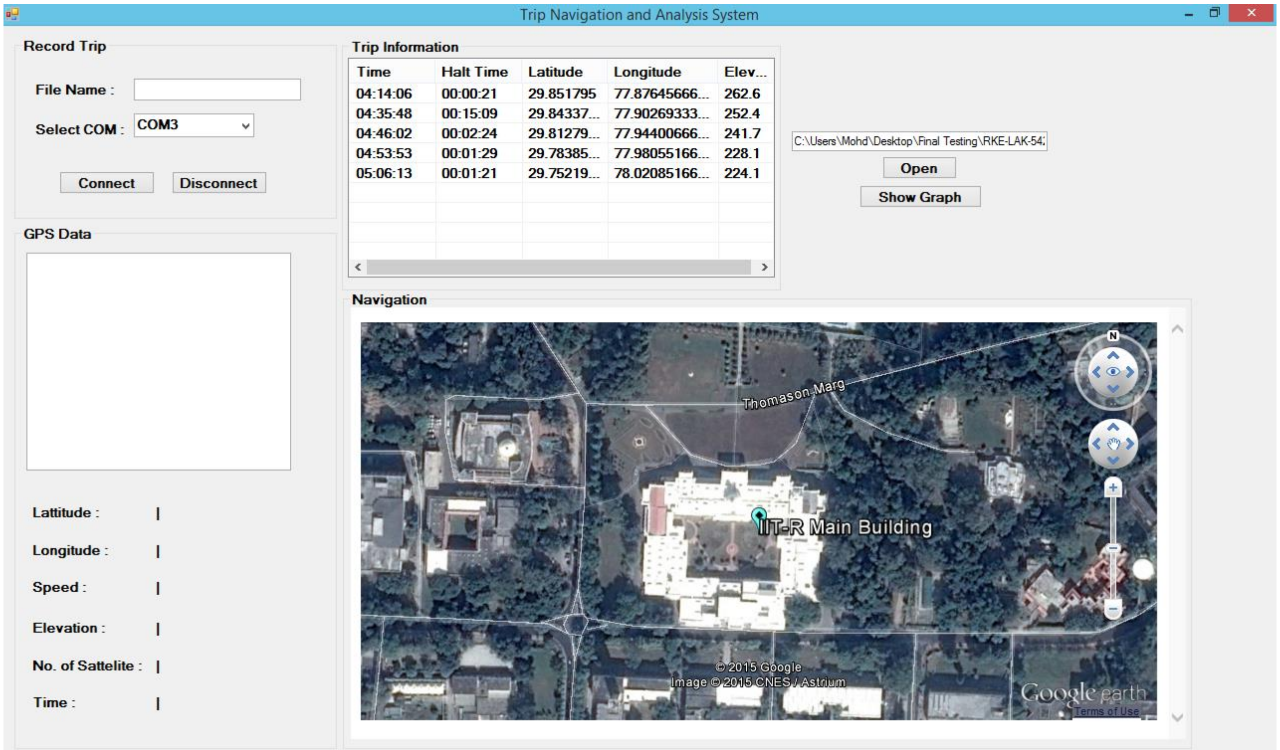

Figure 8.8 (b): Train trip information in tabular form.

If user wants to analyze trip in graphical form then open trip file and press Show Graph button. Following options are available on graph form:

- Halt Locations.
- Show Track.
- Clear Map.
- Graph.

On pressing Halt Locations button it shows the positions on Google earth where speed was below a threshold speed (See figure 8.9a and b).

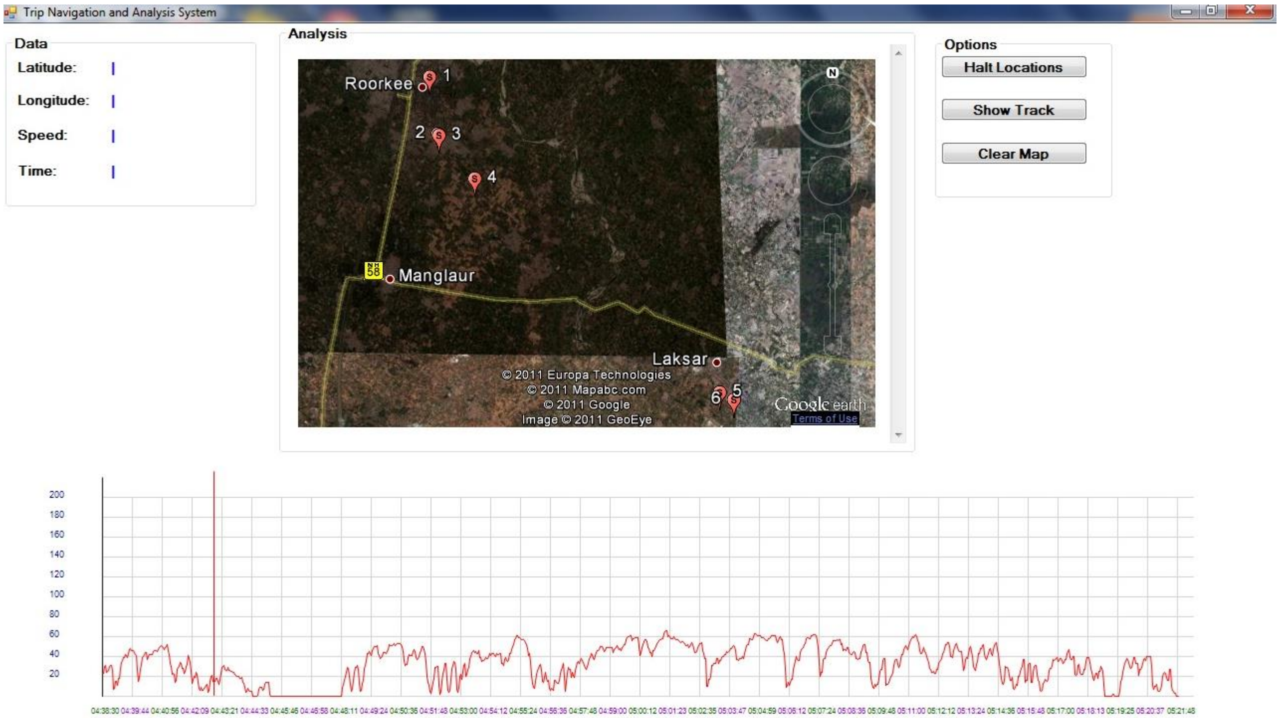

Figure 8.9 (a): Car halt locations on Google Earth.

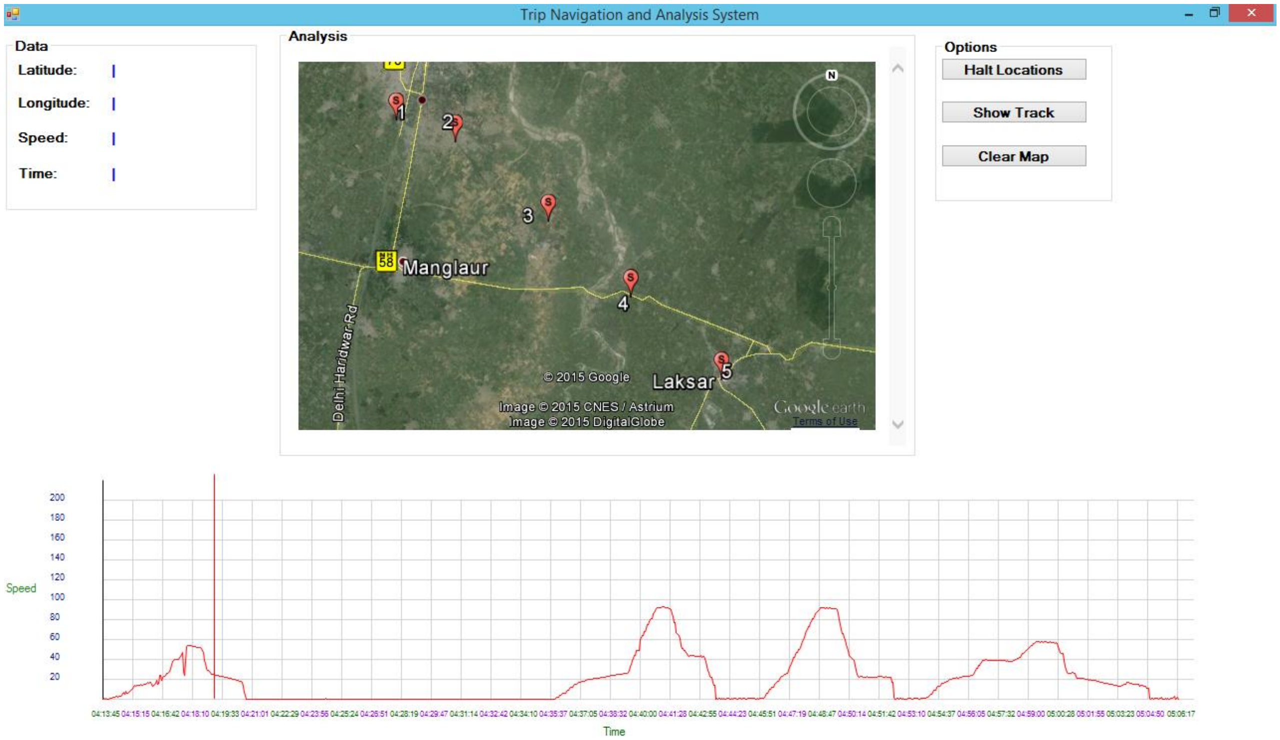

Figure 8.9 (b): Train halt locations on Google Earth.

On pressing Show Track button, it shows trip on Google Earth, red line shows the trip (See figure 8.10a and b).

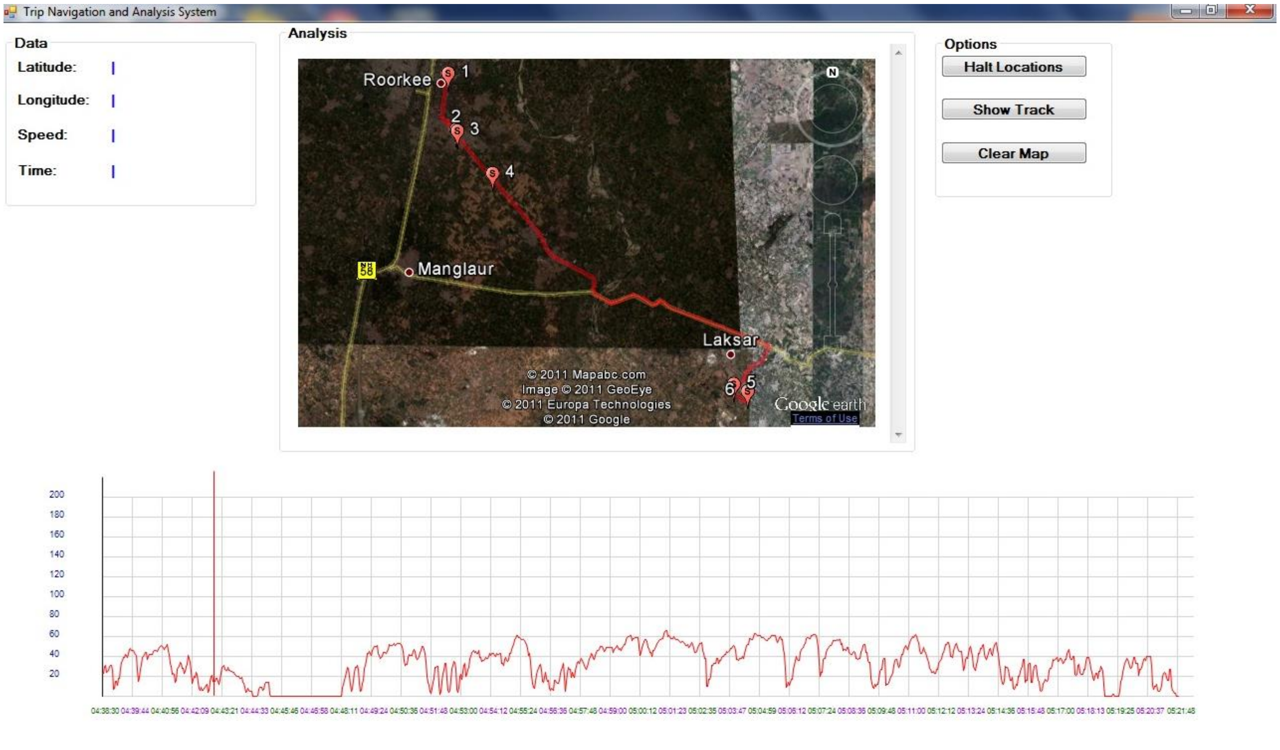

Figure 8.10 (a): Red line in Google Earth shows car trip.

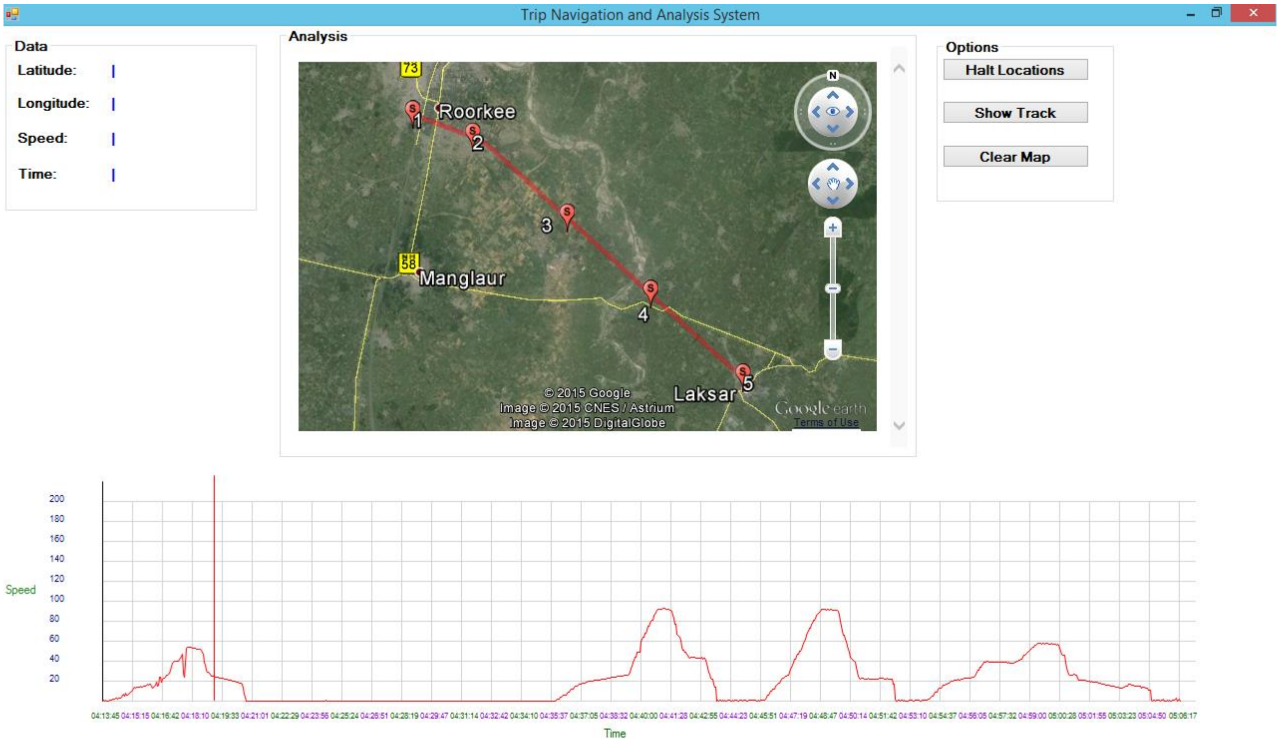

Figure 8.10 (b): Red line in Google Earth shows train trip.

On pressing Clear Map button it will reload Google earth and clear all data on Google earth.

Graph shows Speed v/s Time graph, it shows speed up to 200 km/h. When cursor moves on graph, vertical red line move along with cursor and corresponding location and speed will be shown on Google earth as well as in Data panel with additional details like Latitude, Longitude and Time in UTC (See figure 8.11a and b).

Figure 8.11 (a): Location with speed on Google Earth at time 05:01:04 UTC while cursor moving on graph of a car trip.

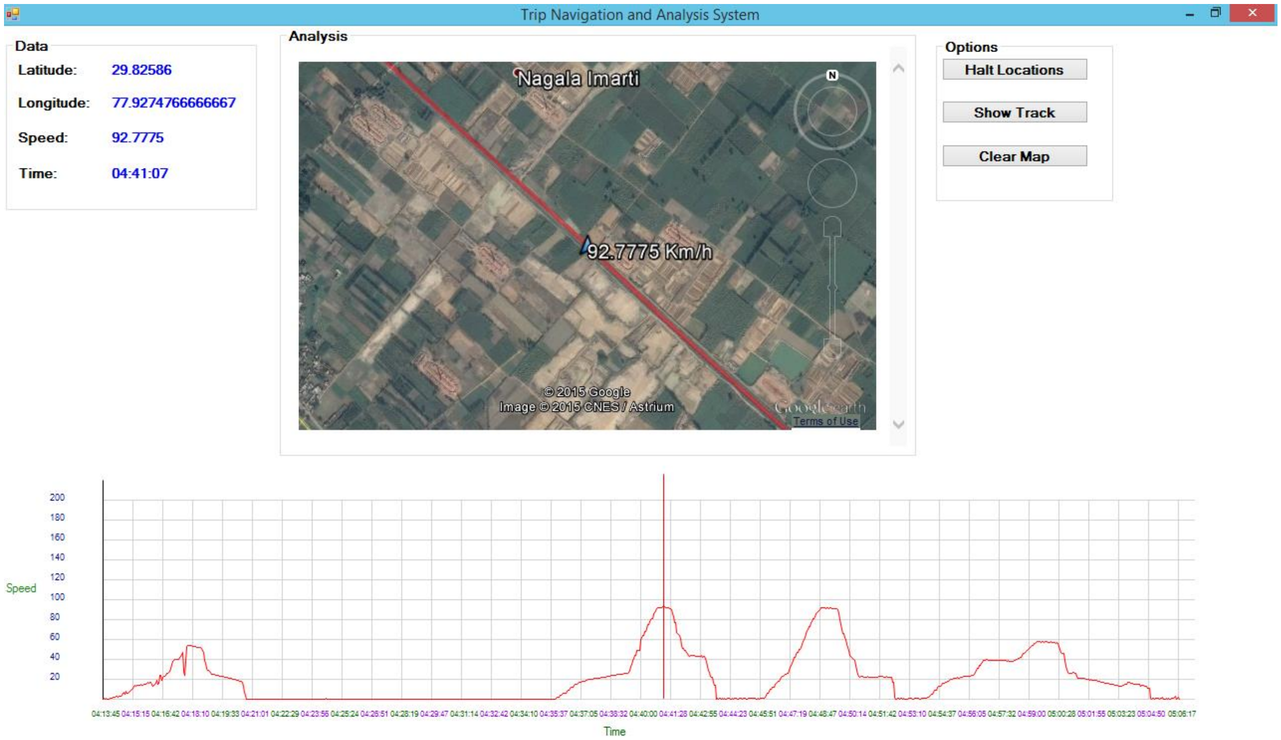

Figure 8.11 (b): Location with speed on Google Earth at time 04:41:07 UTC while cursor moving on graph of a train trip.

In figure 8.12, black circle on graph shows halt and red circle shows traffic congestion.

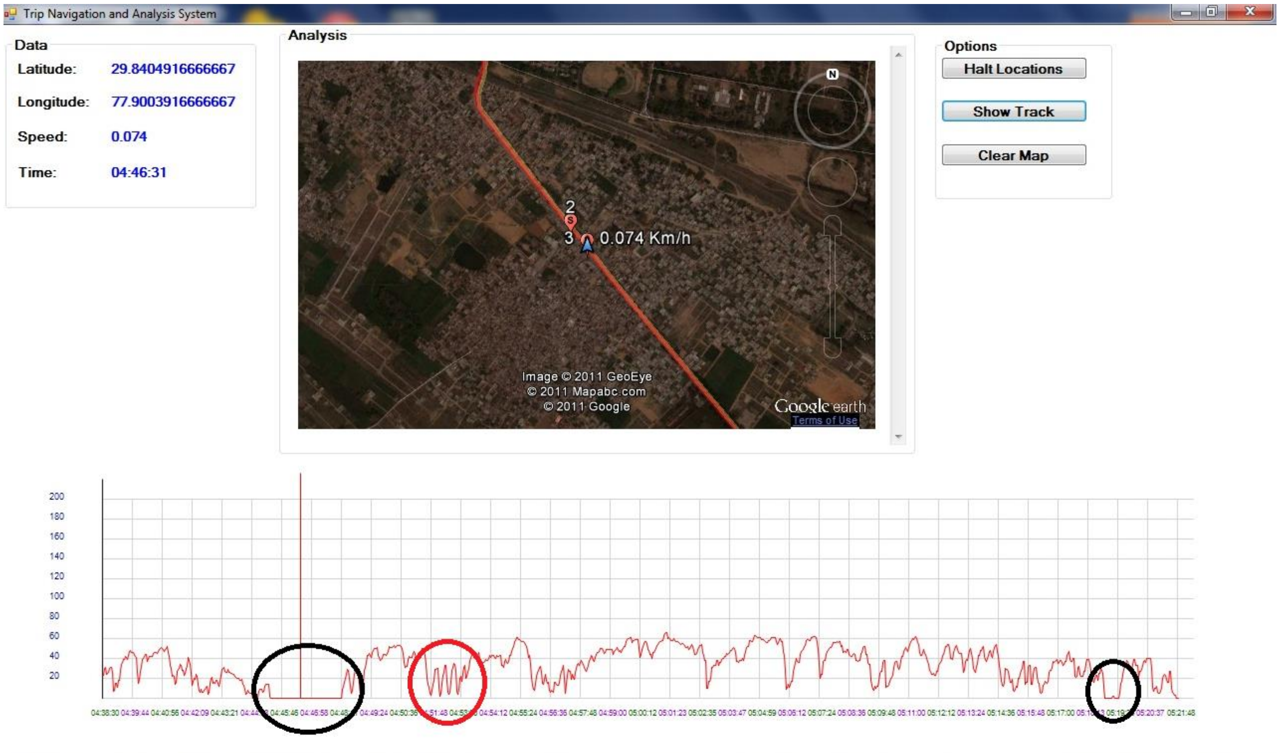

Figure 8.12: Circles shows halt location and road traffic congestion.

Figure 8.12 (a): Shows Red circle location in Analysis Panel.

Figure 8.12 (b): Shows Black circle location in Analysis Panel.

Figure 8.13a and b shows halt locations of train.

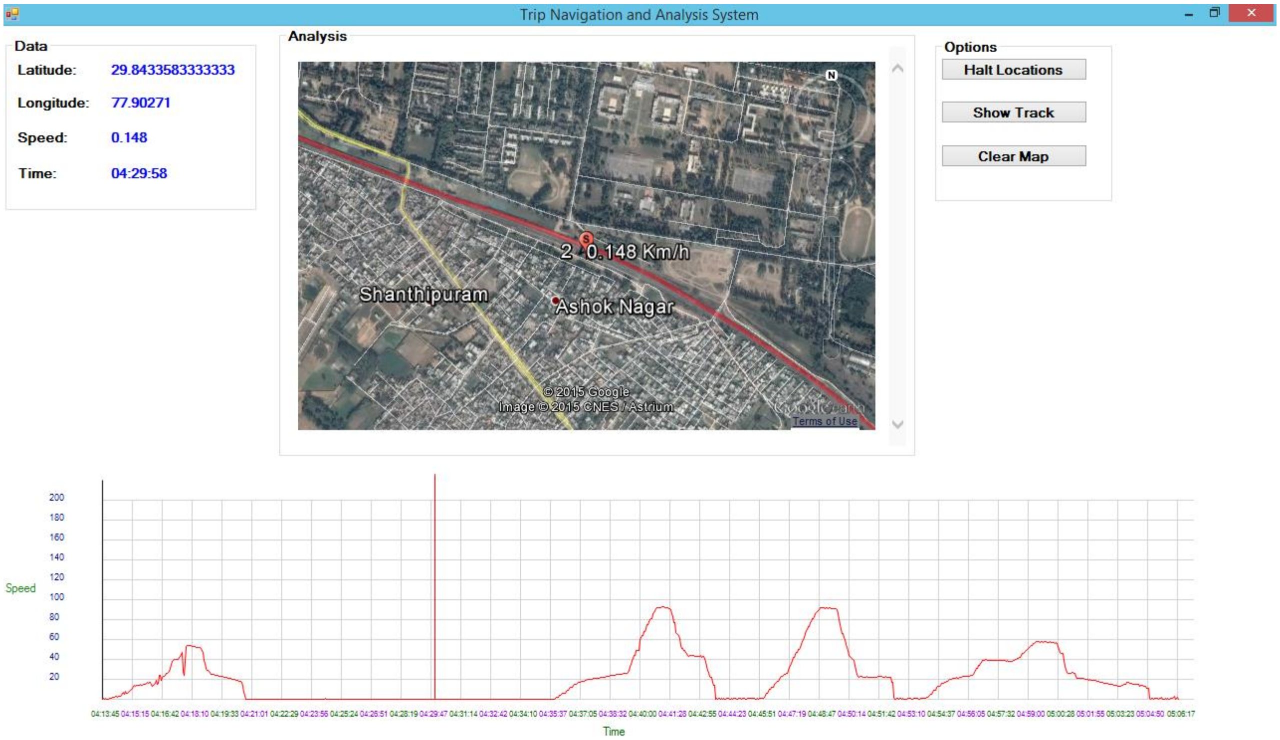

Figure 8.13 (a): Halt location of train at Dhandera station.

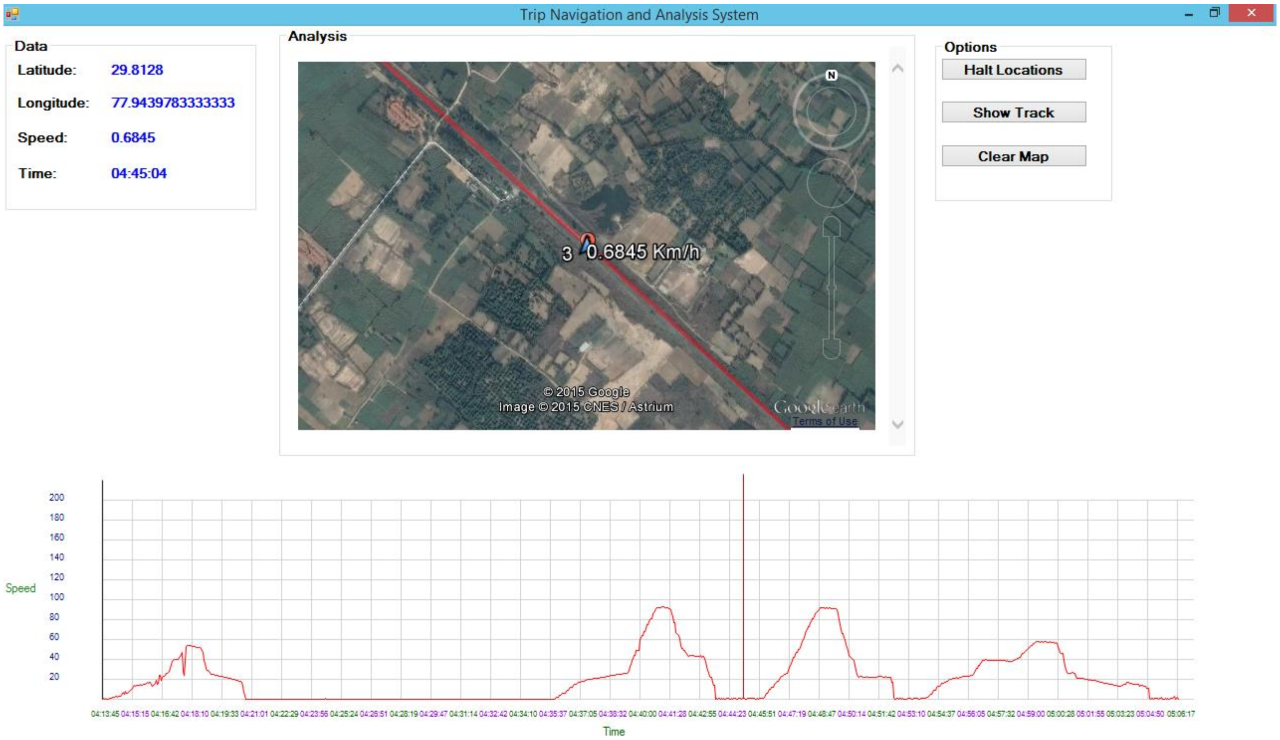

Figure 8.13 (b): Halt location of train at Landhaura station.

In Figure 8.14a and b, red circle on graph shows congestion at level crossing and corresponding location shown on Google earth. The latitude, longitude, speed and time at level crossing is shown in Data panel.

Here graph shows less congestion at level crossing. If speed is more, congestion is less, if speed is less, congestion is more.

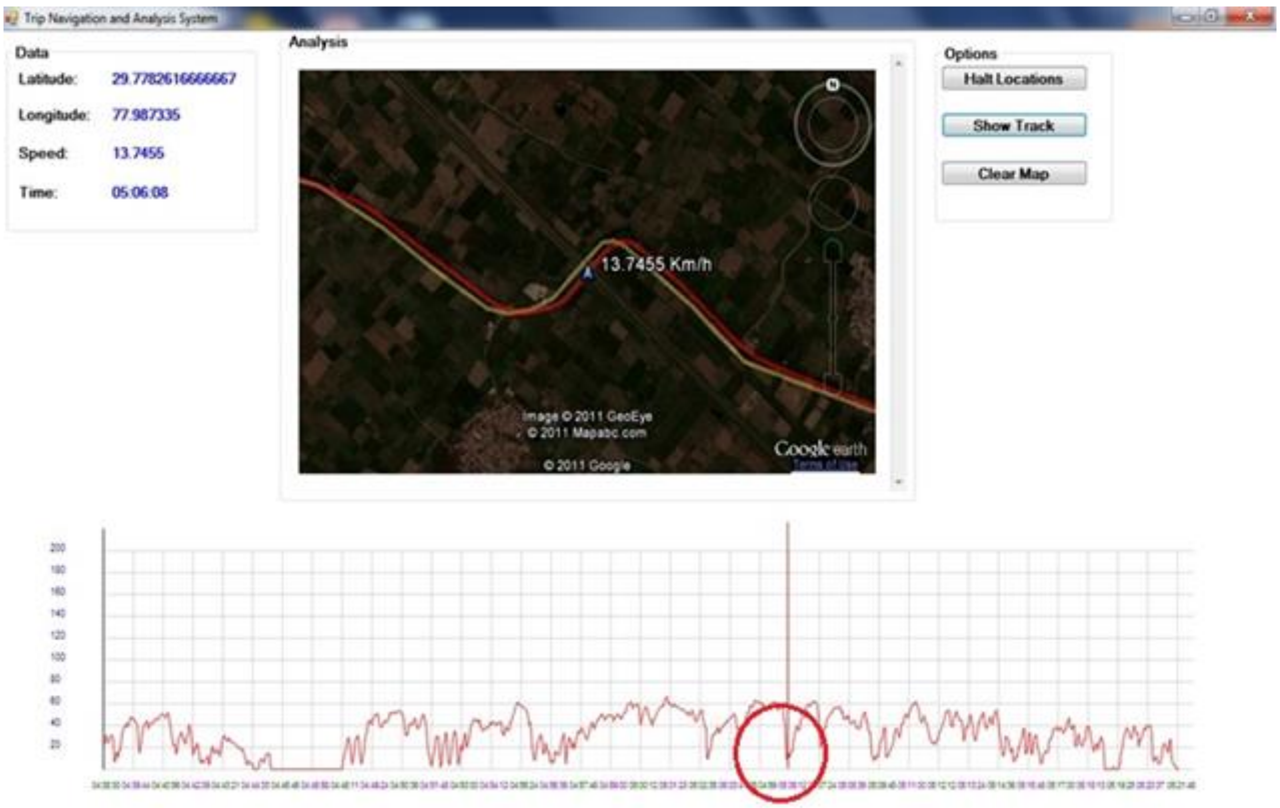

Figure 8.14 (a): Circles shows congestion at level crossing.

Here graph shows more congestion at another level crossing. By this analysis feature user can identify congestion locations (See figure 8.14b). This is a unique feature of TNAS.

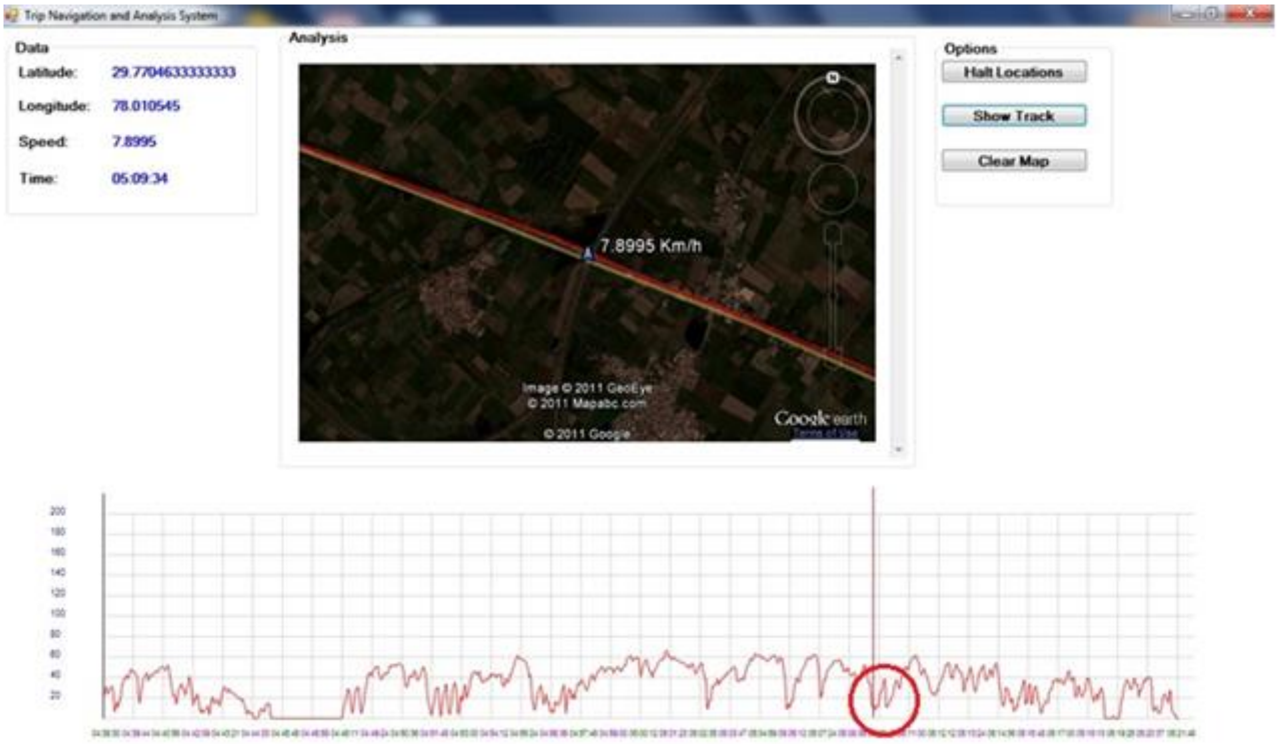

Figure 8.14 (b): Circles shows congestion at another level crossing.

Chapter 9

Summary, Conclusions and Future Scope

9.1 Introduction

Railway means conveyance of goods and passengers by way of wheeled vehicles on rails. Railway industry has the valuable role in economic development of any country. The railway network is considered is to be the safest and easiest mode of transportation and more than 10 billion of people and 1050 millions of fright traveled by train annually worldwide. Indian Railway is the backbone of country's transportation system. Indian Railway is one of the world's largest railway network. IR carried over 8,900 million passengers annually or more than 24 million passengers daily and 2.8 million tons of freight daily (Indian Railways, 2014). So there is an urgent need to enhance capacity of and modernize the Indian Railways to meet country's social and economic aspirations in the 21st Century. With modernization and restoration of balance in the inter-modal transport mix railways can be a significant engine of inclusive growth and development for the country and can potentially contribute an additional 1.5% to 2% to GDP (Modernization of Indian Railway, 2012).

This research is mainly focused on knowledge based approach to navigate and control the train. During this research four objectives are achieved, 1) Location Based Asset Management System for Railway, 2) Knowledge Based Train Operator Module, 3) Web Based Train Navigation and Tracking System and 4) Trip Navigation and Analysis System and the Knowledge Based Train Navigation System is integration of these systems.

9.2 Summery and Conclusion

The first train was introduced in India on 16th April, 1853 between Boribandar (Mumbai V.T.) and Thane. Since then Indian Railways has successfully adapted itself to the changing needs of travel and transport in the country. It has also absorbed various advancements in the field of railway technology and kept itself equipped continually to meet the growing requirements of passenger and freight traffic. This thesis started with an attempt to provide a broad overview of the salient aspects of the growth story of Indian Railways. A review of previous work in this field has been undertaken and methodologies using GNSS, GIS and GSM technology that have the potential to enhance local rail demand models have been identified.

This research highlights that the current reforms in railway sector is not sufficient and there is a strong improvements required in railway sector to make them more profitable, safe and justifies the requirement of a technically enhanced system that optimizes passenger and delivery services.

This thesis provides the background for the research problem and sets out a theoretical framework for the study based on previous researches done on related topics and examines conventional navigation and control systems used by Indian railway for determining the specific gaps in existing railway infrastructure that is to be fulfilled by using advance spatial information technology. Before finalizing a deployment methodology for improving existing railway system in typical Indian scenarios this research summarizes current advanced train navigation and control systems used by different countries. Going one step further, it reviews two advance train controlling systems ACD and SIMRAN used by Indian railway with their key features and the modern technologies. This can be concluded as a foundation which:

- Summarize major contributions of significant railway projects and studies to the body of knowledge under review.
- Evaluate the current "state of the art" for the body of knowledge reviewed, pointing out major methodological flaws or gaps in current rail management system used by different countries and Indian railway, inconsistencies in theory and findings, and areas or issues pertinent to advance Indian railway management system.

High demands on positioning with respect to reliability, availability and integrity is influenced by railway control system. These requirements can only be fulfilled by integrated positioning systems, which combine GNSS with other sensors.

The use of GNSS in railway systems have many advantages, in particular the monitoring of train's exact location, logistic information management, enhanced train signaling (which improves safety, but also enables e.g. reduced distances between trains and therefore increased train frequencies), and the possibility to map the transport infrastructure.

It reviews the background of GNSS and its fundamentals and the principle of GNSS operation, error sources and current augmentation systems for GNSS are introduced. This concludes that GNSS is world-wide positioning infrastructure using navigation satellite, applied to various positioning applications (e.g. current transportation systems). It is required for GNSS based system to which applied safety-relate system such as aviation, railway system to ensure higher reliability and safety. Currently operating GPS does not provide integrity information directly to user. European GNSS, GALIEO is in the process of development in Europe and is expected to provide system level integrity information through SoL (Service of Life) service. In Korea, the research on ground based augmentation system and its applicability to railway has been undertaken to ensure the integrity of GPS.

A work plan presents an outline of a set of goals and detailed description of processes by which we have accomplished objectives of the thesis, offering a better understanding of the scope of the Knowledge Based Train Navigation System. Throughout the thesis, work plan helped to stay organized while working on a wider and complex research domain of Indian railway. Developed research plan refers to how the research was done and its logical sequence. Architecture represents no of components we are using as part of services and the flow of request processing. i.e what components involves in procession the request and in which order. The architecture of this system defines how sensor network communicate with remote server.

This research has developed and tested a train navigation and control system integrating GNSS, GIS and GSM technology. GNSS can be used to get position of the train in terms of Latitude and Longitude from the satellite. GSM can be used to transmit the data obtained using GNSS receiver to the server using GPRS. It would be helpful for a passenger to catch a train if he knows its exact location. This enables a person to trace a train on GIS ready map, while sitting in any part of the world using internet. In the safety-critical environment, train can take decisions automatically at signals and level crossing using knowledge based approach.

Location Based Asset Management System for Railway (AMS-R) provides a comprehensive solution for smartly managing massive railway assets. This asset information is further utilized in Knowledge Based Train Operator Module in which a knowledge based approach is used to fulfills the high requirements on service reliability for Railway Traffic Scheduling and controlling that is often considered as one of the most complex problem in Indian railway. This thesis illustrates the potential of Web Technology in Indian Railway, this description followed with the development of Web Based Train Navigation and Tracking System which integrate Web GIS and GNSS technology to bring end user comprehensive services.

India is a developing country and people can appreciate the technology if cost effectiveness is followed. In the current scenario GNSS information cannot be analyzed in a way that it can be customized so a Trip Navigation and Analysis System is developed in which GNSS information is customized and analyze the trip in tabular and graph form. This system can be used for both railway and individual vehicles like cars, buses, trucks etc.

9.3 Major Contribution of the Research

- This research address the gaps in present navigation and tracking systems for trains.
- This research integrates the recent technologies like, web technology, GNSS and Web GIS on a single platform.
- The developed web based train navigation and tracking system shows real time train location information on the web.
- A knowledge based approach is used to develop train operator module which can take decision in safety critical situation.
- Track maintenance updates are made available to train operator module to avoid accidents.
- The status of signals and level crossing is made available to train operator using train operator module.
- Asset management system is developed for railway which is using GNSS technology to locate the assets.

9.4 Recommendation and Scope of Future Research

This research address the gaps in current navigation and tracking systems of train, so a knowledge based train navigation system is developed which can integrate navigation and tracking on a single platform for Indian Railways.

GSM/GPRS technology is used to communicate with the central server but still there are several areas where GSM/GPRS are not available so the communication between remote Train Operator Module and the central server terminated several time. Due to this, some position information is lost and users are unable to track the train. So the GSM/GPRS network should be available everywhere near the railway track.

The developed system is using GNSS, GSM/GPRS and GIS technologies to navigate and control trains. The results of this system shows that it achieved the Level 3 of Japan's Automatic Train Control for Bullet Train, Level 4 of Chinese CTCS and Level 3 of European ETCS. Integration of Automatic Breaking Unit with this system can put this system to the next level where automatic train control take place and enhance the performance of this system. This system meets the current requirement of Indian Railway's train navigation and control so this system can be applied with the existing train control system to improve safety and reliability of trains.

The developed Trip Navigation and Analysis System is a windows desktop application which log real time positioning information into a defined file after that user can analyze the trip in tabular form and in interactive graph form. This application can be generalized and can be web based application.

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Copyrights/Patents

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