HIGHWAY ASSET MANAGEMENT IN PAKISTAN USING GEOGRAPHICAL INFORMATION SYSTEM (GIS)

By

Ayesha Mahmood

(2009-NUST-MS PhD CE&M-10)

A Thesis submitted in partial fulfillment of
the requirements for the degree of

Master of Science

in

Construction Engineering and Management

DEPARTMENT OF CONSTRUCTION ENGINEERING AND MANAGEMENT
NATIONAL INSTITUTE OF TRANSPORTATION
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING
NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY
SECTOR H-12, ISLAMABAD, PAKISTAN

(2012)

HIGHWAY ASSET MANAGEMENT IN PAKISTAN USING GEOGRAPHICAL INFORMATION SYSTEM (GIS)

By

Ayesha Mahmood
(2009-NUST-MS PhD CE&M-10)

A Thesis submitted in partial fulfillment of
the requirements for the degree of

Master of Science
in
Construction Engineering and Management

DEPARTMENT OF CONSTRUCTION ENGINEERING AND MANAGEMENT
NATIONAL INSTITUTE OF TRANSPORTATION
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING
NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY
SECTOR H-12, ISLAMABAD, PAKISTAN
(2012)

This is to certify that the
thesis entitled

HIGHWAY ASSET MANAGEMENT IN PAKISTAN USING GEOGRAPHICAL INFORMATION SYSTEM (GIS)

Submitted by

Ayesha Mahmood

has been accepted towards the partial fulfilment of the requirements
for

Master of Science in Civil Engineering
(Specialization in Construction Engineering & Management)

Dr. Muhammad Irfan, PhD
National Institute of Transportation

NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY, ISLAMABAD

HIGHWAY ASSET MANAGEMENT IN PAKISTAN USING GEOGRAPHICAL INFORMATION SYSTEM (GIS)

By

Ayesha Mahmood

A Thesis of Master of Science

Submitted to the

NATIONAL INSTITUTE OF TRANSPORTATION
SCHOOL OF CIVIL & ENVIRONMENTAL ENGINEERING
NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY
ISLAMABAD

In partial fulfilment of the requirements for the degree of

Master of Science in Construction Engineering & Management

(2012)

DEDICATION

This Thesis is dedicated to my beloved Parents and siblings for their necessary support and prayers. My husband also helped me a lot in dedicating my full efforts to the research.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my respected supervisor Dr. Muhammad Irfan for his ever ready help, unmatched thoughts, critical appreciation and for providing me an opportunity to perform research on a study area in which our country is lagging far behind. He kept my moral at esteem and enabled me to execute this task in a manner that would definitely contribute to our nation.

I feel grateful to Dr. Rafiq Muhammad Choudhry for his valuable suggestions and appreciations during the course of my thesis. The technical assistance provided by Dr. Ejaz Hussain is highly acknowledged. I am also thankful to Lecturer Rabia Haroon for her help and support.

I am also grateful to the Faculty of Department of Construction Engineering and Management and National University of Sciences & Technology for providing me with the financial support and guidance during this research work.

(Engr. Ayesha Mahmood)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

In developing countries like Pakistan, major investment on infrastructure is for building roads and bridges including maintenance and rehabilitation, which improve economy on long term basis. A comprehensive asset management system is needed to store, retrieve and query data such as maps, aerial photographs, satellite imageries, basic physical attributes of roads, pavement conditions, maintenance and rehabilitation strategies. There is an earnest need to introduce Geographic Information System (GIS) based asset management for transportation infrastructure which assists in planning and prioritization of assets with its storage, transformation, analysis, modelling and reporting capabilities.

GIS based highway asset management system (GHAMS) of Lahore – Islamabad Motorway (M-2) was developed. Data pertaining to Design, Construction, Operation, Maintenance & Rehabilitation activities, pavement evaluation, satellite imageries and maps, etc. has been collected and database developed which is then linked with Environmental Systems Research Institute (ESRI) ArcMap & TransCAD Software. GHAMS can be updated easily and provides information for the complete life cycle of an asset which includes the design, construction, performance, rehabilitation, maintenance, reconstruction or replacement of the asset.

This system made readily available the data associated with asset performance, maintenance and rehabilitation cost by generating reports for performance monitoring and evaluation, record of repair and maintenance activities, minimizing existing budgets and preparation of future budgets.

Chapter 1

INTRODUCTION

Road Transport is one of the main components for the social and economic development of a country and therefore gets the greatest proportion of budget. It provides improved accessibility of the people to jobs and the market besides contributing in education and health care sectors and thereby facilitates development activities within a country and across the border. Each travelled kilometer has an effect on the Gross National Product (GNP). Efficient transportation system not only results in reducing the production costs but also improves the quality of services delivered to the consumers.

The benefits derived from road transport are not, however, without their problems, such as, many people are killed and injured in road accidents, or suffer through pollution. The challenge of road management in today's world is not only limited to minimize adverse impacts, but to utilize these road assets in a manner that best supports economic and social development.

In the past, road professionals were mostly involved in the construction of roads and road maintenance remained ignored, but now the emphasis of work is changing and road administrations are more concerned about the Road Assets and their management that they generated over the years.

1.1 TRANSPORTATION ASSET MANAGEMENT IN PAKISTAN

In Pakistan, transportation by means of road dominates over the other two modes of transportation i.e. rail and air. Approximately 107,000 million ton-kilometers of freight per anum is carried by the roads as compared to 5,000 million ton-kilometers by rail and 25 million ton-kilometers by air (RAMD 2005). Similarly, roads carry 90% of passenger traffic as compared to rail and air which carry 8% and 2% respectively (RAMD 2005). However, as per the Economic Survey of Pakistan of year 2010-11, reliance on roads was only 8 % in 1947, but, today the roads are carrying over 96 % of freight and 92 % of passenger traffic. Clearly, roads are the backbone or lifelines of Pakistan's economy (Ministry of Finance 2011).

The length of the road network in Pakistan has increased from around 50,000 km in 1947 to now more than 260,000 km which includes 12,000 Km of National Highway Authority (NHA) network. This NHA road network comprises of motorways, expressways, highways and strategic roads providing inter-city and inter-provincial linkages and carry 80% of Pakistan’s commercial/ freight traffic (Ministry of Finance 2011). Results of pavement condition surveys conducted in year 2005 by NHA shows that 43% of the existing NHA's network has Remaining Service Life (RSL) from 0 to 1 year and therefore requires major maintenance and rehabilitation or reconstruction. The asset replacement value of National Highways was more than Rupees 600 billion in 2005 and today it will be much more than that (RAMD 2005).

1.2 INTEGRATION OF GEOGRAPHICAL INFROMATION SYSTEM (GIS) IN TRANSPORTATION ASSET MANAGEMENT

An asset management system assists the agencies in the planning and prioritization of the asset investment. Information about these assets related in different ways to the highway is usually maintained by the highway departments in separate systems and is generally dispersed in the entire organization.

Pakistan, like other developing countries is lacking in effective management of the national road and bridge assets which are extremely important for economic development. This is primarily because of the absence of efficient asset management system which leads to difficulty in gathering, keeping and maintaining huge amount of data of the country’s transportation system. Moreover, the country’s transportation infrastructure is predominantly Government owned and represents one of the biggest and crucial investments. For the successful implementation of an asset management system, the interaction of processes, people and technology is enormously important (McPherson and Bennett, 2005).

Therefore, technologically, there is a need to introduce a Geographical Information System (GIS) based highway asset management (GHAMS) for transportation infrastructure of Pakistan that can significantly improve the efficiency of the system. Integration of GIS into the asset management systems in public agencies significantly improves the quality of services delivered to consumers (Ramlal 2006).

1.3 PROBLEM STATEMENT

In Pakistan, unfortunately, with the increase in axle loading and the traffic volume, and inadequate maintenance, the largest investment i.e. highway infrastructure in Pakistan is deteriorating at an alarming rate. The present situation of the road network is due to disinterest (political expediency) and neglect (unawareness of economic consequences of deferred and/or underfunded maintenance). These two factors resulted in a tendency that promoted disproportionate budgeting that resulted in a vast imbalance in development and maintenance expenditures. Besides this, the country’s transportation organization lacks an integrated information management system that supports gathering and integration of the information and access to it. This situation has ultimately lead to failure of the country’s transportation authorities to achieve the utmost benefit from the available systems, resources and initiatives with the available and limited budgets.

In Pakistan, transportation asset management is done by the Road Asset Management Division (RAMD) of NHA using software package of HDM-4. Asset management using GIS has not been done yet. GIS also allows graphical display of assets, and produces “Highway Asset Management System Maps” which can further be analyzed for transportation planning using various GIS based software packages. GIS is greatly helpful in integration of data and graphic information besides graphical display and colored maps can also be easily obtained (NCHRP 2004). Such a system is very essential in decision support system as it enables preparation, analysis, display and management of roads (Jain et. al. 2003). This research involves Development of GHAMS of an in-service Motorway.

1.4 OBJECTIVES

Highway asset management systems normally involve collection & retention of huge amount of data that is available in different format, referencing or coordinate system and media. A GHAMS is very appropriate for collecting, collating, integrating, managing and analysing and presenting these datasets (NCHRP 2004). Such a system therefore proves very helpful for planning, budgeting, resource allocation and repairing of assets and the information obtained is precise and accurate. The overall objective is to produce an effective Highway Asset Management system using GIS that can systematically, safely & economically handle the country’s large infrastructure data and can analyze, manipulate and display the required information instantly. Following are the identified objectives for this research work:

- To develop the GHAMS which includes all the pertinent information such as maps, aerial photographs, satellite imageries, transportation inventory, basic physical attributes of roads, pavement conditions, and maintenance and rehabilitation strategies for decision making;
- To present the applicability of developed GHAMS using the data of an in-service Motorway.

1.5 SCOPE OF THE THESIS

The scope of this research is the development of GHAMS applicable to any highway/ motorway of Pakistan. As a case study, GHAMS of Lahore – Islamabad Motorway (M-2) is developed. The Motorway (M-2) is selected for the present study as it is presently the best highway facility available in Pakistan. Also, it was the first ever Motorway built and opened for operation in Pakistan. The scope also includes download of the Satellite Imagery from the Google Earth. This is then followed with the development of database and geo-referencing of the data. The database is also linked with TransCAD software for exploring the transportation related GIS functions.

1.6 STRUCTURE OF THE THESIS

The thesis comprises of five chapters. *Chapter 1* provides an introduction to the transportation assets of the Pakistan and their present condition. The chapter also highlights the importance of GIS in general as well as in transportation and describes the problems currently being faced currently by the Country due to absence of such a system. It also includes the research scope and objectives. *Chapter 2* details the literature review of asset management and GIS based asset management. The chapter also discusses such asset management systems developed across the world and the significant findings derived from these studies. *Chapter 3* present the methodology adopted for accomplishment of this research. The various steps undertaken for development of GHAMS including collection of the data and development of strategy is explained. It also includes the procedure for downloading of the Satellite Imagery through the Google Earth using available software. *Chapter 4* presents the applications of the GHAMS and development of link with TransCAD for Maintenance and Rehabilitation cost calculation. *Chapter 5* summarizes the main conclusion and recommendations formulated for the GHAMS of Pakistan.

Chapter 2

LITERATURE REVIEW

2.1 INTRODUCTION

The construction of roads and bridges in Pakistan over the last few years has increased its pace and the trend is likely to grow in the future years. Management and maintenance of these national assets is one of the major problems being faced by the country these days. The solution to this problem lies in development and implementation of asset management systems such as pavement management system, accident management system, decision support systems etc. These systems augmented with analytical tools capable of performing engineering, accounting and economic analysis help in organizing, prioritizing and strategizing investments for better planning and implementation of objectives (Aboki 2005). Lack of an ‘asset management mindset’ in an organization or lack of teams within an organization specifically responsible for implementation of such systems, or even non-utilization or validation of the results obtained from such systems is regarded as a failure of the system (McPherson and Bennett 2005). For the successful implementation of an asset management system, the interaction of processes, people and technology is enormously important (McPherson and Bennett 2005). Therefore, technologically, there is a need to introduce a GIS based highway asset management for transportation infrastructure of Pakistan that can significantly improve the efficiency of the system. Integration of GIS into the asset management systems in public works departments significantly improves the quality of services delivered to consumers (Ramlal 2006).

2.2 GIS BASED STUDIES – GLOBAL PERSPECTIVE

The American Association of State Highway and Transportation Official's subcommittee on Asset Management defines Transportation Asset Management (TAM) as "Transportation asset management is a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively through their life cycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision making based upon quality information and well defined objectives." (AASHTO 2011).

For effective planning, construction, management, and maintenance of transportation assets, it is pre-requisite that these are modelled first by using some information system (Hall 2004). GIS in combination with other technologies can be very helpful for an effective asset management of the national highway network. GIS uses hardware, software and procedures in order to capture, manipulate, model, analyze and display complex planning and management problems. A GIS based Highway Asset Management (GHAMS) system will allow integration of datasets (information) such as public safety information, pavement distress information etc. across business system with in a transportation organization. This system will help different components of the organization to work together on the available data and therefore will help in achieving the maximum potential from the existing system with limited budgets. GIS is also suitable for analysis of information and display in the form of maps. Because of the spatial relationship amongst various transportation facilities and assets, utilization of GIS in transportation is beneficial.

Lemer, A.C. in his study on GIS based asset management system defines asset management as “the collection, processing, analysis and maintenance of extensive information about various types of assets such as equipment, facilities and other resources to plan work to be executed to maintain these assets at an operational level in the most cost-effective fashion possible” (Lemer 1998).

Alterkawi, M. studied applications of GIS in transportation planning and considered Riyadh, the capital of Saudi Arabia as a case study. The study incorporated link volumes ensuing from the travel demand forecasting models and identified deficient and congested facilities where demand exceeds capacity. The study also investigated air quality analysis, shortest path and travel time allocation of major activity centres. It was concluded that GIS provides a means of interactive communication between the public and transportation professionals (Alterkawi 2001).

County Surveyor's Society defines asset management in the following words "Asset management is a strategic approach that identifies the optimal allocation of resources for the management, operation, preservation and enhancement of the highway infrastructure to meet the needs of current and future customers." (CSS 2004)

Land Transport GIS Data Hub (LTGDH) developed by Land Transport Authority (LTA) of Singapore produced future road and railway line maps which could be purchased by surveyors, real estate developers, lawyers, architects, and engineers to perform property transactions and draft development proposals thereby reducing LTA time, resources and money by not only assisting private industry but by also reducing the number of plans that could impact the road and rail systems. A GIS based system was also used to coordinate road construction in order to minimize disruption to the commuters. The LTGDH capability to visualize the pavement condition was also used to plan the maintenance and rehabilitation of the road assets based on prioritization and budget (Freeman 2009).

In California, the Department of Transportation has recently successfully integrated GIS with the street, signs, trees and other right of way assets inventory and with the existing work order management system. The system collects and manages assets and synchronizes it with the work order management system. The data was inventoried using the Tablet PC loaded with ArcPad and high resolution street maps, street centrelines, address database and digital orthography that enabled identification of assets through visual inspection and without GPS. The system helped in efficient and streamline data collection, management and updation besides effective labour and expense tracking (Jennings 2009).

City of Colorado was ranked as the best place to live in the categories of cities with 300,000 or more people by the Money magazine in 2006. In order to continue their ranking, the city's transportation system needed to be improved. With a 30% growth rate and lesser budget, the traffic engineering and public works focused their attention towards development of a transportation asset management especially sign and school markings. To increase the speed of asset management system, a team from traffic engineering and public works staff was created. The team evaluated the situation and chose to develop a GIS based asset management system. Applications were developed such as CALLdirector that linked a request for a new or repaired asset to a map and address locator file. Similarly, WORKdirector allowed technicians to easily see and navigated to the location of the request. Upon the approval, the request was assigned to a field crew who using wireless Toughbooks easily navigate to the site and process the work orders related to that area thereby saving time and money. The time involved in completing a work order from traditional paper based processing was 49 hours which reduced to 18 minutes by using GIS thereby increased productivity without having additional staff. Prior to GIS based asset management system, the department had no information about asset inventory and therefore the requests and work orders to fix the damaged assets could not be easily and readily entertained. The traditional work order process for asset management was paper based and very time consuming (Thomas et. al. 2009)

Land Transport Authority (LTA) of Singapore also combined geotechnical information pertaining to structural foundations of the transport infrastructure projects. For soil analysis, sit excavation, foundation design and tunnel alignment, GIS technology was used for capturing borehole information and a data of more than 8,000 boreholes was captured by the LTA. The data also helped in location of water table for determination of safe tunnelling methods. Particularly for tunnels, soil movement detection enabled instruments mapped with GIS were also placed in ground to track any movement in the soil (Freeman 2009).

Traffic Analyst extension and Geo-processing wizard tools of GIS have made easier building and using advanced transportation forecasting models which have been realized in TRANS-TOOL forecasting model. The consequences of the different European level transport policies are predicted and new investments in large scale infrastructure projects are evaluated using this TRANS-TOOL model to support decision making process. The submodels of TRANS-TOOL were Economic, Freight Trade, Freight Modal Split, Freight Logistic, Passenger, Environmental Impact Model and Traffic Assignment (Israelsen 2009).

Land Transport Authority (LTA) of Singapore developed a GIS based, multi query accident application that was linked to the geographic analysis tools. Previously, LTA used graphs, charts and tables for accident analysis and identification of hazardous locations for road safety improvements. Utilizing the visualization capabilities of GIS, LTA conducted Black Spot analysis for identification of accident prone areas. This resulted in reduction in traffic accidents by 90% at expressways and by 66% at treated intersections. The information such as the average travelling speed, accidents location, and construction/ maintenance activities on main roads are also broadcasted via an interactive map having three minutes update time (Freeman 2009).

Airport management and operations depend on very specific and crucial information that is needed to support their mission. Airport serves as a host to airlines, retailers, and service providers and thereby involves land use; construction activities at large scale and maintenance of facilities affected by various reasons including structural age, weather, and frequent use. Also, systems are required that track flight times, gate use; control aircraft movement, security and access to the airfield; manage revenue from the users; allow processing of passenger and baggage, manage parking and traffic, and provide landing guidance. As per the aviation specific laws and regulations (FAR Part 139), airports are required to track and log the daily condition of the facility, manage and report incidents, apply for and receive funding from the federal agencies, construction management with minimum impact on aircraft movement. Keeping in view the above, airport management system using GIS was developed that stored the physical layout of the facility and provided access to the stored data besides analysis capabilities. Queries related to indoor can be made to identify even who occupies & leases a specific room in an airport and when the lease expires and who is responsible for cleaning the room. For outdoor, the queries can be the shortest taxi time between two points, effects of maintenance and construction operations on flight operation, coverage of CCTV cameras, etc. (Carlson 2009).

GIS was used to develop the Engineering Document Retrieval System (EDRS) for the Baltimore-Washington International (BWI) Thurgood Marshall Airport. Approximately 30,000 documents, drawings and specifications spatially associated with airport features were accessed through web portal using ERDS. Search by attributes and location capabilities were built in to find the documents associated with that geographical location (Carlson 2009).

Southwest Florida International Airport developed GIS system integrated with an airport property management system PROPworks to query and visualize lease information through an authenticated web portal. An authorized user can search for the occupant or lease agreement and the system will find the leaseholders, and display the corresponding area on the web-based map interface (Carlson 2009).

Geospatial Airfield Pavement Evaluation and Management System (GAPMS) was developed for the Denver International Airport (DIA) that links airfield pavement management and GIS. Tablet PCs, GPS enabled digital cameras and receivers were used by the crews to record distress type, severity and nature while walking on the runway, taxiway, and apron structure. The collected information was also related to the historical data such as the construction contractors, aggregate type used for construction and the prevailing weather conditions at the time of construction for each pavement section (Carlson 2009).

Eppley Airfield in Omaha, Nebraska, USA is a medium sized commercial airport having runways length of 26,155 linear feet and total paved surface of more than 11 million square feet. With this much paved area, the asphalt and concrete pavement maintenance was a challenge. GIS technology was used to track airport surface defects and repairs. To receive funding from the Federal, the Omaha Airport Authority's (OAA) Operations Department must ensure funding eligibility by maintaining detailed self-inspection reports and reports on maintenance and rehabilitation activities carried out. Previously, manual methods were used such as walking along the runway to find defects in the runway and track work orders for their repair. Paints were used to mark the deficient pavement but the same diminishes due to air traffic movement on the runways. Lamp, Rynearson & Associates (LRA) was asked to investigate a better way to track surface defects of airport pavements and their repairs. LRA's method used GPS and GIS technology to accurately map each surface defect and also provided electronic forms for keeping track of maintenance history and linking the data to the map locations. In the field, inspectors record each defect's location on the airport base map using PDA or handheld computer equipped with customized GIS software and a Leica GPS receiver, and reports to the maintenance personnel responsible for repairs for creation of a maintenance work order (Preston 2009).

Auckland Motorway Alliance (AMA) of New Zealand wanted to get maximum return from the investments by maximizing the asset performance and keeping a balance between the asset performance and cost. In order to do so, AMA required accurate and detailed information about each asset condition. A GIS based system containing distinct information in 150 layers and capable of displaying results with a variety of base maps, symbols and scales was developed. On the average, 60 people view 22 maps per day or in other words 26,000 map views per month. The system helped and benefited AMA in routine operations as well as in asset management (Eagle Technology 2011).

Numerous past studies were also carried out internationally which discussed the state of the practice and knowledge of asset management applications using Geographic Information Systems (GIS) and other spatial technologies.

GIS is useful for analysis of information and display of maps which can be produced for any specific purpose and printed at any scale and can also be updated easily with GIS based asset management system. Present and future road conditions, maintenance and rehabilitation required, benefit cost analysis can be displayed using the charts and the graphs.

According to Longley et al. (2001), geographic information systems capture, manage, manipulate, analyse, model and display geo-referenced data that provides solution for difficult management and planning issues. Salim et. al. (2002) in a study optimized the cost of asset management for roads and bridges by integrating Artificial Intelligence (AI) and GIS.

National Cooperative Highway Research Program (NCHRP) in its synthesis report 301 presented the practices for collection, processing, and integration of GPS Data into GIS that can be helpful in development of database for Asset Management of Highways (NCHRP 2002).

Hegyi and Mookerjee (2003) overviewed the GIS and GPS based transportation asset management system for road and railway in India particularly with reference to the applicability of the system in terms of accidents on highways and railways and natural disasters.

Sinha (2003) developed prototype municipal asset management system and describes GIS as the system that ties together and implements the data and management procedures.

Jain et. al. (2003) in a study reviewed the role of GIS in pavement management system and road information management system and concluded that such a system is very essential in decision support system as it enables preparation, analysis, display and management of roads.

Central Road Research Institute in its conference on GIS in Transportation Planning summarized that GIS provides a platform where data for various purposes can be integrated, analysed, queried and can be updated easily when fresh information is available. This leads to the continuous development of the database. Further, the various functionalities of the GIS and the topological information can be used for transportation assets management and analysis in a new dimension on daily basis (Map Asia 2003).

Moreover, Central Road Research Institute in its conference on GIS for Pavement Management System presented a GIS – PMS Integration Framework and after analysis concluded that GIS helps in decision making by facilitating in development of the highway database and its analysis, besides graphical display, and management of the data. This decision making feature, in particularly, is used for pavement management systems because the road networks are characteristically geographic (Map Asia 2003).

A GIS based highway asset management system (GHAMS) comprises of two types of information; one is spatial data and the other is non-spatial data (attribute data). Spatial data includes the data which is geo-referenced and have a projection and coordinate system associated with it whereas non-spatial data defines the attributes associated with the spatial data which may point, line or polygon. In case of a highway, non-spatial data includes carriageway width, shoulder width, right of way, number of lanes, history of construction, pavement condition survey data, traffic volumes and accident studies etc. These datasets of diversified nature (whether spatial or non-spatial) and having different referencing systems are integrated and manipulated using a well-designed GIS. Once the GIS is developed, the coordinates can be transformed into other projection systems (Jain et. al. 2003).

National Cooperative Highway Research Program in its another synthesis report: 335 presented the practices, techniques and knowledge of using GIS applications in Pavement Management and concluded that GIS is greatly helpful for integration of data with graphics besides graphical display and colored maps can also be easily obtained (NCHRP 2004).

GIS and the related spatial technologies have long been in use for transportation asset planning, monitoring and management. Using GIS, data can be collected, integrated and analysis can be performed for assessing the present and the future road conditions, which can further be utilized for preparing budgets and map generation. Besides the great usefulness of GIS applications, various transportation departments still oppose to use it (Aboki 2005).

A comprehensive database on a well-designed GIS based asset management system provides information for the complete life cycle of an asset which includes the design, construction, performance, repair, reconstruction or replacement of the asset. Using GIS based asset management system, data associated with asset performance and maintenance & rehabilitation cost can be easily made readily available for generation of reports on asset inventory, performance monitoring and evaluation, record repair and maintenance activities, assisting in maximizing existing budgets and the preparing of future budgets. The evolution of GIS and spatial technologies is providing powerful mechanisms for developing asset management decision-making products (TRB 2006). Further, in case of natural and man-made disasters, appropriate information can be provided.

Ramlal (2006) in a study of using GIS for asset management concluded that the integration of GIS into the asset management systems in public works department significantly improves the quality of services delivered to consumers.

Roshannejad (2007) carried out a study on enriching the Highway Asset Management (GHAMS) program with GIS and presented GIS development activities in the design and implementation of Highway Asset Management (GHAMS).

North Dakota, a state in USA, has a very small population to support a very large road network. In order to efficiently manage and utilize current infrastructure, North Dakota Department of Transportation (NDDOT) determined that a web based GIS is an economical solution for information accessibility and utilization. Such a system integrates multiple data sets relating to transportation assets in a user friendly and easy to access interface. The system is also capable of integrating with other geospatial applications. As a pilot application for this integration model, images of the road were taken from the vehicles running down the road. A tool was also developed that locates image on the roadway using either GPS or route interpolation such as route name, milepost and image sequence thereby enabling dynamic update of images with accurate location and reference data (Bieber et. al. 2009)

Since its independence in 1965, South East Asian Island Country of Singapore has developed and grown very rapidly. In 1995, a Land Transport Authority (LTA) was established by the Government with the aim to fulfil the long term transportation needs and provide smooth journey to those who travel by public transportation. LTA was created by amalgamation of four public sector entities which included the Registry of Vehicles, Mass Rapid Transit Corporation, the Roads and Transportation Division of the Public Works Department, and the Land Transport Division of the Ministry of Communications. Merging of these well-established public entities each working for more than 30 to 40 years with disparate information technology systems and geographically dispersed offices introduced problems in work and information flow. Besides this, duplication of data captured by various departments and uncertainty in the accuracy of the data was also observed. In order to overcome this problem, a GIS based network was developed with the capabilities to centrally govern its spatial data and support the activities such as planning, surveying, designing, construction, operation and maintenance of the whole transportation assets. The developed system enabled

LTA to manage its own resources and assets and interaction with public and private agencies. The system was known as Land Transport GIS Data Hub (LTGDH) and managed all the geospatial data related to transportation infrastructure like road protection, road record, and rapid transport information system (Freeman 2009).

Also, report of ESRI on Highway Data Management in ArcGIS (2010) helps in understanding the development and use of highway database necessary for asset management especially in Linear Referencing. Particularly in transportation, GIS is largely utilized for inventory and management of assets, planning, tracking and analysing development and maintenance activities.

2.3 GIS BASED STUDIES CARRIED OUT IN PAKISTAN

Naqi and Siddiqui (2006) developed and implemented a GIS based asset management system for Sui Southern Gas Pipeline Limited (SSGPL). The system served as an analytical decision support tool for efficient planning, management and development of expansion and maintenance activities. The system also obsoleted the traditional way of handling information contained on the papers having various scales and geometric problems.

Ahmed (2009) performed geo-spatial analysis of satellite imagery for a sample study area of Karachi. The study was undertaken to develop road and landscape maps and traffic flow and density estimates. Analysis was performed using GeoMedia Pro 6.0 for seven urban road sections and three intersections and Level of Service (LOS) were estimated.

Adeel (2010) developed a GIS based guided development plan for the Rawalpindi city of Pakistan. The system used high resolution satellite imageries overlaid with other geo-spatial layers that helped in identifications of the road network and any illegal/ unauthorized construction within the right of way limits. It also aided in selection of alternate route alignment in case the primary route is unavailable.

Razzak et al. (2011) used GIS for mapping and spatial analysis of road traffic injuries (RTIs) in Karachi city using data of three trauma centers for a period of one year. Of the total 3650 road traffic injuries, only 3% were located on GIS map in the first attempt. Even after using detailed town maps and field exercises, 70% of road traffic injuries were located. It was observed that 25 places having areas of one kilometer or less accounted for 27% of all RTIs. Five corridors of road measuring 27.7 km accounted for 23% of all RTIs with known locations.

Chandio et al. (2011) performed a GIS based accessibility analysis system for public parks in Larkana City using the GIS spatial analysis technique. GIS was adopted to find a suitable land for access to the parks. It was discovered that accessibility to these public facilities are equally important as finding suitable land for these facilities.

Nawaz-ul-Huda et al. (2012) proposed GIS for power and energy sector in Karachi. A GIS based spatial electricity management system was developed integrated with the demand, supply, consumption and losses data of electricity that helped in prioritization of the electric supply and overcoming the theft and mal-distribution of electric supply in the city.

Hashmi et al. (2012) studied the inundation and devastation caused by the Floods in Lai stream in the Rawalpindi City. Digital Elevation Model (DEM) was created for the area of Islamabad and Rawalpindi using Shuttle Radar Topography Mission (SRTM) 90 m data. Mike 11 GIS software was used to calculate water levels over each of the DEM either by extrapolating or interpolating. Flood maps for the various future scenarios such as for example, the maximum extent and depth were developed that could be really helpful to the inhabitants of the city.

GIS has been used in several fields in Pakistan, but its use for highway asset management has not yet been done. Since 2003, the National Highway Authority (NHA) is using the Highway Development and Management (HDM) Model 4 for prioritization of the assets and development of Annual Maintenance Plan. This model requires pavement condition, road roughness survey, existing traffic characteristics and residual pavement strength as input data and performs the analysis for the complete life cycle of the pavements normally 10 - 40 years and predicts the pavement deterioration and its impact on road users besides social, economic and environmental impacts. The model performs analysis at three levels; strategic level, program level, and project level out of which two types of analysis are carried out by NHA i.e. strategic level and program level analysis. The strategy level analysis computes the net present value (NPV) of the benefits and compares it for the various possible project alternatives and selects the ones with highest NPV in 'free budget' situation. When budgetary constraints are involved, incremental benefit/ cost analysis techniques is used for optimal expenditures for multiyear programs. The program level analysis is short term and includes the development of a prioritized and optimized work program for achieving the objectives targeted for each financial year.

In order to manage the maintenance and prioritization of bridge assets on the national highway network, Bridge Management System (BMS) is being under a process of development by the Road Asset Management Division (RAMD) of NHA. This BMS includes inventory, inspection, condition survey, and collection of data pertaining to dimensions of structures, GPS position, pictures etc. of all the 6000 bridges and 20,000 culverts on the National highways.

2.4 SUMMARY

GIS has been in use worldwide in different areas such as Business, Crime Investigation, Communication, Defence, Education, Government, Hydrology, Intelligence, Mapping, Natural Resources, Public Safety, Public Health Engineering, Remote Sensing, Transportation and Utilities such as waste water and storm water management. A thorough literature review of use of GIS in transportation asset management revealed that GIS has been used in different countries for pavement management and maintenance (whether airport or highway), route and fleet management, street sign management, land record and property management, transportation planning and traffic management, accident recovery systems.

GIS technology has also been used in Pakistan but to a limited extent such as agriculture and irrigation, route mapping, power and energy management, flood mapping, traffic incidents, etc. The use of GIS applications in the field of transportation is almost negligible and for highway asset management nothing has yet been done. NHA has been using HDM-4 for preparation and prioritization of Annual Maintenance Plan since 2003. In order to manage the maintenance and prioritization of bridge assets on the national highway network, Bridge Management System (BMS) is also under development by the Road Asset Management Division (RAMD) of NHA.

However, there is currently no system to collect, store, analyse and display all the information about a particular transportation infrastructure. Such a system which stores, analyses, manipulates and displays all the relevant information about each highway of the network is called the GHAMS (GHAMS) which needs to be explored and developed.

Chapter 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

The development and economy of a country relies on the efficiency of its transportation system. Since roads are the most widely used mode of freight transportation within a country, huge amount of investment is made on their construction. These road assets are designed for a particular design period and serviceability and require Maintenance and Rehabilitation (M&R) in order to have increased service life. Presently, as such there exists no systematic and scientific approach for M&R of these road assets. Also, the M&R works that are undertaken are mostly unplanned and based on poor practices. Therefore, an Asset Management System is required for better planning, budgeting, resource allocation & management of these road assets. The system will thus enable provision of reliable and accurate road data including the condition of the road network, replacement cost of road network and the funds required to maintain the network to the required level of service.

Further, the integration of such a system with the GIS enables more efficient capturing, storing, visualization, querying, analysis & management of databases that are linked to different locations. In the absence of a GIS based asset management system, the data is usually managed in unrelated systems which make it difficult to understand the relationships between various attributes of pavements and their location on the network. This system at network level also helps in prioritization of the routes for M&R strategies based on their benefit cost ratio.

In Pakistan, RAMD of NHA ensures the road asset preservation, reduction in network level roughness and low cost maintenance and operation of road assets through preparation of Annual Maintenance Plan using HDM-4. This HDM-4 requires as an input the pavement condition survey, road roughness survey, traffic characteristics and residual pavement strength and predicts the road deterioration and its effect on the users, operating costs and the social, economic and environmental effects over the life cycle of the pavement. This system is mostly used for network level pavement management and as such the detailed decision making data regarding individual roadway sections may not be available. The use of GIS in pavement asset management system has not yet been made.

3.2 GEOGRAPHICAL INFORMATION SYSTEM (GIS)

World's leading GIS software developer ESRI defines GIS as "A geographic information system (GIS) integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information" (ESRI 2011). Using GIS, data can be viewed, queried, interpreted and visualized in different ways that reveal patterns, relationships and can be printed or displayed in the form of maps and charts.

GIS platforms vary in varieties having different information collecting, storing and integrating capabilities. The sources of the information may be external as well as local sources and typically includes satellite imagery, databases in the form of digital tables, existing maps, and airborne photographs. All of these datasets are integrated in a common spatial reference in GIS. A well designed GIS requires:

- Satellite imageries, airborne photographs, database, and existing maps as input data.
- Storage, retrieval, transformation, analysis, modelling and querying the data.
- Maps, graphs, charts and reports as output data.

3.2.1 Components of GIS

The essential components of the GIS are explained below:

3.2.1.1 Hardware

GIS software requires a hardware (computer system) on which it will run which ranges from Personal Computers to Server Computers. These computers should have essentially an efficient processor to run the software and sufficient memory to store enough information (data). The hardware also includes scanners, digitizers, GPS and printers as input and output devices (Carver, 1998; Fazal 2008).

3.2.1.2 Software

GIS software has the functions and tools required to store, analyze, manage, transform, analyse and display geographic information. All GIS software generally fit all these requirements, but their on screen appearance (user interface) may be different. Presently, object-relational model is in use in which the software packages allow both graphical and tabular data sets to be stored in a single database. Previously, the geo-relational model was used in which graphical and tabular data sets were stored in separate databases (Lo and Yeung, 2002; Fazal 2008).

3.2.1.3 Data

Geographic data and related tabular data are the backbone of GIS which are most time consuming and costly. It can be collected in-house or purchased. The primary input data is spatial data (digital maps) which can further be linked with the tabular data associated with the map objects (Fazal 2008). Quality of the data set is important because any errors in the data set effects the accuracy of the results of the analysis and could ultimately lead to difficulty in implementing a GIS.

3.2.1.4 Method

A well designed GIS operates according to the models and operating practices exclusive for each task. For example, maps can be developed using various techniques such as by automated raster to vector conversion or by digitizing the scanned images which can be utilized for any purpose. A typical operation includes input, storage, retrieval, management, transformation, analysis and output of the data (Fazal 2008). The transformation processes includes conversion of the coordinate and projection system, vector to raster and vice versa (Heywood 1998).

3.2.1.5 People

GIS users include technical specialists responsible for designing and maintain the GIS. These include GIS managers, database developers and administrators, application developers and systems analysts. GIS users also include professionals who use GIS systems to accomplish their everyday work. GIS operators solve real time spatial problems. They plan, implement and operate to draw conclusions for decision making (Lo and Yeung, 2002; Fazal 2008).

3.2.1.6 Network

The most fundamental development of Information Technology in today's world is the network which is solely responsible for quick communication and sharing of digital information. GIS uses internet for acquiring and sharing large geographic data sets (Fazal 2008).

3.2.2 Benefits

Due to the increasing awareness of the economic and strategic values of GIS, different organizations and industries are getting benefited from the use of GIS. The GIS benefits in the following five ways:

- Cost and Time Efficient - GIS helps in optimizing maintenance schedules and logistics movements. This optimization results reduced operational expenditures through efficient scheduling, reduced fuel usage and staff time besides improved customer service.
- Better Decision Making - GIS with its database and decision support systems enable better and quick decisions about a particular problem. The most relevant example is route/corridor selection. Making correct decisions about a particular problem is critical to the organization success.

- Improved Communication – GIS develops maps and charts besides graphical visualizations which provide a better understanding of the ground realities and in storytelling. These maps and charts provide improved communication among various departments, organizations and the personnel.

- Better Record keeping – GIS stores a huge quantum of database which keeps on increasing with time. Organizations responsible for maintaining records use GIS and its tools for keeping the records and the supporting documents.

- Managing Geographically - GIS coupled with remote sensing technologies enables understanding what is happening presently and what will happen in future in the geographic space and thereby allows initiation of an appropriate action.

3.3 METHODOLOGY FOR DEVELOPMENT OF GIS BASED HIGHWAY ASSET MANAGEMENT SYSTEM (GHAMS)

The methodology that has been adopted for the development of GHAMS involves the following tasks outlined below:

- Collection of reliable and accurate data and application of data handling techniques.
- Development of Database and input of Data into the GIS Software and Database Geo-referencing and development of GHAMS.
- Development of a Query Based System to get the required outputs from the GHAMS.
- Linkage of database with TransCAD to explore transportation related GIS functions.

Figure 3.1 presents the flow chart for the methodology adopted for development of GHAMS.

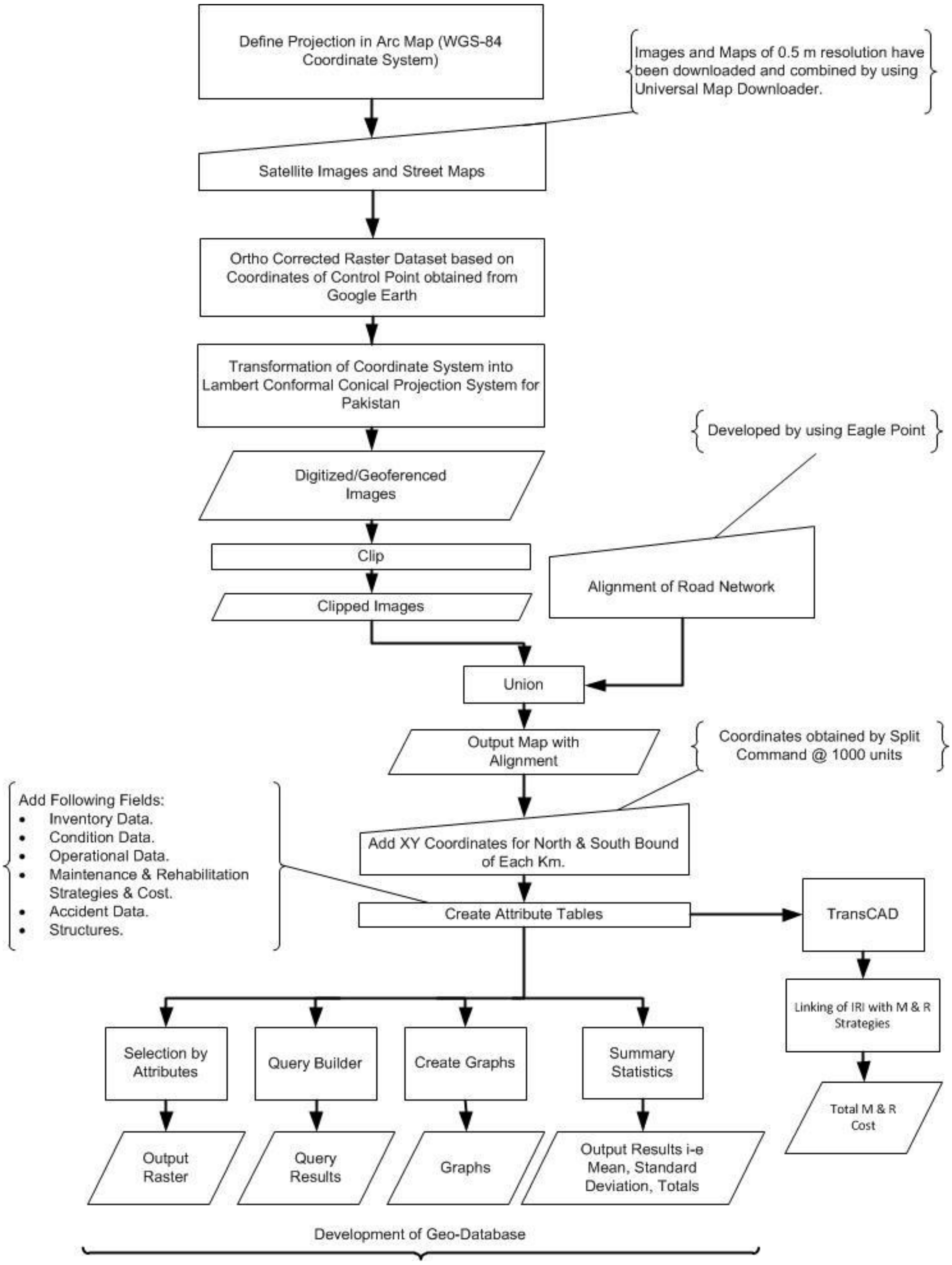


Figure 3.1. Flow Chart of Methodology Adopted

Step-wise procedure for development of the GIS based highway asset management framework is given as below:

3.3.1 Download of Satellite Imagery and Street Maps

To develop the GHAMS, Satellite Imageries and Street Maps of road network under consideration were required. Google Satellite Imagery & Street Maps were downloaded using the software Universal Map Downloader available on the internet. Downloading of the satellite image and street map of an area of approximately 4,000 Sq. Km. was a big task and if downloaded in one piece could result in a size of the file greater than terra bytes. Therefore, the satellite image and street maps were downloaded in various pieces at a zoom level of 18 (almost equivalent to 0.6m resolution) by specifying the coordinates of four points which are top latitude, bottom latitude, left longitude & right longitude as shown in Figure 3.2.

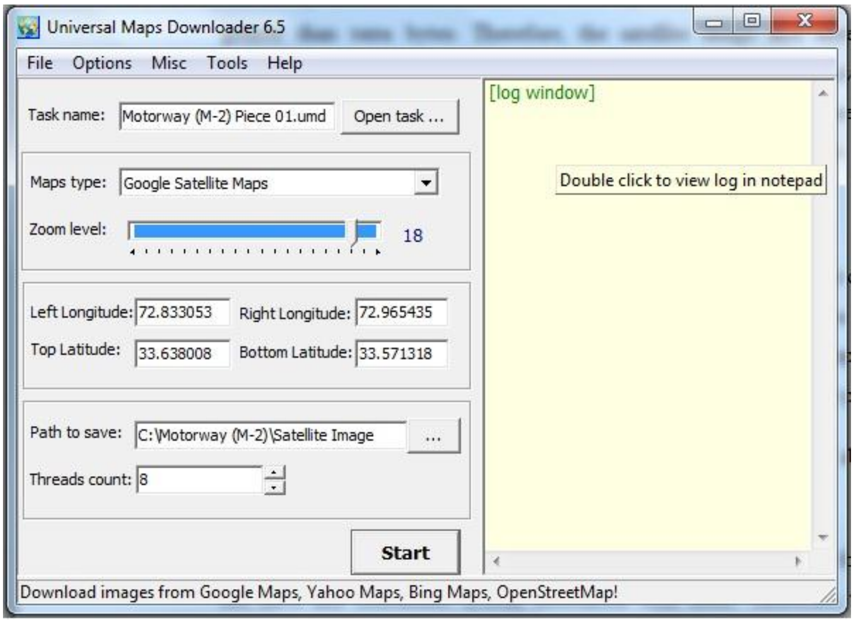


Figure 3.2. Input Data required in Universal Map Downloader

Based on the provided coordinates, the software selects the extent of the satellite imagery to be downloaded and then further splits the piece into various small size pieces and then downloads all the pieces as shown in Figure 3.3.

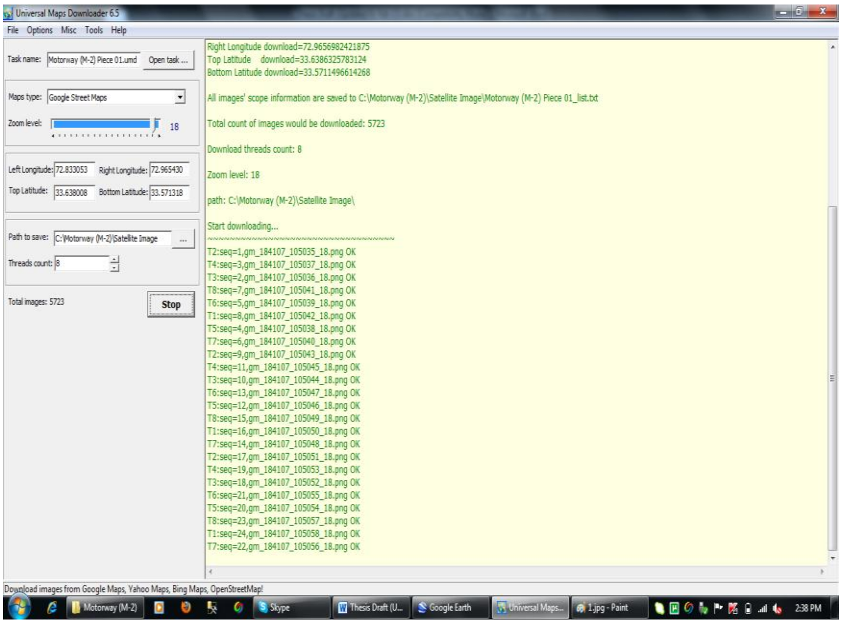


Figure 3.3. Image download in progress in Universal Map Downloader

After the completion of the download of all the pieces, the software automatically joins all the pieces using the "Map Combiner" option in the "Tools" drop down menu as shown in Figure 3.4. The satellite imagery and street maps of Motorway were completely downloaded in 50 pieces each piece having a size of about 2 GB.

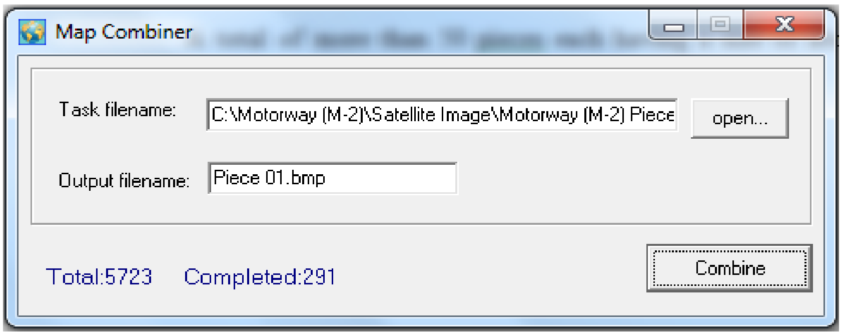


Figure 3.4. Map combining in progress using Map Combiner option in Universal Map Downloader

3.3.2 Geo-referencing of the Downloaded Satellite Imagery and Street Maps

The pieces of the satellite imageries and street maps were downloaded in the bitmap format and did not have any coordinate system associated with them.

Therefore, in order to geo-reference the satellite imageries and street maps, all of the pieces were imported in the ArcMap in World Geodetic System (WGS) 84 coordinate system. Visible and identifiable points at the four corners of the each of the piece were selected and provided with the coordinates (in latitude and longitude) of the same points that appear in the Google Earth. Resultantly, the satellite imageries and street maps were geo-referenced and by simply clicking or moving the pointer over the satellite imagery gives the coordinates.

3.3.3 Transformation of the Coordinates system

After geo-referencing the satellite imagery and the street maps in WGS84 coordinate system, each point on the satellite image and street map was represented by coordinates in latitude and longitude. However, since, the mapping system of the survey of Pakistan is based on the Lambert Conical Projection System with two standard parallels, most of the agencies collect the data with coordinates in Northing and Easting which are in meters. Therefore, the WGS84 coordinate system was transformed into Lambert Conformal Conical Projection system. The transformation was done using the parameters shown in Table 3.1.

Table 3.1. Transformation parameters

Projection	Asia Lambert Conical Projected Coordinate System.
Spheroid	Everest 1830
Grid	Grid – I
Latitude of Origin	32.50 m
Longitude of Origin	68.00 m
Northern Standard Parallel	35.31222222 m
Southern Standard Parallel	29.65555556 m
False Northing of Origin	914,398.80 m
False Easting of Origin	2,743,196.40 m

3.3.4 Development of Horizontal Alignment

The Lahore – Islamabad Motorway (M-2) was designed in the early 1990’s at a time when most of the drafting was done manually in Pakistan. Therefore, horizontal alignment of the Motorway (M-2) was not available in soft form and only hard copy was available. To draw the horizontal alignment, Autodesk AutoCAD and Eagle Point Roadcalc software were used. The coordinates of all the Points of Intersection (PIs) mentioned on the drawings in the Lambert Conformal Conical Projection System (LCCPS) were added in the Eagle Point Roadcalc Software which displayed the line graphics of the centreline on the AutoCAD software. Similarly, the radius of curvature at each PI was inserted in the Eagle Point and the same was reflected in AutoCAD.

According to the cross-section of Motorway (M-2), the centreline was given an offset on each side of 0.3 m for New Jersey Barrier line, 1.3 m for inner shoulder line, 12.25 m for carriageway (3.65 m x 3 lanes), 15.25 m for outer shoulder line, 40.00 m for right of way. The New Jersey barrier, carriageway, inner and outer shoulders were hatched with different colors to show their width.

3.3.5 Importing the Horizontal Alignment

Once the horizontal alignment was drawn in AutoCAD in LCCPS, it is added into the ArcMap using the “Add Data” icon and it overlaid exactly on the alignment visible on the Satellite Image and Street Map as shown in Figure 3.5.

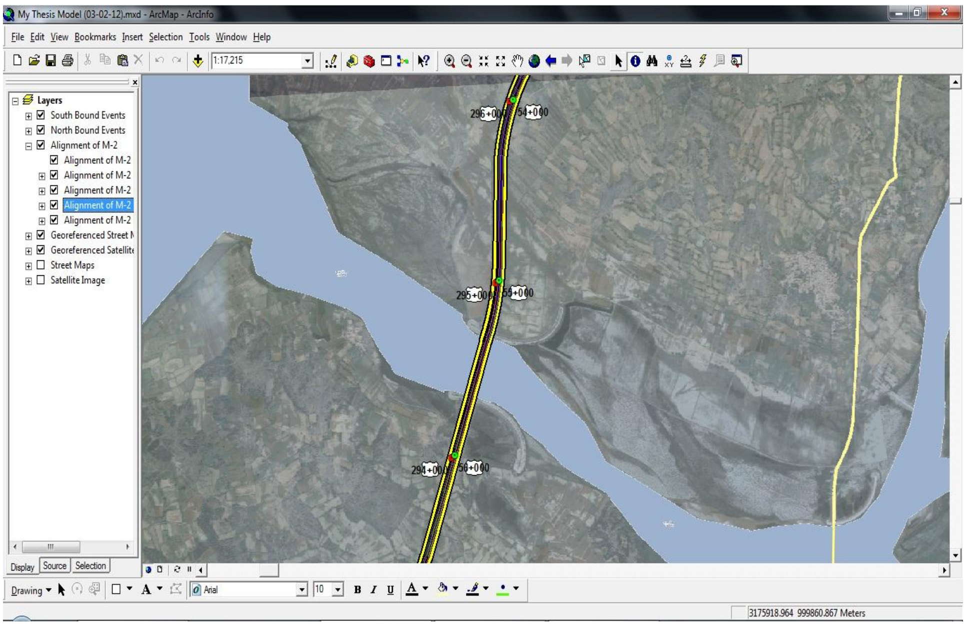


Figure 3.5. Horizontal alignment placed on the Satellite Imagery

3.3.6 Development of Database

The most important component of GHAMS is its database which keeps stored all the relevant information about the highway. The problem aroused here as how to link the collected kilometre wise information with the horizontal alignment. To solve this problem, the horizontal alignment was divided into segments of 1,000 m each in the ArcMAP using the "Start Editing" command. The process is described in the following steps:

- Select the polyline (centerline) to be divided into points.
- From Source tab, right click centerline and convert features to graphics. Check the "Selected" box.
- Then click "Drawing" drop down menu and select convert graphics to features.
- Then click "Stop editing".
- Again start editing and select the converted polyline.
- Click "Divide" and set divide by 1000 units for per kilometer division of the alignment.
- Then finally click "Stop editing".
- Open attribute table for the converted polyline (centerline). From options, click add field for xcoord and ycoord.
- Then right click the column of xcoord and select "Field Geometry" option. A window will open and select "X-Coordinate of the Start Point". The ArcMAP software will automatically calculate the x-coordinates of each kilometer.
- Then right click the column of ycoord and select "Field Geometry" option. A window will open and select "Y-Coordinate of the Start Point". The ArcMAP software will automatically calculate the x-coordinates of each kilometer.

Once the horizontal alignment was divided into kilometer wise segments and the coordinates of each kilometer were calculated in the attribute table, all the relevant information about the highway as collected above was linked with it. To link the information, the attribute table in the ArcMAP was exported in the

Microsoft Excel format. The kilometer wise information was inserted against the kilometer wise coordinates in individual columns in the exported Microsoft Excel Worksheet. The worksheet was then converted into Microsoft Access Database files (.dbf format). Based on this, a user friendly database was developed with the capability of easy update and compatibility with other databases. Major columns of the Attribute Table are shown in Table 3.2. A sample portion of the Attribute Table is attached as Appendix 1.

Table 3.2. Sample Attribute Table

Chainage (Km)	X Coordinate	Y Coordinate	Cracking Index	Roughness Index (m/Km)	Remaining Service Life	AADT
0+000	3334143.41	817160.28	0.00	4.31	3.54	15,028
1+000	3333924.14	818093.74	0.00	5.36	3.25	15,028
10+000	3336108.97	826154.30	25.00	4.60	2.81	15,028
11+000	3335343.70	826798.01	25.00	4.88	2.81	15,028
110+000	3250777.39	863136.78	2.50	3.46	3.76	7,281
111+000	3249783.86	863046.03	0.00	3.58	3.83	7,281

3.3.7 Global Positioning System (GPS) Coordinates

GPS Coordinates of the Alignment were collected for verification of the Designed Horizontal Alignment and incorporation into the GHAMS. Mobile GPS was purchased which was attached to automobile during the visit of Motorway and it recorded per second Latitude and Longitude.

3.3.8 Linkage of Database with ArcMAP

The database was imported using the “Add XY” command in the ArcMap which then takes the shape of Attribute Table. The kilometer wise and direction wise pictures taken were linked with the database. The database was linked with the ArcMap in such a way that any changes made to the database are automatically updated in the software.

Since the effectiveness of the data analysis relies on quality of the input data, the use of usable, consistent, accurate and recent data was ensured. Information regarding all the pavement related activities was collected from the

RAMD of National Highway Authority (NHA) which may be categorized as follows:

3.3.8.1 Inventory Data

- ***Design Service Life*** is the time period assumed by the pavement designers during which it will work within its specified parameters.
- ***Horizontal Alignment*** consists of horizontal tangents, circular curves, and possibly transition curves.
- Type of Pavement (Flexible, Rigid, Composite).
- Width of Travelled way.
- Number of Lanes.
- Year of Construction.
- Quarry Sites.
- PC-I Cost of Construction.
- Structures (location, type and size).

3.3.8.2 Condition Data

- ***Pavement Condition Survey*** is conducted to identify the prevailing roadway pavement conditions that alter the capacity and safety of pavement such as permanent deformation or fatigue cracking, pavement rutting, patching, edge step, raveling, potholes, drainage conditions etc.
- ***Road Roughness Survey*** is conducted to identify the unevenness in the pavement surface that adversely affect the riding qualities.
- ***Road Traffic Survey*** is conducted to determine the traffic volume (24 hours traffic count). It also includes axle load survey which considers vehicle type, its classification and the axle load.

3.3.8.3 Maintenance & Rehabilitation Data

- ***Types of M&R Strategies*** are the strategies necessary (strengthening activities) to restore the pavement's (in roads and bridges) structural strength and functional performance to the originally constructed conditions.

- Cost of M&R Strategies based on CSR 2009 have been used and are shown in Table 3.3.

Table 3.3. Maintenance and Rehabilitation Strategies and Costs

Maintenance and Rehabilitation Strategies	Financial Cost 7.3 M wide Per Km. (Rs. In Million)
Routine Maintenance For Single Carriageway	0.07
Functional Overlay 30 mm thick For Single Carriageway	4.25
Functional Overlay 50 mm thick (With deep patching) For Single Carriageway	5.92
Hot Recycling unit rate For Single Carriageway	2.60
Structural Overlay 100 mm thick For Single Carriageway	9.22
Reconstruction 25 cm WBM Base / 13 cm Asphaltic Concrete For Single Carriageway	20.74

3.3.8.4 Operational Data

- Weigh Station.
- Toll Tax.
- Service Areas Revenue.
- Fine Collection.

In conjunction with the above mentioned, the following additional data of the road alignment was collected/ downloaded:

3.3.8.5 Accident Studies

These studies are essential in order to ascertain the accidents/ causalities caused due to poor riding qualities of the road asset for taking appropriate measures. The accident data for year 2010 was provided by the RAMD of NHA.

3.3.8.6 Remaining Service Life (RSL)

One of the outputs of the Highway Development and Maintenance Management System (HDM-4) developed by World Bank is the Remaining Service Life. This RSL has been used as input in the GHAMS.

3.3.9 Development of a Query Based System

Querying is the process of retrieval of the required information from the data sources or drawings. As the command of a certain query is placed, the software automatically searches for that object and displays the required information. Further, a query based system was developed that displays all relevant information of a desired location as shown in Figure 3.6. The system not only graphically displays the severity level of distresses but it also helps in making decisions regarding pavement rehabilitation treatments and their costing.

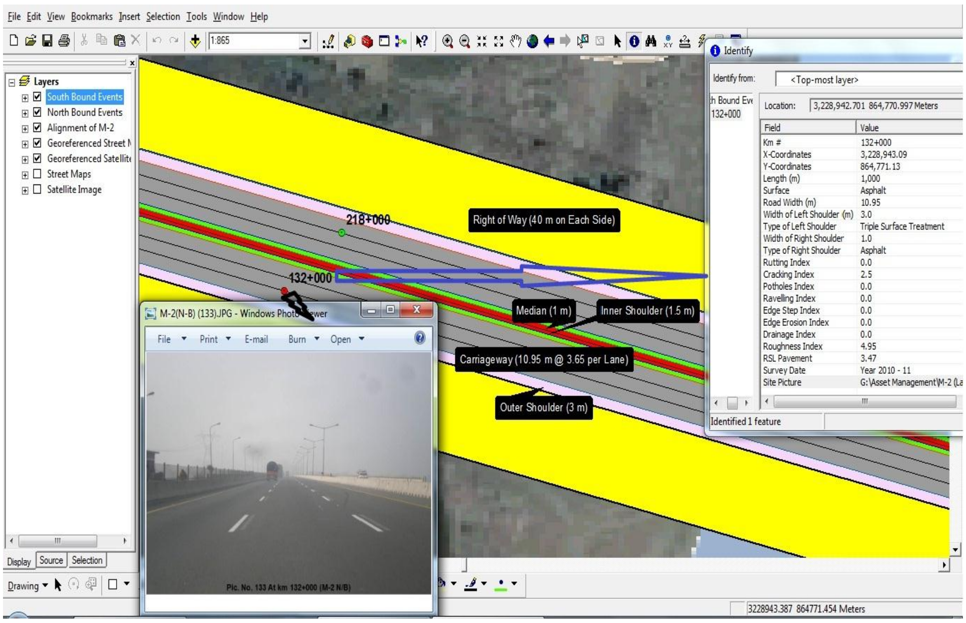


Figure 3.6. Information Display at KM 132+000 (North Bound)

3.3.10 Linkage of Database with TransCAD

GIS can support and perform spatial and transportation analysis on various activities relating to transportation planning. The first GIS designed specifically for the storage, display, analysis and management of transportation data is TransCAD. TransCAD is the most powerful GIS-Base software that helps in creating and customizing maps. It can develop and maintain Geo databases and can perform various spatial analyses. It combines GIS and transportation modelling capabilities at one platform that can be utilized for all modes of transportation at any detail level. It comprises of polygon overlay, buffering, and geocoding features of GIS. Moreover, it also includes modules for routing, travel demand forecasting, public transit, logistics, site location, and territory/land management. Tools specific to trip analysis include trip generation, trip attraction, trip distribution, trip balancing, mode choice analysis, traffic assignment, shortest path finding, emergency management and LOS analysis. Furthermore, it is the most suitable software for development of transportation information and decision support system.

In this study, TransCAD has been used to obtain the Maintenance and Rehabilitation Cost required for an in-service Motorway for certain year. The database developed and used in the GHAMS was exported in the .dbf format. The exported .dbf file was opened in the TransCAD which displayed the alignment of the road network along with the attribute data on the TransCAD window. The attribute data was further linked with the Maintenance and Rehabilitation (M&R) strategies and their treatment costs.

3.4 SUMMARY

This chapter presented the work methodology adopted for development of a GHAMS. The chapter presented the method to download the satellite imagery and street maps utilizing the free sources on the internet. Geo-referencing of these freely downloaded satellite imageries an street maps is also described. The transformation of the coordinate system from WGS 84 to Asia Lambert Conformal Conical is also described in detail. The chapter also presented the data collected and creation of database from it. Integration and linking of the database with the ArcMap is also discussed. Use of TransCAD software for linking the Maintenance and Rehabilitation (M&R) Strategies and their costs is also described.

Chapter 4

APPLICATIONS OF GIS BASED HIGHWAY ASSET MANAGEMENT SYSTEM (GHAMS)

4.1 INTRODUCTION

Database being the heart of the GHAMS is of no use unless it is presented in a meaningful and interactive way. The GHAMS uses various analysis procedures to transform the raw data into graphs, charts & reports. The integration of GHAMS with TransCAD helps in calculating Maintenance and Rehabilitation Costs that indeed makes the decisions to be made easily. The GHAMS makes possible transformation of the spread sheet data into the map form which enables user to examine the highway condition in a way that is not apparent from the spread sheet data. The chapter also describes how to place labels and queries in GHAMS for display of the required information. The procedure for creation of layouts and their utilization for display of the GHAMS Maps are also explained. The outputs of GHAMS provides information that can be used in implementing cost effective reconstruction, rehabilitation & maintenance programs.

4.2 APPLICATON OF RESEARCH ON AN IN-SERVICE ROAD – A CASE STUDY

As a case study, GHAMS of Islamabad – Lahore Motorway (M-2) is developed. M-2 was the first ever Motorway built and opened for operation in Pakistan. It was originally conceived by the Govt. of Punjab under the then constituted Punjab Highway Authority (PHA) but soon was taken over as a federal function. It was opened to regular traffic in 1997.

The Motorway starts near Thokar Niaz Beg at Lahore, passes close to Sheikupura to reach Pindi Bhatian, takes a slight right turn to cross River Chenab near Sial Mor, move to Kot Momin, crosses River Jehlum near Bhera, passes close to Lilla to enter the Salt Range, comes out to pass close to Balkasar and Chakri to end close to Tarnol – Fateh Jang and Rawalpindi – Peshawar Roads.

The length of M-2 is 367 Kms including Islamabad and Kala Shah Kaku Link Roads. It is a 6-Lane motorway with 3 major bridges on river, 8 interchanges, 27 flyovers, 17 canal bridges, 39 drain bridges, 4 railway crossing overhead bridges, 183 subways and cattle creeps, 22 culverts on canals and 73 culverts on drains. Approximately 50,000 vehicles use this motorway daily.

Road condition of M-2 is comparatively better than other highways in the country. Due to enormous increase in traffic volume and aging phenomenon of asphalt, it has started to show some functional distresses.

The applications of GHAMS can be categorized as follows:

- Thematic Maps
- Graphs & Charts
- Reports
- Labeling
- Query based results
- Single Click Information Display
- Print and Export
- Rehabilitation and Maintenance Cost Calculation

4.2.1 Thematic Maps

Choropleth maps or thematic maps are the symbolic representation of the geographic features according to the attribute data through the use of colors, symbols, labels and other user defined display properties. These maps can be created from the feature class or alternatively using the query command. Structural and functional attributes such as the inventory data or the condition survey data can be shown in the Thematic Maps. These maps can also be drawn for a range of values or for a unique value with range calculation and clustering techniques. The thematic maps also display the scales, legends, direction arrow and labels. Figures 4.1 – 4.2 shows few examples of thematic maps that can be generated.

Figure 4.1 below presents the thematic map showing the GPS coordinates of the south bound and the north bound carriageway collected at each kilometer in green and red color points. Figure 4.1 also shows the Motorway (M-2) with chainages mentioned at each kilometer interval for south bound and north bound respectively.

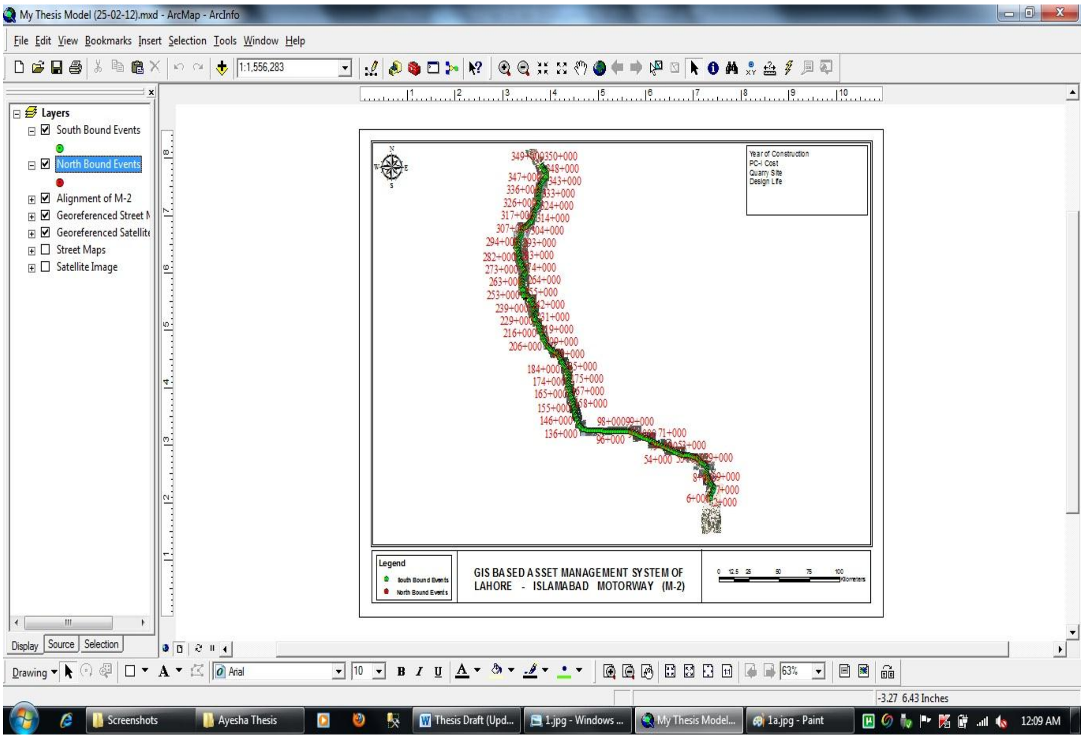


Figure 4.1. Thematic Map of Motorway (M-2) with Chainages

Figure 4.2 shows another example of the thematic map which presents Km 198+000 to Km 203+000 of Motorway (M-2) with satellite imagery in the background. Figure 4.2 also displays the kilometer wise chainages and the Average Annual Daily Traffic (AADT) prevailing on the section. As can be seen from Figure 4.2, the AADT from Km 200+000 to Km 203+000 is 5,502 veh/ day in each direction whereas it is 4,934 veh/ day/ direction from Km 198+000 to Km 200+000. The figure also labels the various components of the roadway such as the median width, carriageway width, inner and outer shoulder width and the right of way. Likewise, thematic maps can be displayed and printed for any particular sections along with its AADT information.

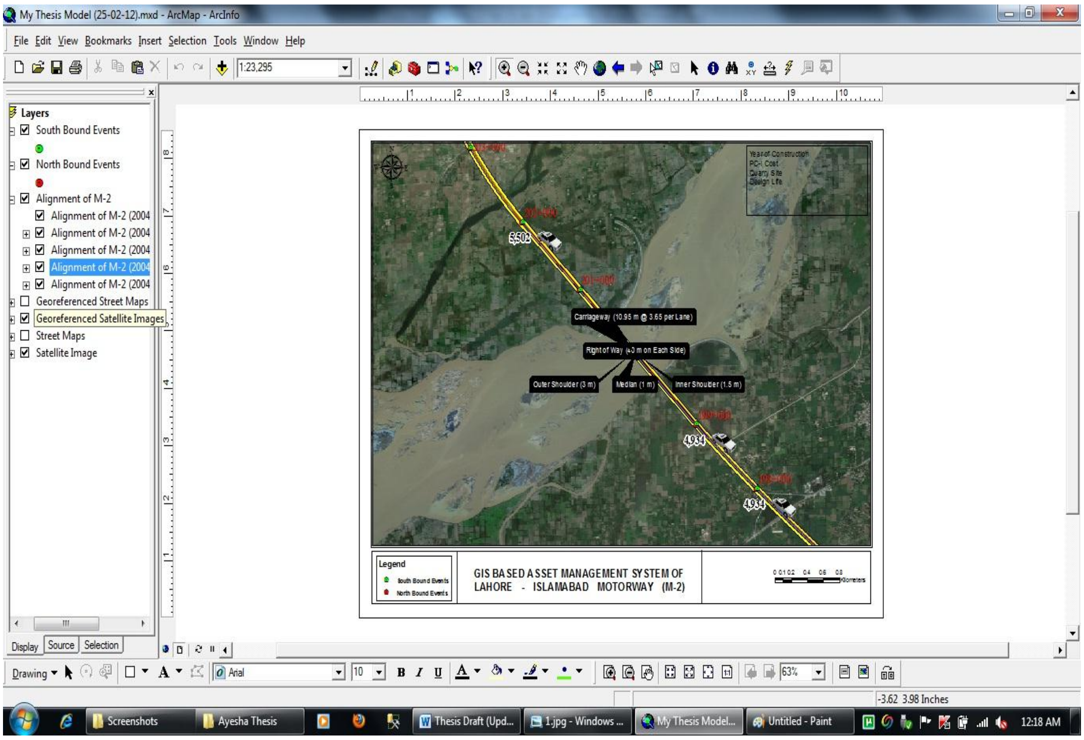


Figure 4.2. Thematic Map of Motorway (M-2) with Satellite Image in the Background and Labels on Roadway components and AADT.

4.2.2 Graphs & Charts

A useful output of the GHAMS is the development of Graphs & Charts of the attribute data. These graphs and charts can provide meaningful information about the roadway conditions which coupled with the satellite imagery and photographs can greatly help in decision making.

In order to plot the graphs, click on the “Tools” drop down menu of ArcMap software, then click on “Graphs” and select the “Create” option. The “Create Graph Wizard” will open as shown in Figure 4.3. Select the “Graph Type” from the drop down list and also select the “Layer/ Table” which contains the required fields between which the graph is to be plotted. Then select the “X Field” and the “Value Field”. Select the other options and formatting as per requirements and click “Next”. Define the “Axis Properties” and “Graph Legend” such as their titles, positions and other options as per requirement and click “Finish”. A graph will be created.

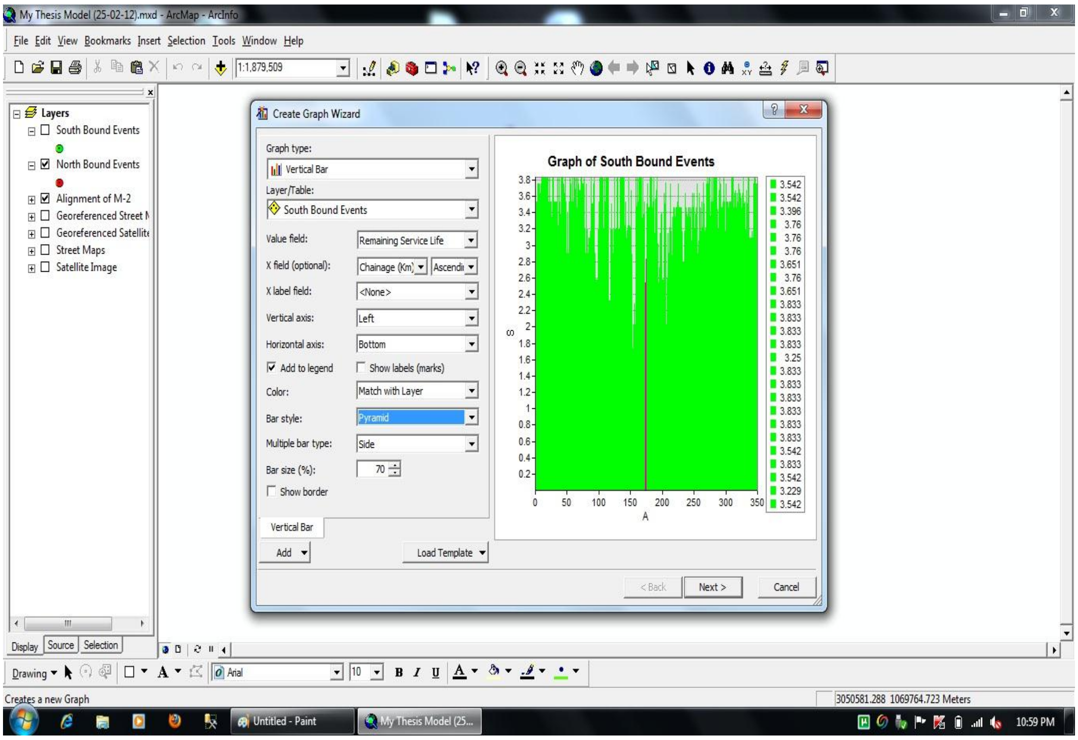


Figure 4.3. Create Graph Wizard (Step-1)

Using the procedure described above, a graph between Remaining Service Life (RSL) and Chainage has been plotted as shown in Figure 4.4. The graph shows that the RSL values range from 3.833 maximum to 1.190 minimum which simply means that Motorway must be rehabilitated within the next 4 years in order to enhance the service life. Otherwise, its RSL will drop down to zero and then reconstruction will be required which will involve more cost than that required for rehabilitation. Therefore, graphical information supplemented with satellite imagery and photographs showing the roadway conditions can be very useful for making correct decisions at the appropriate locations in time.

Similarly, graphs between chainage and other pavement condition indicators such as rutting index, cracking index, potholes index and roughness index can also be plotted.

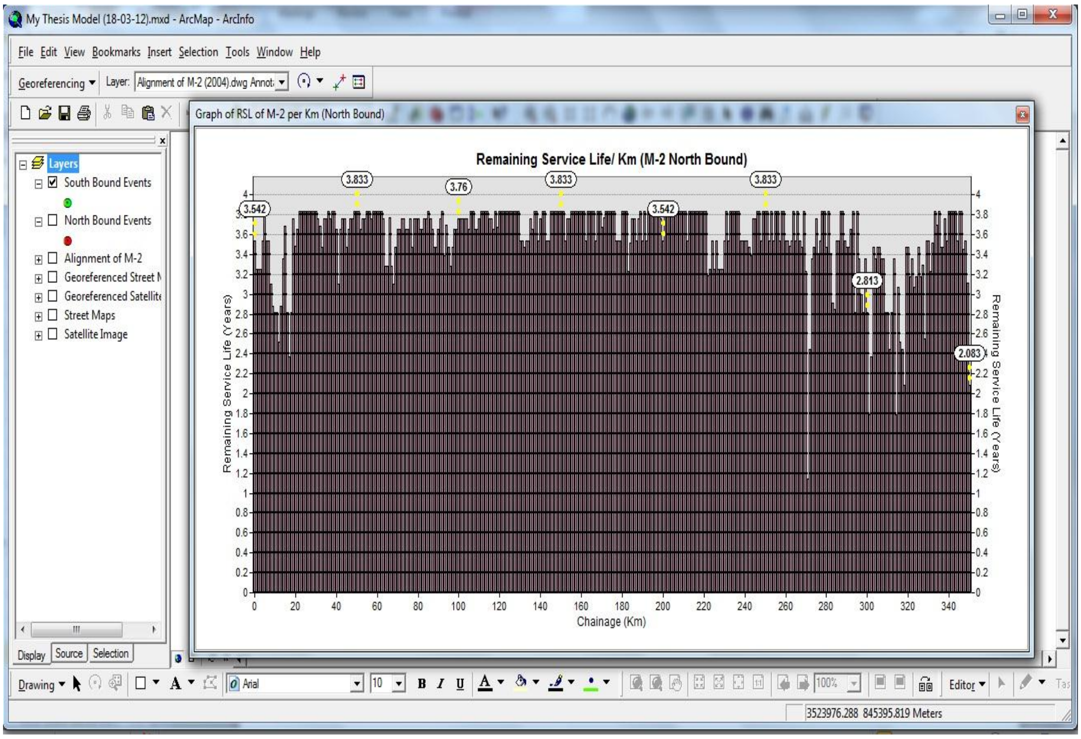


Figure 4.4. Graph between Remaining Service Life and Chainage

4.2.3 Reports

Another useful output of the GHAMS is the creation of report from the attribute table data. In order to create the reports, click the "Tools" drop down menu of ArcMap software, move the cursor to "Reports" and then select the "Create Report" option. The dialogue box named "Report Properties" will open. Select the "Layer/ Table" which contains the data about the field(s) to be reported. Then select the field(s) to be reported from the available fields. Once selected, the field to be reported will appear in the right column under the "Report Field" heading. Also, select the appropriate options and formatting settings as per requirements and click "Generate Report".

Using the procedure mentioned above, a report between the Remaining Service Life and Chainage is generated and displayed in Figure 4.5. The report shows the remaining service life against each kilometer. The report can be printed or saved into various formats such as Adobe PDF, Microsoft Excel, etc. Likewise, reports can also be generated for various roadway parameters such as kilometer wise carriageway width, shoulders width, right of way; pavement condition indicators such as rutting index, cracking index, potholes index and roughness index.

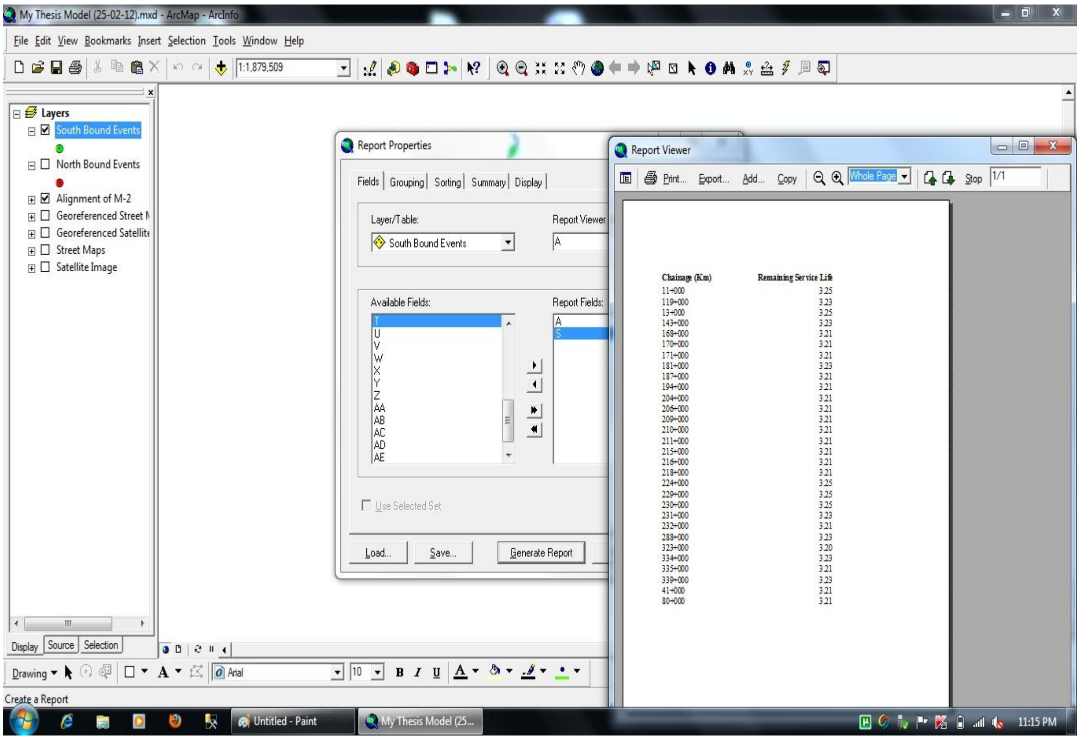


Figure 4.5. Report of Remaining Service Life and Chainage Data

4.2.4 Labeling

An important feature of the GHAMS is labeling the geographical location of the data that it represents. In order to label the features, right click on the layer to be labeled in the “Layer” menu of the ArcMap software, then click on the “Properties”. Select the “Labels” tab and then select the features to be labeled and their symbols.

For example, if a user is interested to label the X-Coordinates of the alignment on the map, then, click on the “Add” Button. A dialogue box will appear naming “Enter New Class Name”. Enter the “Class Name” as “X-Coordinates”. Then Click “OK”. Select the “X-Coordinates” against the “Label Field” drop down menu as shown in Figure 4.6 and then Click “Apply” and “OK”. X-Coordinates of the alignment will be displayed on the map window.

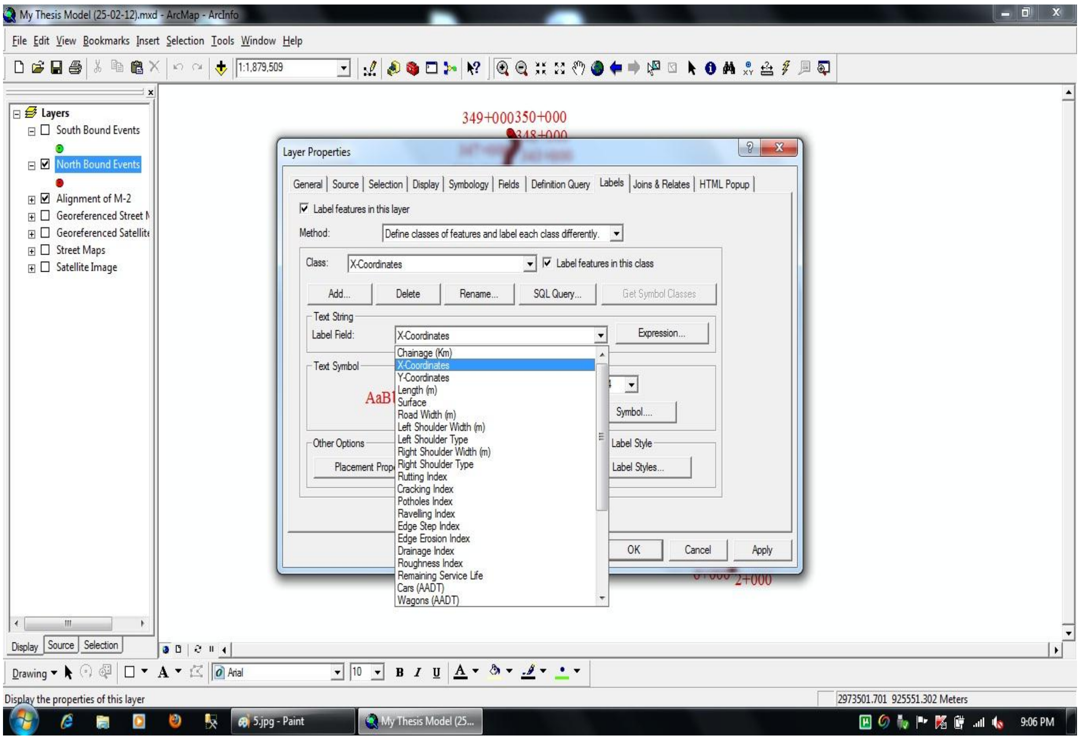


Figure 4.6. Labelling of the Data

4.2.5 Query Based Results

GHAMS also enables the display of appropriate information using the query command. In order to place the queries and display the resulting outputs, from the "Layers" menu of the ArcMap software window, right click on the layer to be queried, click on the "Properties". Select the "Definition Query" tab and then click on "Query Builder" or alternatively click "Select by Attributes" from the "Selection" drop down menu of the ArcMap 9.1. Query Builder window will open as shown in Figure 4.7.

Suppose if a query is to be made for the sections where the value of remaining service life is between 3.20 to 3.30 years, then, the following command will be entered:

"Remaining Service Life" >= 3.2 AND "Remaining Service Life" <= 3.3.

Click "OK" and then click "Apply". The GHAMS will display the sections where the values of the remaining service life is between 3.20 and 3.30

years. Figure 4.7 shows sections with the remaining service life between 3.20 and 3.30 highlighted in green color.

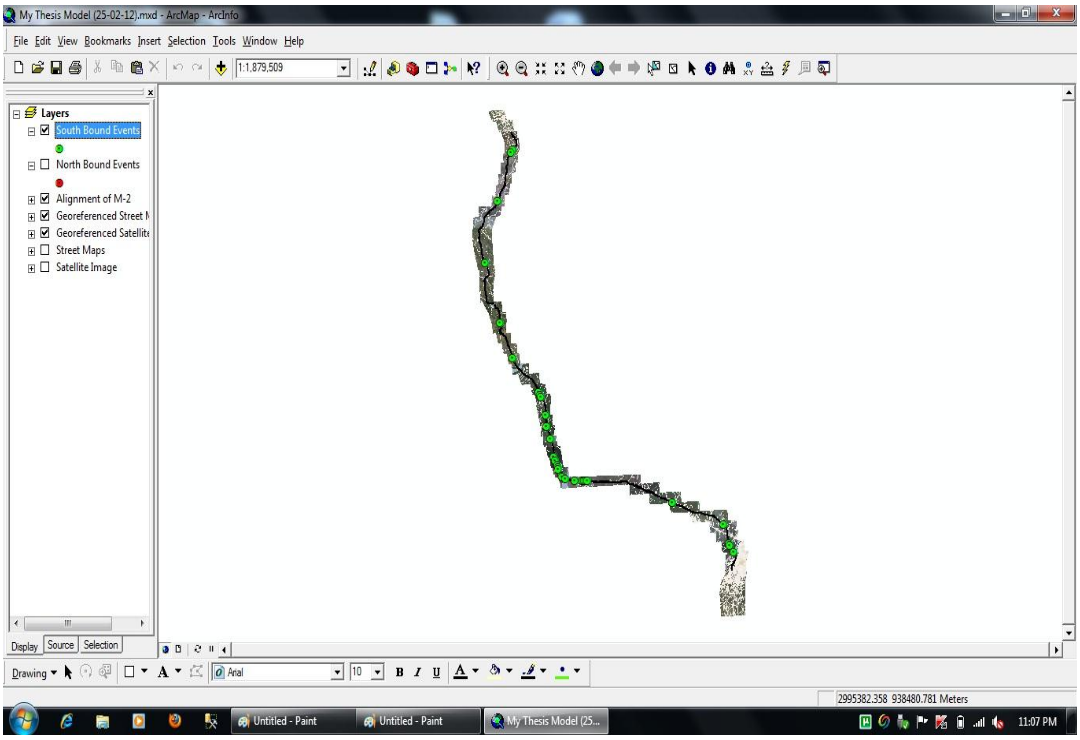


Figure 4.7. Display of the Query Results for Sections with Remaining Service Life between 3.20 and 3.30 years.

Similarly, queries can also be placed for roadway sections where the Average Annual Daily Traffic (AADT) is greater than or smaller than a particular value. For example, if we desire to find sections on south bound where the AADT is greater than 5000, then the following command will be entered in the "Query Builder Window:

"Average Annual Daily Traffic > 5000"

The GHAMS will highlight all the sections where the value of the AADT is greater than 5,000 veh/day.

Queries can also be placed for the identification of black spot analysis or accident location determination. In order to place a query to determine the locations of accidents that have occurred on the north bound, enter the following command in the "Query Builder Window:

"Accidents=Yes"

This command will highlight all the portions of North Bound of Motorway where accidents have occurred as shown in Figure 4.8.

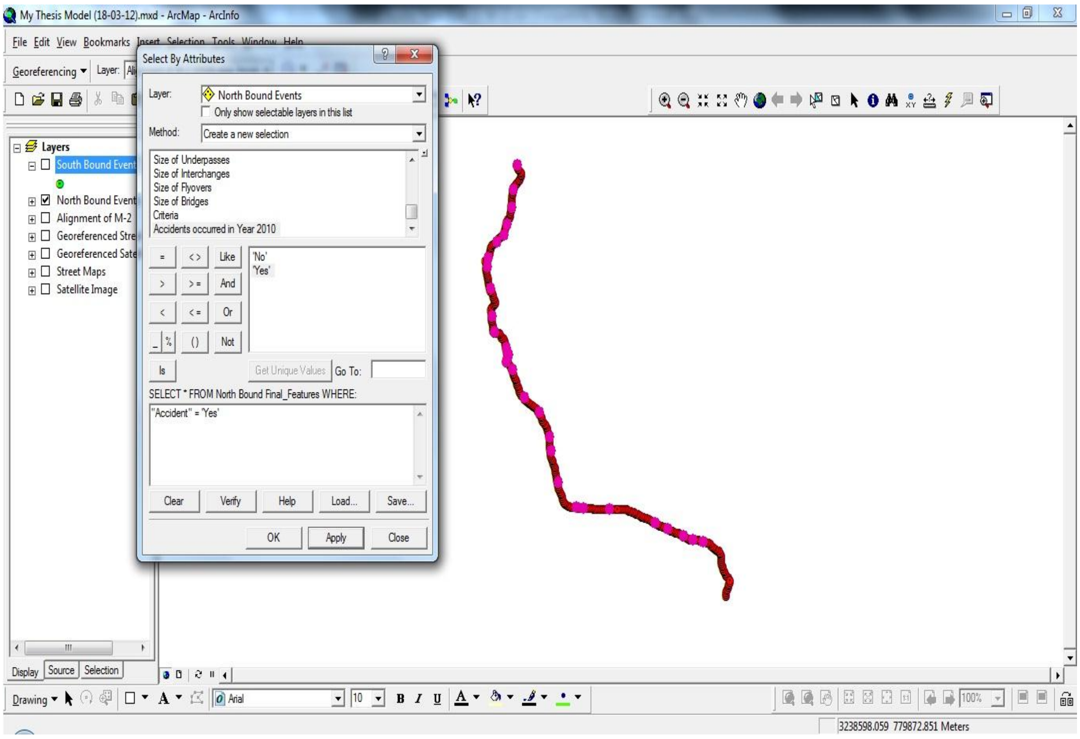


Figure 4.8. Query for Accidents occurred

Likewise, queries can also be placed to determine the locations of the structures such as bridges, flyovers, culverts, cattle creeps, interchanges, weigh stations, etc.

4.2.6 Single Click Information Display

Using the GHAMS, the information about a feature can be obtained on a single click. Click the "Identify"  icon in the ArcMap. "Identify" window will open. Select the feature for which information is required. Complete information about that geographical location available in the database will be displayed as shown in Figure 4.9. Clicking on the "Site Picture" will display the Picture of that location as well.

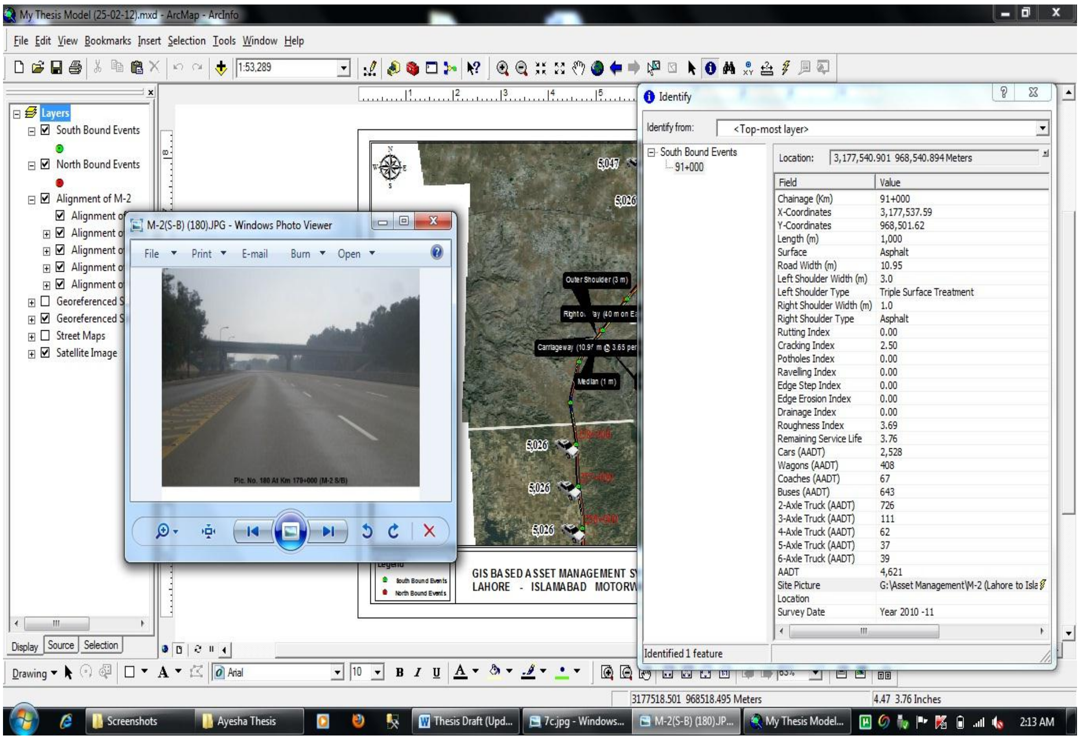


Figure 4.9. Information and Site Picture Display using the "Identify" feature of ArcMap.

4.2.7 Print and Export

The map displayed on the screen and information can either be printed or exported into various formats using the print and export capabilities of the ArcMap software. In order to do so, click the "Layout View" from the "View" drop down menu. Then click on the "Change Layout" option in the "Label" toolbar. Browse to the destination of the template or select from the available templates. In this study, the layout shown in Figure 4.10 has been created and used for display of maps.

Once the layout has been created and applied, the next step is to print the map which is very similar to the printing options available in the common softwares. The layouts can also be exported to .pdf and .jpeg etc. formats. The attribute table data can also be exported in Microsoft Excel and Access format by right clicking on the layer and select the "Export Data" option.

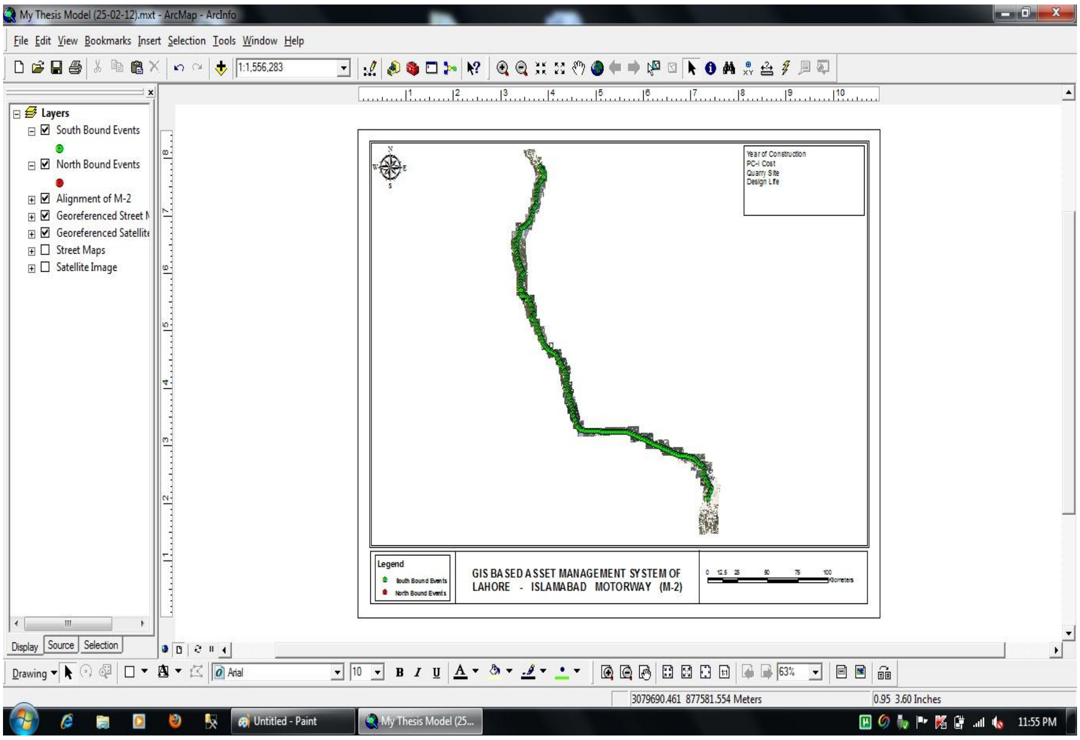


Figure 4.10. Layout for Printing of Maps

4.2.8 Maintenance and Rehabilitation (M & R) Cost Calculation

To develop the link with TransCAD, the complete database for GHAMS needs to be exported in Microsoft Access Database format which is compatible with TransCAD. Therefore, the attribute table data was exported in .dbf format by right clicking on the layer and select the “Export Data” option.

The database was then imported in the TransCAD by simply clicking on the “File” drop down menu and then selecting “Open”. In the “Open” dialog box, select “dBASE file” from the drop down menu against the “Files of Type”. Then browse to the location of the exported file and click “Open”. The database will be imported in the TransCAD.

Once the database was imported, TransCAD automatically identified the coordinates present in the file and displayed the alignment as per its coordinates as shown in Figure 4.11.

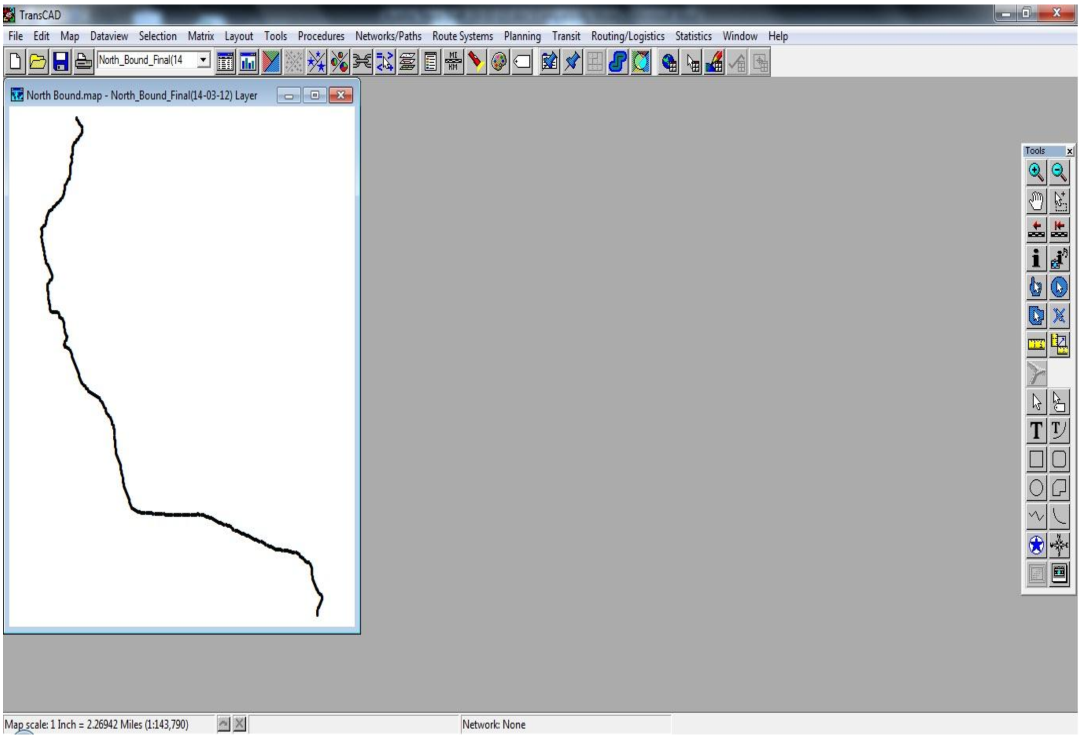
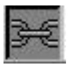


Figure 4.11. Alignment Displayed in TransCAD Window.

Click on "Open Dataview"  icon. This will display the database linked with the imported alignment. Now, the Pavement Maintenance and Rehabilitation (M&R) Strategies and their costs were linked with the database. The M&R Strategies and their Costs based on Composite Schedule of Rates (CSR) 2009 of National Highway Authority (NHA) are attached at Appendix 2 and their selection criteria as per NHA Standards are attached at Appendix 3.

In order to develop the link, click the "Join Dataviews"  icon. Type the name of the new joined view. Under the "Joining from" Select "North_Bound_Final(14" from Table drop down menu and select "Criteria" in the "Field" drop down menu. Then under "To" browse to the location of the file which is to be joined against the "Table" drop down menu. In the present case, select "M&R Strategies & Costs" and select "S_No" against the "Field" drop down menu and then click "OK".

The TransCAD automatically picks the required M&R strategy at each kilometer and the cost associated with the strategy as shown in Figure 4.12.

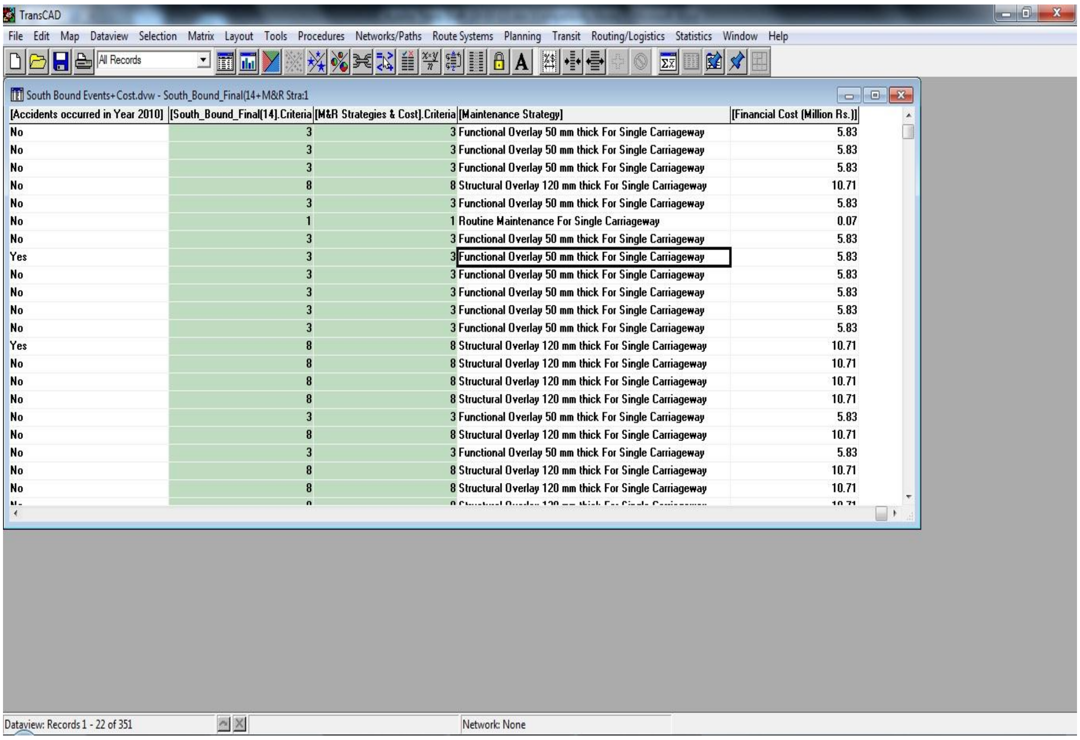


Figure 4.12. Output showing Relative M&R Strategies & Costs

Using the Statistics module of the TransCAD, the total cost involved in M&R can be calculated. In order to do so, click on the "Compute Statistics"  icon. The results shows that total cost of maintenance and rehabilitation of Motorway for the particular year as per CSR 2009 i-e Rs. 2,580 Million.

The TransCAD was linked with the database in a manner that allowed automatic updation of the database once the data is modified in the attribute table of the GHAMS.

4.2.9 Development of Geo-Database

Geo-Database stores spatial and non-spatial data and their relationships. It has .mdb extension which can be read by anyone but can be edited by the original used. It can accommodate large sets of vector features. Moreover, flow of resources can also be stored in the database.

Open the "ArcCatalog" Program. Right click the window and select "New" and then "Personal Geodatabase". The data used for the development of

GHAMS will be imported in the Personal Geodatabase as show in Figure 4.13. It includes Feature Classes, Tables, Datasets, Outputs in the form of Graphs and Queries.

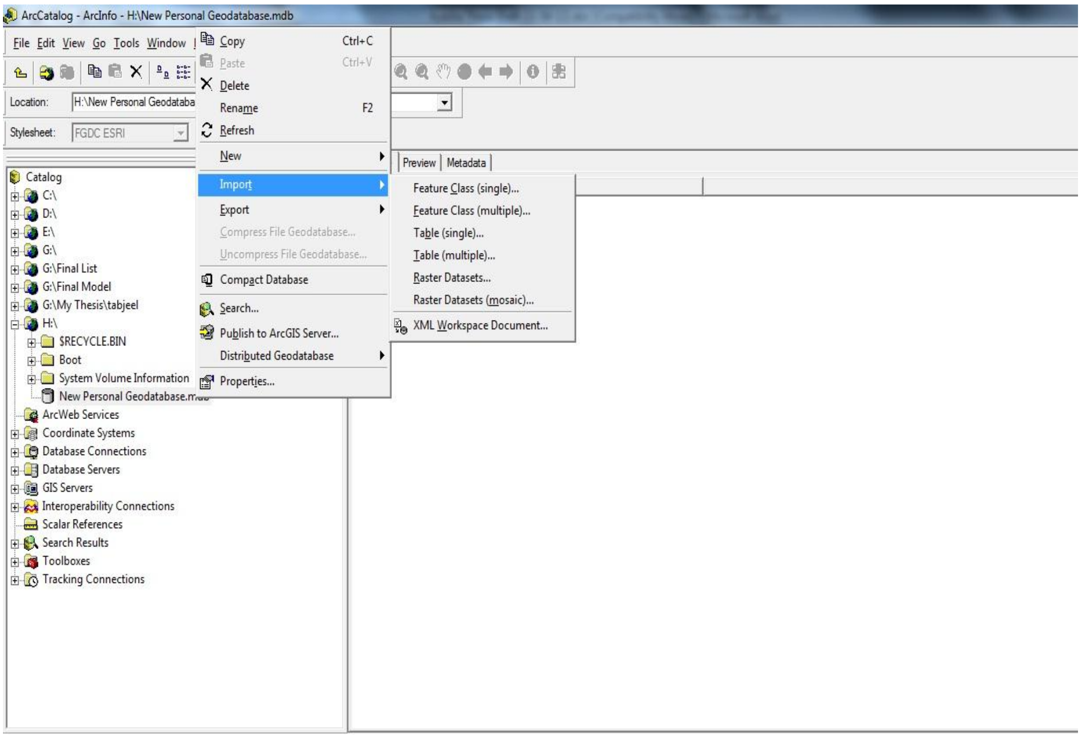


Figure 4.13. Development of Geo Database (Step-2)

4.3 SUMMARY

This chapter presents the methodology adopted for development of GIS based Highway Asset Management System (GHAMS). As a pilot project, GHAMS of Motorway (M-2) is developed. To develop the GHAMS, Satellite Imageries and Street Maps of M-2 were downloaded using the software Universal Map Downloader. These imageries and maps were the geo-referenced and then transformed into the Lambert Conical Projection System with two standard parallels. Information regarding all the pavement related activities was collected from the RAMD of NHA. Then alignment of the Motorway (M-2) was drawn in AutoCAD using the Eagle Point Software in the Lambert Conical Projection System and then added into the ArcMap. The horizontal alignment was then split into segments of 1,000 m each to link the Kilometer wise information with the alignment. The kilometer wise data was then converted into Microsoft Access Database files (.dbf format). Afterwards, the database was imported in the ArcMap which then takes the shape of Attribute Table. The kilometer wise and direction wise pictures were taken and then hyperlinked with the database. Based on the above data, a user friendly database was developed with the capability of easy update and compatibility with other databases. The database was linked with the ArcMap in such a way that any changes made to the database are automatically updated in the software.

The database developed and used in the GHAMS was imported in the TransCAD which displayed the alignment of the Motorway (M-2) along with the attribute data on the TransCAD window. The attribute data was then joined with the Maintenance and Rehabilitation (M&R) strategies and their treatment costs for calculation of the M&R Costs.

Chapter 5

CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

This research resulted in Development of GHAMS of an in-service Motorway. The research initiated with the Literature review to write down the level of research/ study already carried out on GHAMS in other countries along with their conclusions and recommendations. This is then followed by collection of information regarding design, construction, operation, pavement evaluation, and maintenance and rehabilitation strategies, GPS coordinates and accident data, etc. The data was mostly provided by the Road Asset Management Directorate (RAMD) department of NHA.

In order to have visual display of the location, Google satellite imagery & street maps of 0.6m resolution using software available on the internet were downloaded. Satellite Imagery and Street Maps each were downloaded in 50 pieces having an individual size of about 2 GB. The satellite imagery and street maps were then geo-referenced in ArcGIS software in WGS84 coordinate system by providing coordinates of visible and identifiable points at the four corners of the downloaded Satellite Imagery and Street Maps with the coordinates of the same points that appear in the Google Earth.

The WGS84 coordinate system was then transformed into Lambert Conformal Conical Projection system with two standard parallels using Everest 1830 Datum which is the mapping system of the survey of Pakistan. This is followed by development of the database and its linkage with the ArcGIS and database geo-referencing. Then, the horizontal alignment of the motorway was drawn using AutoCAD and Eagle Point software by entering Point of Intersections. Same was imported in the GHAMS in Lambert conformal conical projection system.

Once the GHAMS was developed, the outputs of the GHAMS are discussed. The GHAMS resulted in development of Thematic Maps (e.g. severity level of distresses), Graphs & Charts (e.g. Remaining Service Life vs Km), Reports (e.g. Distress/ Pictures at each Km), Labeling (e.g. Information about places), Query based Results (e.g. Identify sections with IRI < 3), Single Click Information Display, Print and export functions.

The GHAMS database was also linked with TransCAD which displayed the alignment of the Motorway along with the attribute data on the TransCAD window. Joining of the attribute data with the Maintenance and Rehabilitation (M&R) strategies and their treatment costs resulted in calculation of the M&R Costs.

5.2 CONCLUSIONS

GIS has been in use worldwide in different areas such as Business, Crime Investigation, Communication, Defence, Education, Government, Hydrology, Intelligence, Mapping, Natural Resources, Public Safety, Public Health Engineering, Remote Sensing, Transportation and Utilities such as waste water and storm water management. GIS in transportation asset management has been used in different countries for pavement management and maintenance (whether airport or highway), route and fleet management, street sign management, land record and property management, transportation planning and traffic management, accident recovery systems, etc.

GIS technology has also been used in Pakistan but to a limited extent such as in agriculture and irrigation, route mapping, power and energy management, flood mapping, traffic incidents, etc. However, the use of GIS applications in the field of transportation engineering is almost negligible and for highway asset management nothing has yet been done.

This research resulted in development of GHAMS of an in-service Motorway which gathers, keeps and maintain huge amount of data of the country’s best facility and can significantly improve the quality of services delivered to consumers. The GHAMS has been designed to facilitate transportation and construction engineers and managers to effectively plan, monitor and manage strategic infrastructure investments. This GHAMS provides information for the whole life cycle of an asset which includes the design, construction, performance, repair, reconstruction or replacement of the asset, maintenance and rehabilitation treatments and their costs. Data associated with the asset performance and maintenance & rehabilitation cost can be easily made readily available for generation of reports on asset inventory, performance monitoring and evaluation, record repair and maintenance activities, assisting in maximizing existing budgets and for preparing of upcoming budgets. Such a system therefore proves very helpful for planning, budgeting, resource allocation and repairing of assets and the information obtained is much precise and accurate.

Further, in case of natural and man-made disasters, appropriate information through visual display and maps such as the flood mapping, earthquake disaster maps, etc. can be provided. Maps can be produced for any specific purpose and can be updated easily with GHAMS, which can be printed at any scale.

The outputs obtained from the GHAMS are Thematic Maps, Graphs & Charts, Reports, Labeling, Query based Results, Single Click Information Display, Print and Export, and the most important is the Rehabilitation and Maintenance Cost calculation.

5.3 LIMITATIONS

For an effective asset management system, tools and support solely within GIS are not sufficient and therefore integration of additional software tools is required which may be costly and based on different platforms and programming languages requiring additional expertise.

In addition, comprehensive and complete data pertaining to assets of the roadway section may not be available owing to the spreading of the data among various departments and the departmental internal limitations. Since GHAMS usually relies on data such as land use, transportation networks, environmental and other socio-economic data provided by other agencies and therefore may have data accuracy problems. Further, the data collection is a specialized task for which teams having relative expertise needs to be deployed. Similarly, inaccuracies introduced during digitization of the datasets, raster to vector conversion errors, transformation errors from one projection system to another, incompatibility of the datasets due to their different formats and the inconsistencies in the developed applications due to different programming languages are also one of the technical limitations.

The cost of the spatial data is another limitation. The spatial data such as satellite imagery and maps which are basic data for an asset management system is very costly. The collection and input of the data may also take a lot of time which may be considered as loss of funding since the benefits are not immediately obtained.

5.4 RECOMMENDATIONS & FUTURE DIRECTIONS

It is recommended that GHAMS be made for the whole National Highway & Motorway Network with proper data import, analysis and results tools for identification & prioritization of assets requiring maintenance and selection of appropriate maintenance and rehabilitation strategies. Further, Pavement management System, Bridge management system, Document Management system and Contract management system may also be integrated with the GHAMS in a single platform.

Since tools and support within GIS solely are not sufficient, therefore, integration of TransCAD having special extensions for transportation may also be explored in routing, travel demand forecasting, public transit, logistics, site location, and territory/land management. TransCAD can help in visualizing geo-referenced data in form of strip charts that depict the characteristics of the facility and its variation along a route which is beneficial for asset management. Also, the GIS softwares and systems are quiet expensive, therefore, use of open source GIS softwares like GRASS GIS and Mapserver be made.

Digital Elevation Model (DEM) be developed either by using a fresh pair of stereo satellite imageries or by using the freely available Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) GDEM 30m data. Same may be added as a layer in the GHAMS that could help in route planning and alignment study, cut and fill details, grades, contour mapping. Similarly, weather data such as fog, rainfall etc., and speed data such as design, operational speed may also be added as a separate layer and connected with the accident data in order to analyse the traffic accidents occurring due to over speeding and weather issues.

REFERENCES

AASHTO. (2011) “Transportation Asset Management Guide: A Focus on Implementation”, Washington, D.C., USA.

Aboki, B. (2005) “The use of GIS to create a heavy vehicle (bus) index for the NYC LION file”, University of New York.

Adeel, M. (2010). "Assessing the implementation of Rawalpindi's Guided Development Plan through GIS and remote sensing", proceedings of Third International Symposium on Infrastructure Engineering in Developing Countries (IEDC-2010), Karachi, Pakistan.

Ahmed, A. (2009). "Geospatial analysis of satellite imagery for mapping road inventory and traffic flow attributes", University of Mississippi, USA.

Alterkawi, M. (2001), “Application of GIS in Transportation Planning: The Case of Riyadh, the Kingdom of Saudi Arabia”, Global Built Environment Review, Vol. 1, Issue No. 2, pp 38-46, http://www.edgehill.ac.uk/gber/pdf/Vol1/issue2/alterkawi.pdf, Accessed on 10/03/2012.

Bieber, B., Sarvis, A. (2009), “Enabling Web Access to Highway Data and Images”, Transportation GIS Trends Fall 2009, http://www.esri.com/library/newsletters/transportation-gis-trends/trans-gis-fall2009.pdf#page=10, Accessed on 10/03/2012.

Carlson, K. (2009), “GIS—A Practical Technology for Airport Systems Integration”, Transportation GIS Trends Fall 2009, http://www.esri.com/library/newsletters/transportation-gis-trends/trans-gis-fall2009.pdf#page=10, Accessed on 10/03/2012.

Chandia, I. A., Matori, A. B., Lawal, D. U. (2011). "GIS-based Accessibility Analysis Using Suitable Land for Public Parks in Larkana City Pakistan", *Research Journal of Applied Sciences, Engineering and Technology*, 3(6): 553-557, Malaysia, ISSN: 2040-7467.

CSS (County Surveyor’s Society). (2004) “Framework for Highway Asset Management”

ESRI. (2010) “Highway Data management in ArcGIS”, Accessed at http://www.esri.com/library/whitepapers/pdfs/highway-data-management.pdf.

Eagle Technology (2011), “Auckland Motorway Alliance: Paving the way to improved asset management with ArcGIS”, Eagle Technology Case Study 2011, http://www.eagle.co.nz/SiteAssets/Public/1011/GetFile/AMA.pdf , Accessed on 11/03/2012.

ESRI. (2011) Accessed at http://www.esri.com/what-is-gis/overview.html#overview_panel.

Fazal, S. (2008). "GIS basics", Aligarh Muslim University, New Age International (P) Limited, India, ISBN (13) : 978-81-224-2639-7.

Freeman, M. (2009), "Singapore Land Transport Authority Takes the High Road with GIS", Transportation GIS Trends Fall 2009, http://www.esri.com/library/newsletters/transportation-gis-trends/trans-gis-fall2009.pdf#page=10, Accessed on 10/03/2012.

Hall, J. (2004) "Development of an Implementation Plan for Geographic Information System: Case of Lincoln County", International Journal of Information Management, No. 24, 267-275.

Hashmi, H. N., Siddiqui, Q. T. M., Kamal, M. A., Mughal, H., Ghumman, A. R. (2012). "Assessment of inundation extent for flash flood management", African *Journal of Agricultural Research*, vol. 7(8), pp. 1346-1357.

Heywood, D. I., Cornelius, S., Carver, S. (1998). "An introduction to geographical information systems", Pearson Eduction, ISBN: 0582089409.

Road Asset Management Division (RAMD). 2005. "Standard Operating Procedures for Road Maintainance Account". National Highway Authority, Islamabad.

Road Asset Management Division (RAMD). 2010. "Annual Maintainance Plan 2009 - 2010". National Highway Authority, Islamabad.

Israelsen, T. (2009), "ArcGIS and Traffic Analyst Improve Strategic Transportation Forecast Modeling", Transportation GIS Trends Fall 2009, http://www.esri.com/library/newsletters/transportation-gis-trends/trans-gis-fall2009.pdf#page=10, Accessed on 10/03/2012.

Jain, N., Nanda, P.K., Durai, B. K. & Road. I. P. (2003) "Geographical Information System for Pavement Management System", Map Asia Conference 2003.

Jennings, N. (2009), "Managing Street Sign Assets – An enterprise geospatial business systems integration solutions", ArcUser Winter 2009, http://www.esri.com/news/arcuser/0109/streetsigns.html, Accessed on 10/03/2012.

Lemer, A.C. (1998), "Progress toward integrated infrastructure-assets-management systems: GIS and beyond", Proceedings of the APWA International Public Works Congress. NRCC/CPWA Seminar Series in Innovations in Urban Infrastructure, pp.7-24.

Longley, P., Goodchild, Maguire, D., Rhind, D. (2001) "Geographic Information Systems and Science", Wiley.

Lo, C. P., Yeung, A. K. W. (2002), "Concepts and Techniques of Geographic Information Systems", Prentice Hall series in Geographic Information Science, New Jersey, USA.

McPherson, K., Bennett, C.R. (2005). “Success factors for Road Management Systems”, Ver. 1.0, pp 5-6.

Ministry of Finance (2011). “Pakistan Economic Survey 2010-11”, Chapter 14, pp 175.

Mookerjee, A. K. & Hegyi, F. (2003) “GIS and GPS based asset management for Road and Railway Transportation Systems in India”, Map India Conference 2003, Geospatial Application Papers.

Naqi, S. A., Siddiqui, Z. (2006). "Systematic GIS Development and its successful implementation in SSGC-Pakistan", 2006 International ESRI GIS User Conference, San Diego.

Nawaz-ul-Huda, S., Burke, F., Azam, M., Naz, S. (2012)." GIS for power distribution network: A case study of Karachi, Pakistan", *Malaysia Journal of Society and Space*, Vol. 8, Issue 1, pp 60 - 68.

NCHRP (2002) “Transportation Asset Management Guide”, Program 20-24(11), American Association of State Highway and Transportation Officials, Washington, D.C., USA.

NCHRP (2004) “Pavement Management Applications Using Geographic Information Systems”, Synthesis 335, Transportation Research Board, Washington, D.C., USA.

Preston, M. R. (2009), “Airfield Improves Pavement Management Tracking with GIS”, Transportation GIS Trends Fall 2009, http://www.esri.com/library/newsletters/transportation-gis-trends/trans-gis-fall2009.pdf#page=10, Accessed on 10/03/2012.

Ramlal, B. (2006) “Using GIS for Asset Management in Trinidad and Tobago”, Journal of Association of Professional Engineers of Trinidad and Tobago (APETT).

Razzak, J. A., Khan, U. R., Jalal, S. (2011). "Application of Geographical Information System (GIS) for mapping road traffic injuries using existing source of data in Karachi, Pakistan — A pilot study", *Journal of Pakistan Medical Association*, Karachi, Pakistan.

Roshannejad, A. (2007) “Enriching the Roads Asset Management Program with GIS”, Geotech Event, Canada.

Salim, M. D., Strauss, T. & Emch, M. (2002) “A GIS-Integrated Intelligent System for Optimization of Asset Management for Maintenance of Roads and Bridges”

Lecture Notes in Computer Science, Vol. 2358/2002,183-205,DOI:10.1007/3-540-48035-8_61.

Sinha, S. K. (2003) “Development of prototype municipal asset management system” www.nastt.org/store/technical_papersPDF/229.pdf, Accessed on 10/03/2012.

Thomas, C., Allen, J., Leadbeater, R. (2009), “GIS Creates a Paperless Asset Management System in Colorado Springs”, Government Matters Spring 2009, http://www.esri.com/localgov., Accessed on 10/03/2012.

Transportation Research Board. (2006) "Geospatial information technologies for asset management, *Transportation Research Circular*, E-C108.

APPENDICES

Appendix 1

ATTRIBUTE TABLE

Appendix 2

Maintenance & Rehabilitation Strategies

&

Treatment Costs

Appendix 3

Selection Criteria for Maintenance & Rehabilitation Strategies