AN APPROACH TO GIS-T DATABASE DESIGN AND APPLICATION FOR PUBLIC TRANSIT PLANNING

A CASE STUDY OF VISAKHAPATNAM CITY, ANDHRA PRADESH

A Project Report submitted in partial fulfillment of
the requirements for the award of degree of

BACHELOR OF TECHNOLOGY
IN
GEOINFORMATICS ENGINEERING

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VISAKHAPATNAM – 530003

APRIL 2014

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CERTIFICATE

This is to certify that the project entitled "**AN APPROACH TO GIS-T DATABASE DESIGN AND APPLICATION FOR PUBLIC TRANSIT PLANNING**" is a bonafide work carried out by **M.ROHIT VENKAT GANDHI** and **P.KRISHNA TEJA** in partial fulfilment for the award of Bachelor of Technology degree in **GEOINFORMATICS ENGINEERING** under my supervision from January 2014 to April 2014

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DECLARATION

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ACKNOWLEDGEMENTS

We would like to express our sincere thanks and gratitude to the College of Engineering (A), Andhra University for providing us an admission into the Bachelor of Technology course in Geoinformatics Engineering and helping us to gain invaluable knowledge with the help of the best and efficient faculty members.

We would like to express our earnest gratitude and thankfulness to **Prof. G. Jai Sankar**, Department of Geo-engineering, Andhra University College of Engineering (A), Visakhapatnam for his constant support, inspiration, timely guidance, encouragement, valuable advice and suggestions throughout the project work. His deep interest and dedication towards the improvement of our research thesis will always be remembered.

We are greatly indebted to **Prof. P. Jagadeeswara Rao**, Head of the Department, Andhra University College of Engineering (A), Visakhapatnam. We are thankful to him for this valuable guidance, persistent encouragement, constant motivation, thoughtful discussion and supervision throughout the course of this work.

Our sincere thanks to **Prof. E. Amminedu**, Department of Geo-engineering, Andhra University College of Engineering (A), Visakhapatnam. We are thankful to him for his timely advice, constructive suggestions, kind support, guidance and encouragement that has resulted in the completion of this project work.

We wish to extend our heartfelt thanks to **Zakaria Robert Ngereja,** a student of Erasmus Mundus Programme in Geospatial Technologies whose thesis work inspired us a lot and was taken as the basis for this project work.

We also take this opportunity to thank all research scholars and our beloved class mates of Geo-Engineering Department, whose suggestions and assistance inspired us throughout the course of this project.

M. Rohit Venkat Gandhi

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ABSTRACT

In the last few decades, the use of Geographic Information Systems (GIS) has been extended to wide variety of fields finding its application with a greater efficiency and productivity. The concept of integrating geographic mapping with the software technology has been trending for many years and found user friendly for the public to extract their required information. Transportation has been one of the major GIS application area mainly for public transport planning, routing and other operations. This necessitated to have a unified universal GIS-T data model mainly for the transportation applications. Over the past 25 years a huge number of data models, like the ArcInfo route system, National Co-operative Highway Research Program (NCHRP), Federal Geographic Data Committee, Enterprise GIS-T data model, UNETRANS data model. Our main motto of this project is the design of a GIS-T database and application for public transit planning and management in the Visakhapatnam city. The UNETRANS model was deeply analyzed, interpreted, examined and the useful elements for the geodatabase design of GIS-T for Visakhapatnam city were extracted. The main result of this project is a designed GIS-T database for Visakhapatnam city and its prototype implementation in ArcGIS 9.3. Besides this, an output of the network analysis for determining the closest bus stop to hospitals, shortest route from an incident location and also the direction for future work is discussed.

Key words:

Database

Data model

Geographic Information Systems for Transportation

UNETRANS

Network Analysis

ACRONYMS

ESRI- Environmental Systems Research Institute

GDFS- Geographic Data File Standard

GIS- Geographic Information Systems

GIS-T – Geographic Information System for Transportation

IRA- Institute for Resource Assessment

NCGIA- National Centre for Geographic Information Analysis

NCHRP- National Co-operative Highway Research Program

TIS- Transportation Information System

UNETRANS- UNified NETwork for TRANSportation

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1. INTRODUCTION

1.1 Brief Overview:

The field of GIS has been trending since the last few decades with a huge reception from all sections of the users in the world. Geographic Information Systems (GIS) is a powerful technology that provides a simplified problem-solution approach in an innovative manner for policy makers, planners, engineers, managers in reputed diverse organizations including the field of transportation. In a broad sense GIS can be coined as "*a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world*". (Burrough, 1986).

Among the wide variety of fields where GIS can be applied, transportation sector has gained a lot of significance and interest in the recent years (Shaw 2006). This is mainly involved in the context that many transport information problems exist in the geographic scenario. The outcome of this is the emergence of a new wing in GIS applied for the transportation issues and problems commonly regarded as GIS-T. GIS-T is a Geographic Information Systems specifically for Transportation and has been defined as "*principles and applications of applying geographic information technologies to transport problems*". (Miller and Shaw 2001)

Since transportation is inherently a spatial activity, GIS is particularly well suited and apt technology to be a platform for managing much of the data used in transportation applications. Moreover, rapid advances in microcomputer and graphics workstation technology during the past few years have moved GIS from the mainframe environment to the desktop of the transportation professional, where it is evolving into a basic analysis tool just like the word processor, spreadsheet, or database manager.

The field of transportation has many dimensional subareas where GIS-T can be implemented, covering a broad range of transportation issues and concerns like infrastructure planning, design of road networks and management, transportation safety analysis, travel demand analysis, traffic control, public transit planning and operations, assessment of environmental impact, hazardous problem mitigation and Intelligent Transportation Systems (ITS) (Shaw 2006). A GIS-T mainly combines the transport network databases and spatial databases in a GIS-based information system to open the door for planning functions and conceptual decision making processes. This also gives us an effective means for systematizing basic transportation related data in order to facilitate the input, analysis, and display of transport networks.

The utilization of GIS for transportation applications gained impetus in the last decade 2000's when Environmental Systems Research Institute (ESRI), an international supplier of GIS software, web GIS and geodatabase applications initiated and funded a project to develop a generic data model for transportation applications. Under the project, ESRI in association with the National Centre for Geographic Information Analysis (NCGIA) at the University of California, Santa Barbara designed a transportation data model called the Unified Network for Transportation (UNETRANS) using ESRIs Arc GIS 8 software (Huang 2003, NCGIA 2003). The data model which has been designed is now the standard data model of transportation which is implemented in Arc GIS 8.3 and its subsequent upgrades like 9.X, 10.X. UNETRANS is a complete conceptual object data model for mapping transport features, and assimilating multiple modes of travel, and accommodating multiple scales of interpretation of real world.

In this case the data model for transportation (UNETRANS) is a complex one because it is used for various purposes in transportation data. Therefore the UNETRANS model can be customized and utilized based on the type of data in transportation. The project is mainly aimed at learning the concepts of UNETRANS model and dig out relevant packages and attributes to design and implement a prototype GIS-T for the *Steel city Visakhapatnam*. Some of the packages, classes, and attributes may not be relevant based on the country's way of storing the transportation data.

1.2 Problem Statement:

Visakhapatnam city is one of the major cities in the state of Andhra Pradesh. Due to the lack of efficient public transport system it experiences major transportation problems. Some of them are lack of passenger trip guidance, conceptual bus route maps and path ways and a GIS for route planning and operational analysis. Hence there is a need for implementing a geodatabase for public operations within the city. This will indeed improvise and enhance the efficiency level of transportation system. It also facilitates the transportation planning and makes the system to be effective with a clear cut conceptual methodology and management. This way of design of a geographic data base majorly helps in the management of the traffic during the peak hours in a day, thereby leading to the minimization of accidents and traffic jams.

1.3 Objectives:

The main goal of this project is to design and create a prototype of Geographic Information System for Transportation (GIS-T) database for public transport route planning and analysis in the Visakhapatnam city. The specific objectives are:

- Review and analysis of existing GIS Transportation data model, especially the ESRI'S Arc GIS Unified Network Transportation (UNETRANS) Model.
- Design a GIS-T database and implement it for public transport planning and operational analysis in Visakhapatnam city.
- Apply the design through prototyping.

1.4 Questions to be addressed:

The questions that this project will address are: What are the suitable packages, classes and attributes in GIS-T data model that will support public transit planning and operations in Visakhapatnam city. This question may lead to other sub-questions:

- Is the Unified Network for Transportation (UNETRANS) data model as a whole appropriate for planning of transportation and other operations?
- Is the available spatial data for Visakhapatnam city fit in the UNETRANS data model and further analysis tasks can be done?

1.5 Hypothesis:

The main statements under the hypothesis are:

- It is possible to build an efficient transportation data model for Visakhapatnam city based on the part of UNETRANS GIS-T data.
- Design and building of an effective transportation data model for Visakhapatnam city requires a complete knowledge and understanding about spatial data and technology.
- Unavailability of well documented and organized transportation data is a hurdle for designing effective GIS-T data base design and implementation of it.

1.6 Structure of Project:

This project is organized and structured into four main parts. Part 1 gives you a brief overview, main problem, objectives, questions to be addressed, and hypothesis. Part 2 mainly examines the literature review about Geographic Information Systems (GIS), the general and technical definitions highlighting the major concepts and emphasizing on transportation scenario. It also reviews about the data model that are generally used for the transportation purposes in GIS namely Enterprise GIS and Unified Network Transportation (UNETRANS). But in our thesis UNETRANS data model is majorly focused. Part 3 is about building a transportation model for Visakhapatnam city. In this section the description of the study area, methods used for building data model, results are presented. Part 4 deals with the recommendations and conclusions assisted with the some of the limitations of this GIS-T and future work to be undertaken.

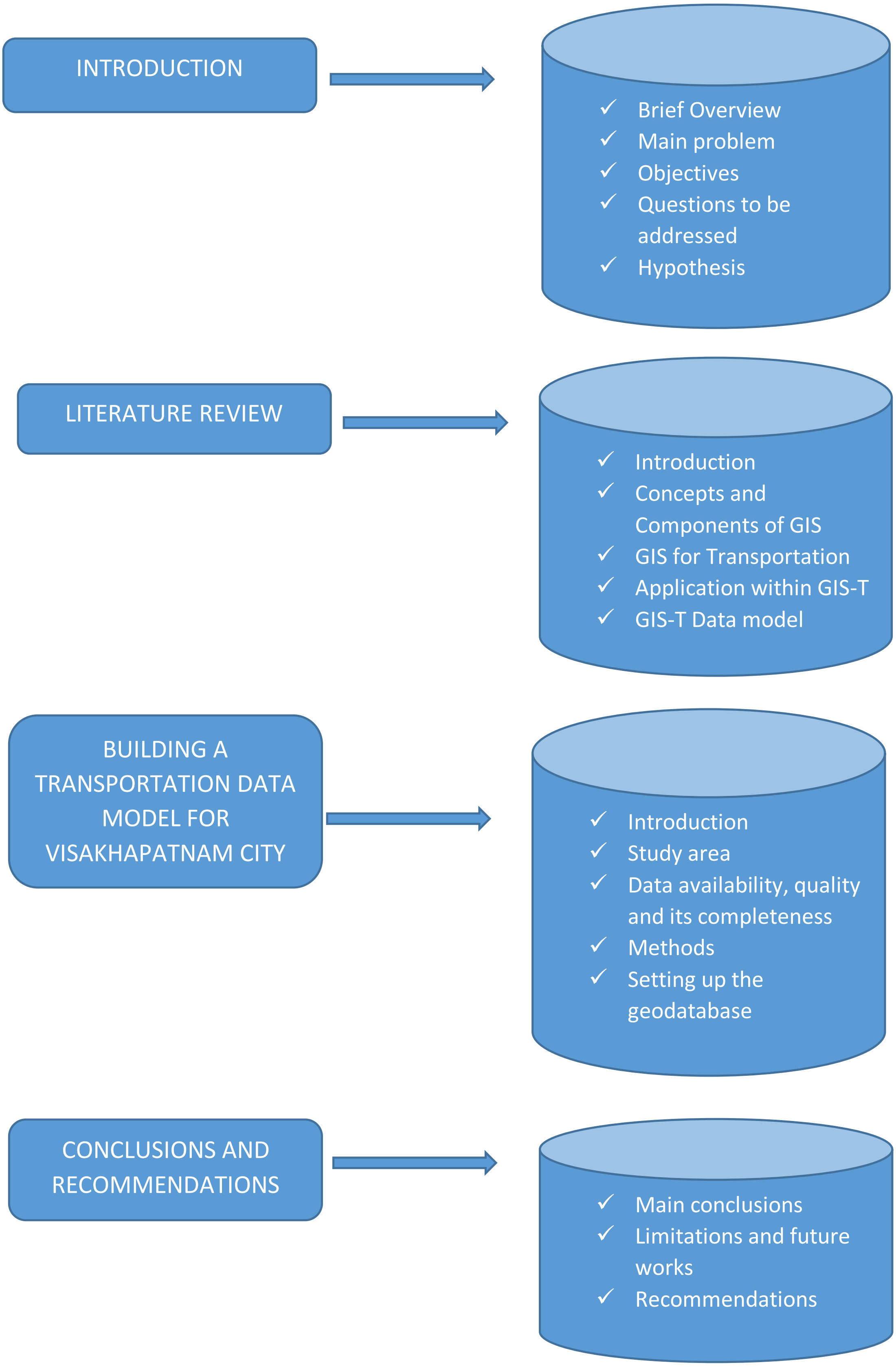

Fig 1: Structure and organization of project work

2. LITERATURE REVIEW

2.1 Introduction:

This section gives you a brief and general overview of GIS concepts highlighting its key features, key components and data structures applied in the GIS systems. The main conceptual overview of GIS-T is also presented in a lucid manner, with a special focus on applications within GIS-T, some selected instances of GIS-T and users of GIS-T. In the second part, the GIS-T data model is explained with more emphasis on Unified Network for Transportation (UNETRANS).

2.2 Core concepts of GIS and its components:

The major concepts involved in the working of GIS and a brief knowledge about its components are almost familiar to the users of GIS. Since the evolution of GIS in 1960's there had been tremendous developments in this technological field which led to the refinements of its definition, key concepts, and key functions. A major myth among the users of GIS is that there is a specified definition for it. But the principle that lies behind this is that the definitions vary from one user to another according to the application area where GIS is intended to apply.

Many definitions of GIS have been suggested over the years, such as "a container of maps in digital form", "a computerized tool for solving geographic problems", "a tool for performing operations on geographic data that are too tedious or expensive or inaccurate if performed by hand" (Longley, et al, Geographic Information Systems and Science, 2001). Let's look at some of the definitions given by the professional institutes:

- **USGS (United States Geological Survey)**: In the strictest sense, a GIS is a computer system capable of assembling, storing, manipulating, and displaying geographically referenced information, i.e. data identified according to their locations.
- **ESRI (Environmental systems Research Institute):** GIS is a system of computer software, hardware and data, and personal to help manipulate, analyze and present information that is tied to spatial data.
- **INHS (Illinois Natural History Survey):** A Geographic Information System (GIS) is an organized collection of computer hardware, software, geographic data, and personnel designed to capture, store, update, manipulate, analyze, and display all forms of geographically referenced information. This System allows users to perform very difficult, time consuming, or otherwise impractical spatial analyses.

In general, we could derive the practical definition of GIS as a computerized system designed to dealing with the collection, storage, manipulation, analysis, visualization and displaying geographic information. GIS is a tool to perform the spatial analysis which will put insight to the activities and phenomena carrying out every day.

Apart from those mentioned above the following definitions are prominent and acceptable among GIS users and researchers.

- ***Longley (2005)*** *defined GIS as follows "Geographic Information Systems are a special class of information systems that keep track not only of events, activities, and things but also where these events, activities and things happen or exist."*
- ***De By (2004)*** *defined a Geographic Information System as "a computerized system that facilitates the phases of data entry, data analysis and presentation especially in certain cases where we are dealing with geo-referenced data."*
- ***Burrough*** *quoted in Maguire (1991) defined it as "a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from real world".*
- ***Worboys (2004)*** *have defined a Geographic Information System (GIS) as "a computer based information system that enables capture, modelling, storage, retrieval, sharing, manipulation, analysis and presentation of geographic data."*

The most rampant and important element in all of the definitions is that GIS deals with data that has a geographic location which is geo-referenced or spatially referenced. The definition given by Worboys (2004) is a functional based definition that enlists the functions of GIS-based information system.

The six chief components as maintained by Longley (2005) and Worboys (2004) are namely,

I. Computer hardware;
II. Computer software;
III. Data;
IV. People;
V. Procedures, and
VI. Network.

Another vital concept to be noted here is the data structure which is the basic fundamental unit which is required for storing of data in any information system. GIS employs two kinds of structures for the purpose of representation of objects in the computer environments. They are namely the Raster data structure and Vector data structure. Much conceptual information have already been written about the data structures and data models which can be found in the literatures like (Maguire 1991, Bernhardsen 1992, Burrough 1998, de By 2004, Worboys 2004, Longley 2005, Neteler 2005 and Galati 2006).

The functions of GIS can be categorized into five core functions according to Worboys 2004 who has enlisted what GIS generally does. They can be listed as under:

I. Data Capture and editing
II. Data manipulation (storage, retrieval, management and updating)
III. Spatial analysis and modelling,
IV. Data integration,
V. Geo visualization (Output/Display on the screen)

2.3 GIS in Transportation sector:

The application and scope of Geographic Information Systems in the transportation sector has become wider and wider as the years passed by. As location information is critical for transportation application like transport planning and management, intermodal facility management, pavement management, bridge inventory, accident analysis, fleet management, transit service planning etc. GIS has become one of the powerful and unique tool for mapping the transport information and managing them inside an information system without the loss of data. All transportation applications require transport network data and GIS has been one of the powerful information system tool for representing and analyzing the transportation networks.

Hence, the acronym GIS-T was coined to refer to Geographic Information Systems for Transportation. In the introduction part of this report GIS-T is defined as "principles of applying geographic information technologies to address the transportation problems" (Miller and Shaw 2001). GIS-T is a very broad term encompassing all the activities that involve the utilization of geographic information systems for transport planning and management. GIS-T research can be approached from two different, but complementary, directions. While some GIS-T research focuses on issues of how GIS can be further developed and enhanced in order to meet the needs of transportation applications, other GIS-T research investigates the questions of how GIS can be used to facilitate and improve transportation studies. The categorization of GIS-T study is necessary for in-depth understanding of the underlying concepts in the transportation sector which facilitates the improvised operational analysis and tasks that can be carried out in transportation field with much efficiency.

2.3.1 GIS-T Study Categorization:

In general, topics related to GIS-T studies can be grouped into three categories:

- **Data representations**. How can various components of transport systems be represented in a GIS-T?
- **Analysis and modeling**. How can transport methodologies be used in a GIS-T?
- **Applications**. What types of applications are particularly suitable for GIS-T?

2.3.1.1 GIS-T Data Representations:

Data representation is a core research topic of GIS. Before a GIS can be used to tackle real world problems, data must be properly represented in a digital computing environment. One unique characteristic of GIS is the capability of integrating spatial and non-spatial data in order to support both display and analysis needs. There have been various data models developed for GIS. The two basic approaches are **object-based data models** and **field-based data models**:

- An object-based data model treats geographic space as populated by discrete and identifiable objects. Features are often represented as points, lines, and/or polygons.
- On the other hand, a field-based data model treats geographic space as populated by real-world features that vary continuously over space. Features can be represented as regular tessellations (e.g., a raster grid) or irregular tessellations (e.g., triangulated irregular network - TIN).

GIS-T studies have employed both object-based and field-based data models to represent the relevant geographic data. Some transportation problems tend to fit better with one type of GIS data model than the other. For example, network analysis based on the graph theory typically represents a network as a set of nodes interconnected with a set of links. The object-based GIS data model therefore is a better candidate for such transportation applications. Other types of transportation data exist which require extensions to the general GIS data models. One well-known example is linear referencing data (e.g. highway mileposts). Transportation agencies often measure locations of features or events along transportation network links (e.g. a traffic accident occurred at the 52.3 milepost on a specific highway). Such a one-dimensional linear referencing system (i.e. linear measurements along a highway segment with respect to a pre-specified starting point of the highway segment) cannot be properly handled by the two-dimensional Cartesian coordinate system used in most GIS data models. Consequently, the dynamic segmentation data model was developed to address the specific need of the GIS-T community.

2.3.1.2 GIS-T Analysis and Modeling:

GIS-T applications have benefited from many of the standard GIS functions (query, geocoding, buffer, overlay, etc.) to support data management, analysis, and visualization needs. Like many other fields, transportation has developed its own unique analysis methods and models. Examples include shortest path and routing algorithms (e.g. traveling salesman problems, vehicle routing problem), spatial interaction models (e.g. gravity model), network flow problems (e.g. minimum cost flow problem, maximum flow problem, network flow equilibrium models), facility location problems (e.g. p-median problem, set covering problem, maximal covering problem, p-centers problem), travel demand models (e.g. the four-step trip generation, trip distribution, modal split, traffic assignment models, and more recent activity-based travel demand models), and land use-transportation interaction models.

While the basic transportation analysis procedures (e.g. shortest path finding) can be found in most commercial GIS software, other transportation analysis procedures and models (e.g. travel demand models) are available only selectively in some commercial software packages. Fortunately, the component GIS design approach adopted by GIS software companies provides a better environment for experienced GIS-T users to develop their own custom analysis procedures and models.

It is essential for both GIS-T practitioners and researchers to have a thorough understanding of transportation analysis methods and models. For GIS-T practitioners, such knowledge can help them evaluate different GIS software products and choose the one that best meets their needs. It also can help them select appropriate analysis functions available in a GIS package and properly interpret the analysis results. GIS-T researchers, on the other hand, can apply their knowledge to help improve the design and analysis capabilities of GIS-T. Due to the increasing availability of tracking data that include both spatial and temporal elements, development of spatio-temporal GIS analysis functions to help better understand the dynamic movement patterns in today's mobile world has attracted significant research attention in recent years.

2.3.1.3 GIS-T Applications:

GIS-T is one of the leading GIS application fields. Many GIS-T applications have been implemented at various transportation agencies and private firms. They cover much of the broad scope of transportation and logistics, such as infrastructure planning and management, transportation safety analysis, travel demand analysis, traffic monitoring and control, public transit planning and operations, environmental impacts assessment, intelligent transportation systems (ITS), routing and scheduling, vehicle tracking and dispatching, fleet management, site selection and service area analysis, and supply chain management. Each of these applications tends to have its specific data and analysis requirements. For example, representing a street network as centerlines may be sufficient for transportation planning and vehicle routing applications. A traffic engineering application, on the other hand, may require a detailed representation of individual traffic lanes. Turn movements at intersections also could be critical to a traffic engineering study, but not to a region-wide travel demand study.

With the rapid growth of the Internet and wireless communications in recent years, a growing number of Internet-based and wireless GIS-T applications can be found. Web sites such as Google Maps and MapQuest are frequently used by people to get driving directions. Global positioning system (GPS) navigation systems also are available as a built-in device in vehicles or as a portable device. Coupled with wireless communications, these devices can offer real-time traffic information and provide helpful location-based services (LBS) (e.g., finding the closest ATM location and reporting the estimated travel time to reach the ATM location based on the current traffic conditions). Another trend observed in recent years is the growing number of GIS-T applications in the private sector, particularly for logistics applications. Since many businesses involve operations at geographically dispersed locations (e.g., supplier sites, warehouses, retail stores, and customer location), GIS-T can be a useful tool for a variety of logistics applications. Many of these logistics applications are based on the GIS-T analysis and modeling procedures such as the routing and facility location problems. GIS-T is interdisciplinary in nature and has many applications. Transportation geographers, who have backgrounds in both geography and transportation, are well positioned to pursue GIS-T studies. A survey conducted by the Sutton (2007) for the transportation research board in the USA categorized GIS-T application into five groups, in which almost all applications of GIS-T falls in one or more of these groups listed as under (table 1)

Group	Description
Planning	Includes route and facility planning, automatic passenger counting systems, demographic analysis and modelling tool
Information Technology	It involves hardware, software, custom tools and standards
Operations	Contains vehicle and facility maintenance, vehicle location, routing and scheduling, and real time traffic information.
Management	It deals with safety, security and incident response, system performance and reporting, asset management and finance.
Customer Service	Deals with route planning, customer relations, real time customer information, public information and marketing.

Table 1: GIS Application groups as identified by Sutton (Sutton, 2004)

GIS-T application requires the design and development of a geographic database which has the following key features:

I. Development of Geodatabase
II. Development of attribute or non-spatial database
III. Development of spatial referencing system.

As a matter of fact GIS-T combines the usage of GIS and Information technology in the transportation field known as Transportation Information System (TIS) into one integrated system framework called as GIS-T as shown in Figure 2

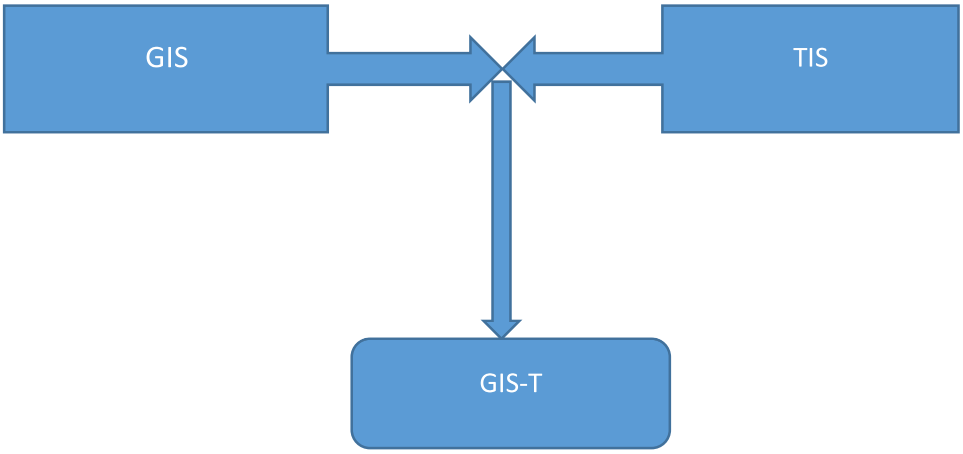

Fig 2: GIS-T as an integrated GIS and Transportation Information System (TIS) (Vonderohe, 1993)

2.3.2 Users of GIS-T:

The users of GIS-T consists of a wide and diverse group. In many metropolitan cities and municipalities, departments of transportation, urban planning, engineering & survey mapping are using GIS-T for multipurpose transportation projects. Not only the government agencies but also the private sectors use GIS-T for activities like fleet management, package and service delivery.

All the users, in general, are technically implementing a database of its kind that requires some type of spatial datasets and business information. The common datasets for all the users will be transportation networks and place names. On the other hand users need to implement a database that can facilitate several functions and major activities of the processes. The common items within several users provide an opportunity of data modelling, which motivates and encourages co-operation and collaboration among users.

2.4 GIS-T Data model:

Any information system whether it be geographic, banking, urban, etc. is generally built in a data model. According to Longley et al (2005), data model is considered to be the heart of any GIS. Data model is generally considered as set of construction plan for the design and implementation of a database. It can also be defined as set of constructs for representing objects and processes in the digital environment of the computer. In order to represent a transportation data having both spatial and non-spatial characteristics in a computer environment there must be a way of representing all objects and processes in a geographic data base. With the help of a data model people can implement, interact, query and make analysis in a geographic data base. Therefore data model plays a key role in GIS functionality as illustrated in figure 3

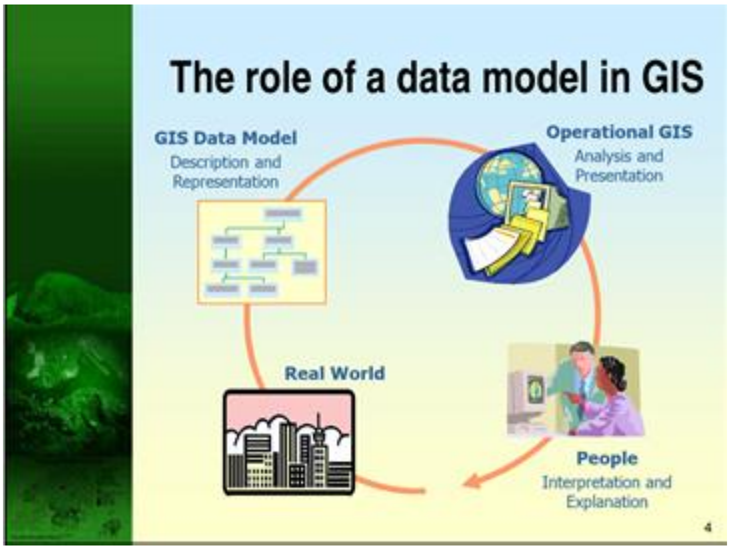

Fig 3: Depiction of importance of data model in GIS

In the past 20 years there have been several data models developed especially to cater the needs of transportation datasets and applications. They mainly include ArcInfo route system structure, National Co-operative Highway Research Program (NCHRP) Project 20-27 (3), the Transportation Feature Identification Standard, which was proposed by the Federal Data Geographic Committee (FDGC), and the Geographic Data File format (GDF) (Butler, 2008). However, Duecker (1997) proposed a new data model called as Enterprise GIS-T data model which actually tried to bring consistency to the representation as well as sharing of transportation data. During the review of GIS-T data sharing issues, Duecker (1999) noted the two specific data models namely Geographic Data File Standard (GDFS) and the NCHRP 20-27 as the mostly utilized by the transportation agencies in USA. The later data model was the one tried to standardize GIS-T data models in USA.

Many endeavors have been continued in order to develop a universal standardized GIS-T data model which resulted in the design and development of Unified Network Transportation Data model abbreviated as UNETRANS. This data model was a result of collaboration between software developers and provider, ESRI and the National Centre for Geographic Information Analysis (NCGIA), University of California, Santa Barbara. The developed UNETRANS is a unified or universal as well as industry standard GIS-T data model. This data model is an ESRI's Arc GIS standard transportation data model.

The main intention of this research is not to make a detailed overview of all the existing data models but only two data models are dealt with in-depth focus in the following sub-sections. More importantly UNETRANS model is the focus of this research work and reviewed.

2.4.1 Enterprise GIS-T Data model:

The enterprise GIS-T data model was developed by Duecker and Butler (1997). It is mainly aimed at providing a universal enterprise-level data model and physical data base design for GIS to be used by transportation agencies. This model is conceptually developed using entity-relationship diagrams and the entire model is comprised of the basic data model in figure 4 and having the following added entities in the complete data model in table 2.

Entity Type	Entity Definition
Intersection of Transportation Features	It keeps all the junctions and intersection on a transportation network
Topological Entities	Creates topology as a means to define path through a transportation systems, it provides information on how the various transportation features connect to one another
Cartographic Entities	Adds cartographic data used to draw maps, it adds elements found on transportation maps
Linear datum Entities	Adds elements for linear referencing on transportation system, such as reference point and geographic datum
Non-transportation features	It adds support for non-transportation features that are not directly related with transportation activities.

Table 2: The Entity Types and definitions for Enterprise data model (Duecker, 1997)

The main focus of the developers of this data model is transportation data sharing among various transportation agencies. The Enterprise data model is one of the data models that endeavored to unify the transportation data that can be shared and represented among GIS-T users.

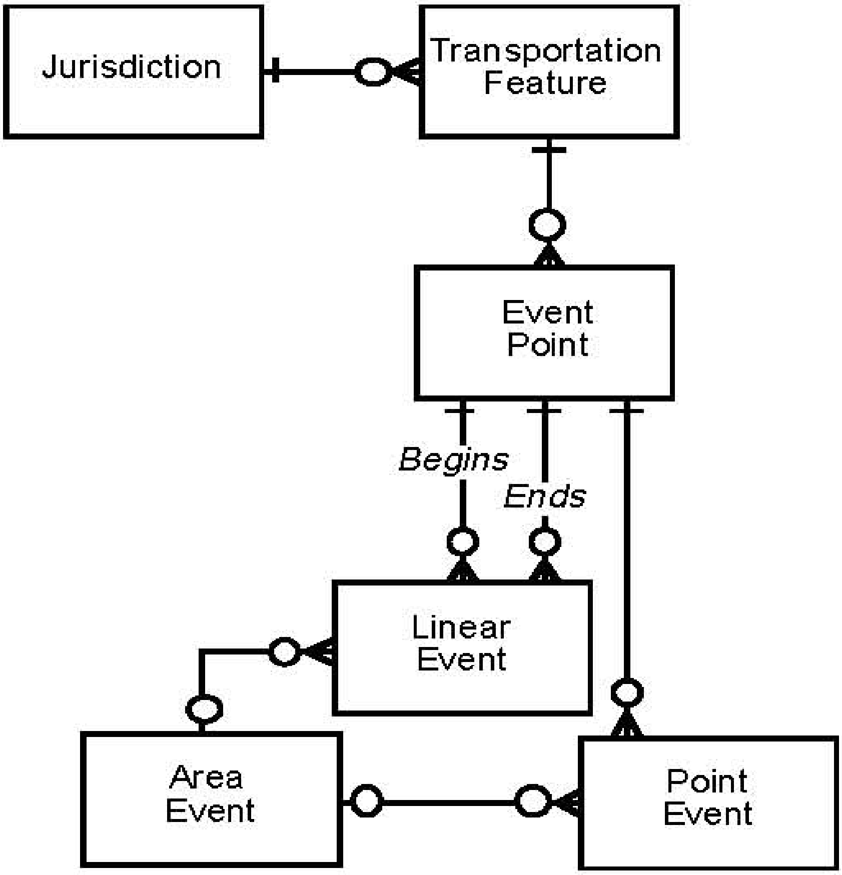

Figure 4: Basic Enterprise GIS-T data model (Duecker, 1997)

The following tables 3 and 4 provides the definitions for the entities of the enterprise data model shown in figure 4 and definitions for the event subtypes.

Entity Type	**Entity Definition**
Jurisdiction	The political or other context for designating transportation features and their names, which may be merely numerical references unique within the jurisdiction.
Transportation Feature	An identifiable element of the transportation system. A transportation feature can be like a point (interchange or bridge), a line (road or railroad), or an area (rail yard or airport).
Event Point	The location where an event occurs. Event Point is defined initially as an offset distance from the beginning of the transportation feature
Event	An attribute, occurrence, or physical component of a transportation feature. Attributes include functional class, speed limit, pavement type, and state road number—things that are not tangible but describe a tangible element, such as a road. Occurrences include traffic crashes and projects. Physical components include guard-railing, signs, bridges, intersections, and other tangible things that are field-identifiable elements.

Table 3: Entity definitions of the basic enterprise data model (Duecker, 1997)

Subtype Event	Subtype Event Definition
Point Event	A component or attribute that is found at a single location (one event point). Point events may occur independently or on transportation features of the linear or area form
Linear Event	A component or attribute that is found along a segment of a linear transportation feature. Linear events are defined by two event points (beginning and ending). Linear events may occur only on linear transportation features
Area Event	A transportation feature component or a non-transportation entity that affects a transportation feature. Areas can be explicitly represented as polygons or implicitly represented as to where they intersect transportation features.

Table 4: Event subtypes for the enterprise data model (Duecker, 1997)

2.4.2 The UNETRANS Data Model:

UNETRANS is an acronym both for a generic ESRI-centric data model intended to provide framework for ESRI users to develop transportation-specific applications using Geodatabase and for the consortium of academics, ESRI software users, and business partners formed to guide the development of the model.

The impetus to develop the UNETRANS model came from the adoption by ESRI of a new object architecture based on the Microsoft Component Object Model (COM) platform. This held out the promise of all the benefits of object oriented computer programming to the users of ESRI software, especially the many users and business partners that use ESRI's generic GIS toolkit approach to develop custom solutions. In the object-oriented future these custom solutions would be easier to develop, more robust, and consist of reusable components, like all other object-oriented applications.

Adopting object-oriented analysis and design techniques was an obvious corollary to the object-oriented technology. ESRI developers and developers of applications based on ESRI software began to use formal methodologies to model and document their programs. They adopted the Unified Modeling Language (UML) developed by Booch, Grady, Jacobson, and Rumbaugh, (Booch et al 1998), which became part of the software documentation. Even ESRI advertising material now includes poster-sized, full-color, high level, UML object diagrams of ArcGIS. Object modeling is the analytical process of describing characteristics of the world that concern a problem. Doing this is not new, but it is traditionally the obscure domain of an incomprehensible few. Object-oriented analysis and design methodologies offer efficient and clear ways to model the world of the software user in a way that is useful to the software developer and that both user and developer can understand. The introduction of ArcGIS resulted in the widespread application of object modeling to GIS applications.

ESRI software traditionally and in its new, object-oriented form provides tools to manage low level spatial feature types that can be used to represent a variety of real-world features. The same polyline can be used to represent a road or a pipeline, or a coastline. Real world meaning is associated with the core features in the form of user-defined attributes. The road gets a number of lanes, the pipe gets a diameter, and the coastline gets a field to indicate level of pollution. Custom applications can be written that enable users to interact with the attributes and the features, but these are separate from the basic GIS software, for which the polyline remains a polyline. The great promise of the object-oriented architecture is that behavior could be built into the database, so that the GIS application can recognize the difference between a road feature and a pipe feature and not allow users to append one to the other.

One particularly well organized group of ESRI software users in the field of water and wastewater management recognized the potential benefits of carrying out a collective data modeling exercise that addressed their common requirements. Even though some of the participants in this effort compete with each other in the consulting and application development markets, there was a clear benefit to all in incorporating core objects that they all need at the core software level. The worse alternative was that they each develop a version of these objects. This group set an example that was followed by users in other sectors.

The transportation sector group with the acronym UNETRANS was launched officially at the 2000 ESRI User Conference, after internal discussions with ESRI and the recruitment by ESRI of academics from UC Santa Barbara to lead the effort.

According to Curtin et al (2003), the UNETRANS data model is presented in two ways: a layer view of the data model, and an analysis diagram view of objects that comprise the data model.

2.4.2.1 Layer View of UNETRANS data model:

In order to visualize the geographic data in a clear cut manner, it is best to separate objects from one another into layers of objects that share some similarity and functions. By categorizing them into layer of objects it is effective to manage and clearly understand the functionality of the transportation data model to a greater extent. All these transportation layers can be combined to develop a transportation application. Hence, UNETRANS data model separates three types of transportation layers as shown in table 5.

Layer	Descriptions
Reference Network	The transportation network consists of several sets of data that represents the roads, railroads, waterways and other pathways along which transportation activities take place in a linear spatial representation
Route Feature	Route feature layer that are built from the links in the Reference Network Layer.
Events	Transportation-related objects that are related to the Reference Network or Route Feature but are not part of the network itself. However, these events are integral to the operation of the transportation system.

Table 5: The layer view descriptions of the UNETRANS data model (Curtin, 2003)

2.4.2.2 Analysis diagram view of UNETRANS data model:

The analysis diagram view is a layout of all the data objects that comprise the data model which is illustrated in Figure 5. Different objects are specified with names and their attributes, and relationship between objects are specified with connections. Hence, all the objects and features consisting the UNETRANS data model are presented in the analysis diagram. These diagrams contain set of packages that contains subsets of these feature classes and tables. Each feature class represents a table of information in the database that is represented by a single class box in the diagram. The analysis diagram uses the Unified Modelling Language (UML) notations.

The UNETRANS data model is sub-divided into six logical groups called packages of related objects and features. A package of objects may be related by function or type. The six packages are:

I. Reference Network;
II. Routes and Location Referencing;
III. Assets;
IV. Activities;
V. Incidents;
VI. Mobile Objects.

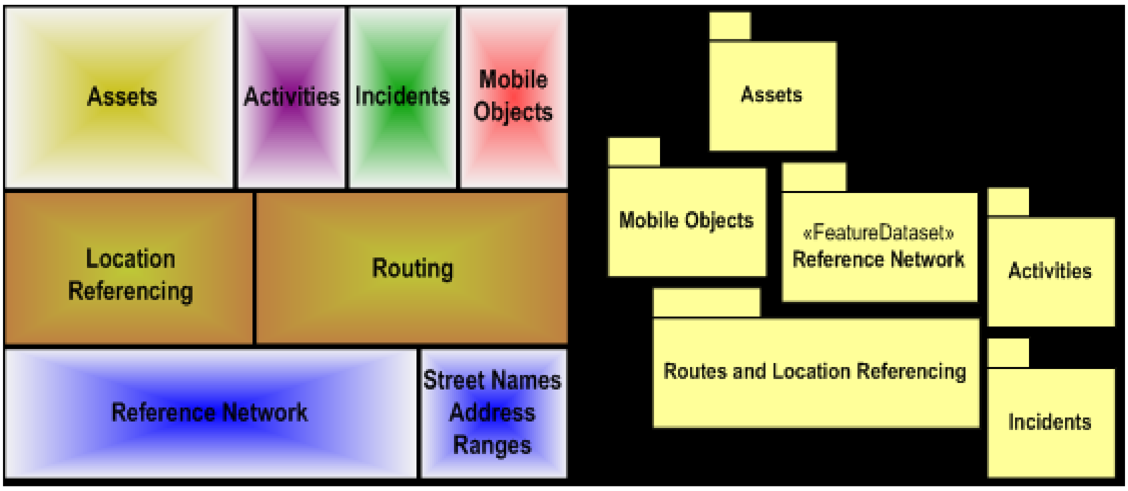

Figure 5: Analysis diagram of the UNETRANS data model (Curtin, 2003)

Each package shown in the figure 5 represents certain activities and functions in the data model, thus the table 6 illustrated below present the definitions related to each of the above packages.

Package	Definition
Reference Network	A representation of physical, semi-permanent infrastructure features intended to facilitate a channeling or control of traffic
Street Names and Address Ranges	Attribute objects associated with one or many objects from the Reference Network
Location Referencing	Objects and procedures for associating transportation related
Routing	Primarily tabular related data needed to support transportation planning processes
Assets, Activities, Incidents	A representation of physical features, planned projects, and unplanned occurrences which are located in reference to Reference Network, but are not part of the network itself
Mobile Objects	An object representing any type of medium through which people or commodities are transported along the Reference Network.

Table 6: Analysis view descriptions of the UNETRANS data model (Curtin, 2003)

2.4.3 Improved UNETRANS data model:

According to Butler (2008), the evolution and the technological development in ArcGIS has necessitated the refinements and improvements of the original data model. This improved data model consists of four packages because of aggregation instead of six packages. These aggregated new packages are shown in the analysis diagram in figure 6, and the associated package definitions in the table 7.

This improved data model include assistance for transportation facilities of all types, including their characteristics and elements, it also include editing support offered by ArcGIS software, another improved feature is the ability to support temporal data and a separation of position data from other entity attributes. This feature allows multiple datums to be accommodated in the geodatabase for both linear referencing and geographic position.

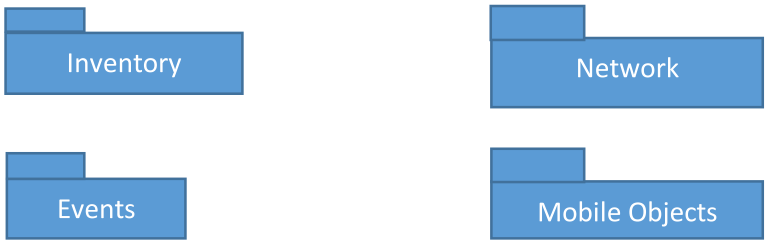

Figure 6: The improved UNETRANS packages (Butler, 2008)

The following table explains various package definitions of the improved UNETRANS data model.

Package	Definitions
Inventory	This package includes support for all types of transportation facilities, including their characteristics and elements
The Network	This takes care of the transportation-specific network data model used by ArcGIS Network Analyst extension, which replaces the geometric network model used by the original UNETRANS
The Events	This combines the former Activities and Incidents packages into comprehensive group of entities that representing things that happens on and to transport facilities.
The Mobile Objects	This package involves users of the transport system and it expands the original Mobile Object package.

Table 7: Aggregated package definition of the UNETRANS data model (Butler, 2008)

2.5 Conclusions:

This chapter has reviewed in brief the concepts of GIS and its functions, various components. It has enlightened the various definitions of GIS depending on the application scenario. It has also highlighted the concepts of GIS-T and its various transportation applications within GIS-T. Finally, it has discussed issues related to data models, specifically GIS-T data models used in the transportation sector, namely, the Enterprise GIS-T and the UNETRANS data models. Parts of the discussed ideas are used in chapter three to build a Transportation data model for Visakhapatnam city. This literature review will also answer some of the research questions and hypothesis argued in chapter one which will be given in detail in part four.

3. BUILDING A TRANSPORTATION DATA MODEL FOR VISAKHAPATNAM

3.1 Introduction:

The main objective of this chapter is about building a data model and designing of a data base for Visakhapatnam city. This chapter gives all the relevant details like the methodology and approach used for achieving the main objectives, hypothesis and questions that are addressed in this project. Road network analysis of Visakhapatnam city and how the data was obtained for our analysis are discussed. Ultimately the results that are achieved from the given input and observations that are drawn from our project are detailed.

3.2 The Study Area:

Visakhapatnam (Figure 7 & Figure 8) also known as Vizag or Vizagapatnam is a port city located on the south eastern coastal part of Andhra Pradesh State in India. It is often called as “Jewel of East Coast” and the “City of Destiny”. The latitude and longitudinal extent of the city are respectively 17.6883° N, 83.2186° E. It is the administrative headquarters of Visakhapatnam district and second largest city in Andhra Pradesh. It is also the third largest city in the east coast of India after Chennai and Kolkata. It has a population of about 2,091,811 and occupies 681.96 sq.km. The city is facing public transportation problems and road congestion due to poor road network infrastructure, increased number of vehicles and lack of an effective transport planning system which could almost all ease the public transport planning and management.

The need for implementation of new transport mechanism requires not only an information system, but also an information system that integrates databases and spatial databases that can be useful for public transport users as well as transportation planners and managers. Therefore, GIS-T is the right technology for the intended purpose.

A GIS-T combines both non-spatial and spatial databases of transport network to allow for planning and routing functions and decision-making processes. This also provides an efficient means for organizing basic transportation related data in order to facilitate the input, analysis, and display of transport networks.

The road network in Visakhapatnam is segregated into roads of national level and regional level. In the national level the National Highway (NH5) runs through the India’s east coast cities like Odisha, Andhra Pradesh and Tamil Nadu. In Andhra Pradesh this highway passes through the city of Visakhapatnam. NH5 runs through 1533 km out of which 1000km is through the state of Andhra Pradesh. Apart from the national level roads there are also regional level roads at district and local level known as access or collector roads and local or feeder roads. This forms the core transportation network of the city.

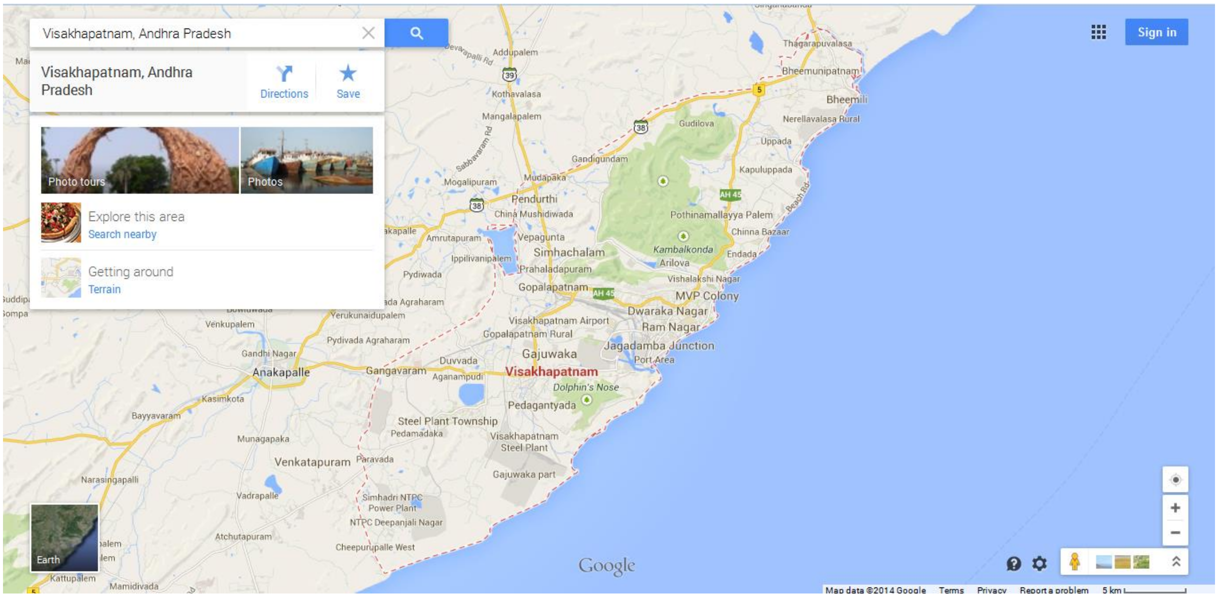

Figure 7: Study area Visakhapatnam that is chosen for the execution of project

Figure 8: A part of the study area Visakhapatnam showing some prominent places

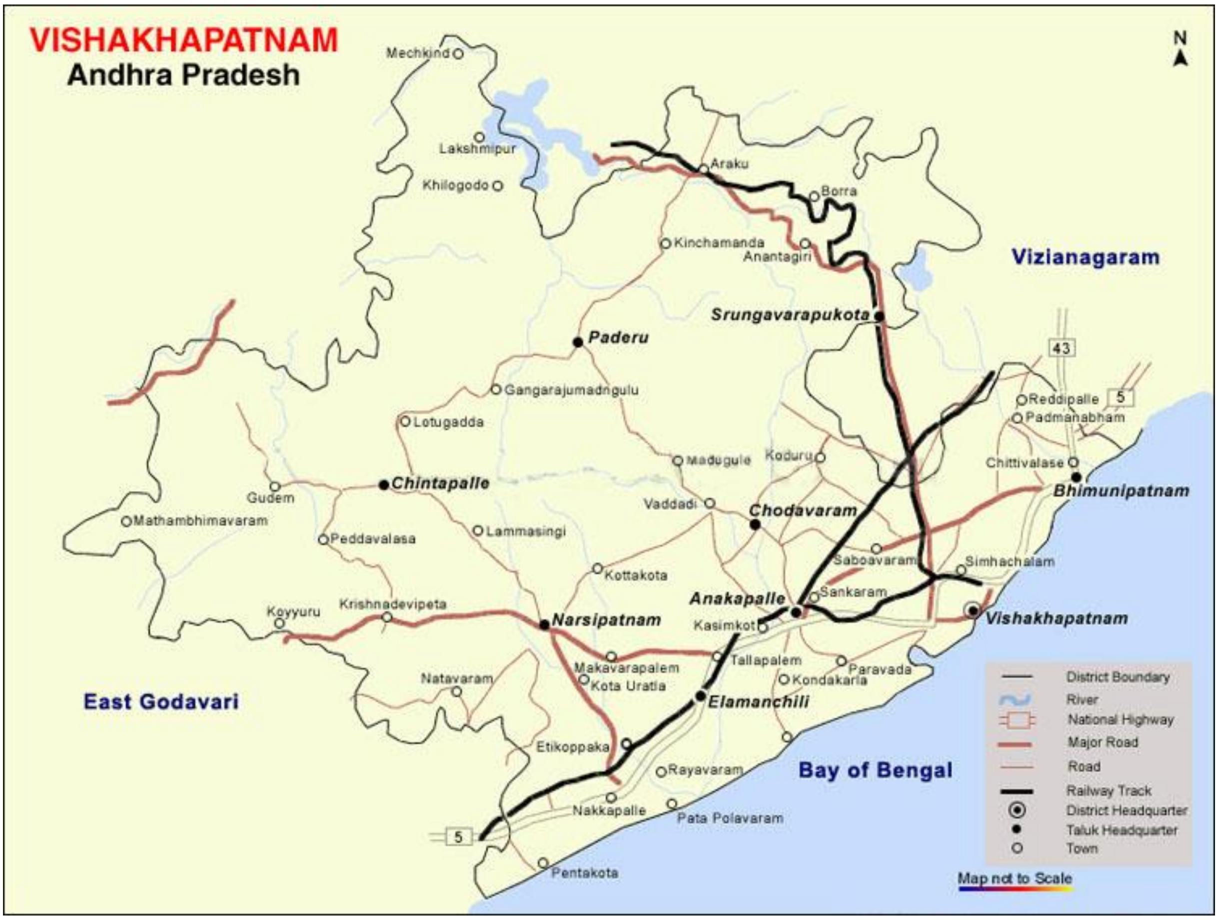

Figure 9: Visakhapatnam Map showing its boundaries and neighboring areas

3.3 Data Acquisition, Quality & Completeness:

The data for this project is obtained by downloading the google earth map of Visakhapatnam with suitable resolution so that the street view of the map can be taken into consideration for digitization of roads, bus routes, junctions, intersections etc. For downloading the city map the classic Google maps are taken into consideration. Here, the embedded html code is copied into a note pad file and saved with .html extension. Then the required width and height are adjusted accordingly for the perfect view of the map, so that major portions of the city are visible for the digitization purpose. When the map with the sufficient resolution is obtained it is downloaded using a software called screen grabber so as to grab the maximum desired portion of the study area. When the sufficient desired portion of the study area is downloaded, it is opened through Arc Map 9.3 and it is firstly geo-referenced with the help of rectified satellite image or toposheet. GIS layers for roads were created and annotated using the help of Google Earth and personal experience within the city. The quality of data sufficed the need of this project, though the attributes of the data was not comprehensive and incomplete to fit into the UNETRANS data model.

3.4 Methodology & Methods adopted:

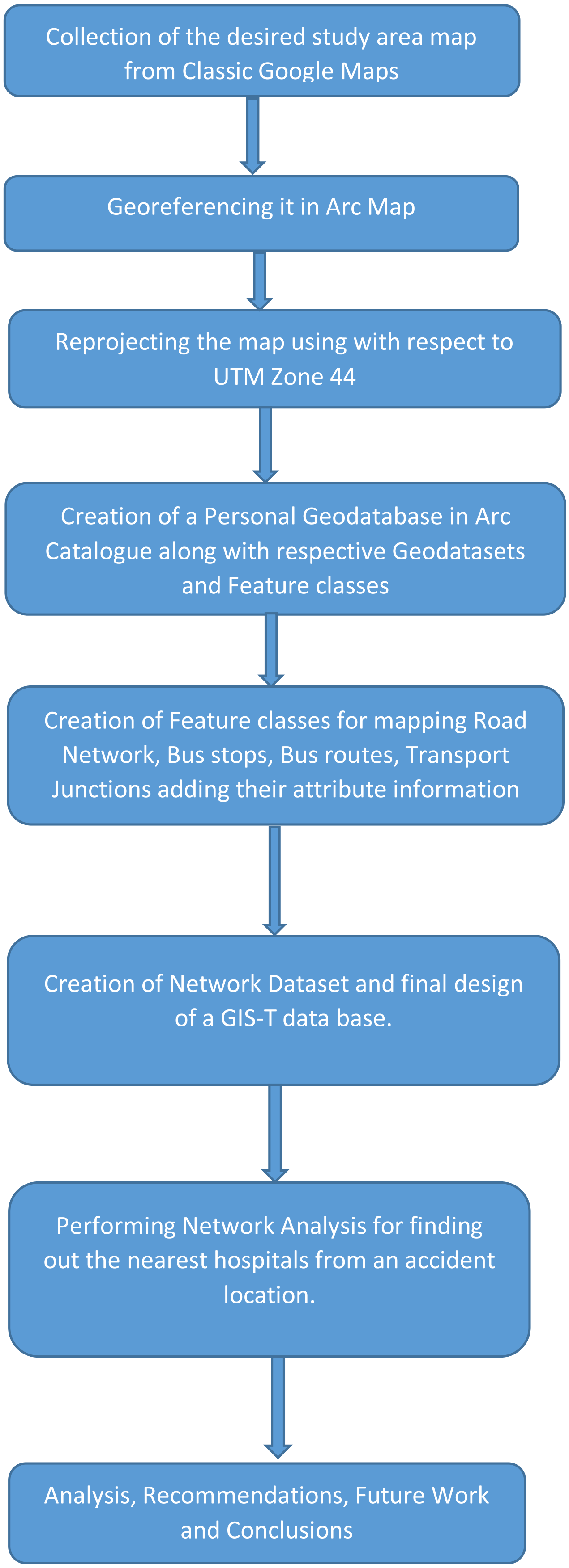

Figure 10: Flow Chart showing the Methodology adopted

In order to deal with the stated problem in section 1.2 and accomplish the objectives in section 1.3, and answer the questions in section 1.4, as well as the hypothesis in section 1.5 the following methodological approach was used:

- Review of existing GIS-T data model, two data model were reviewed, namely; GIS-T Enterprise data model and the UNETARANS model. Also Internet search from reliable websites such as ESRI and published academic sources;
- Having studied the two existing data model, two packages have been adopted for the proposed GIS-T database model for Visakhapatnam City; the packages are the Network and Events packages. Detailed explanation about the data model which includes; conceptual, logical and physical model design is presented in subsequent sections 3.4.1. through 3.4.3;
- Lastly, the proposed model design was implemented through prototyping. During implementation, only a small part of the model was implemented. Specifically, the Events Package was not implemented. The Network package was implemented in ArcGIS 9.3 desktop software. Selected classes were populated with data, but others were not populated due to unavailability of data. The methods used are illustrated in figure 8 below.

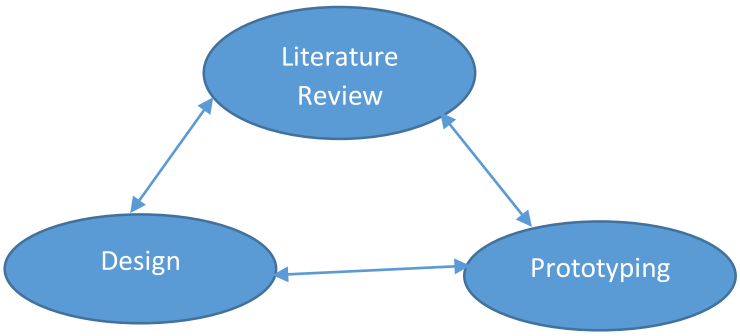

Figure 11: Research methods

3.4.1 Conceptual Model Design:

A Conceptual Model is a model made of the composition of the concepts that exists in the mind. This model helps us to know, understand or simulate the subject matter they represent. The term conceptual model in general refers to the conceptual process that occurs in the mind. The conceptual model design for the Visakhapatnam city is a simplified model that follows the path of the ESRI's UNETRANS data model because it is very comprehensive and having the complete overview of the transportation aspect scenario. Hence the conceptual model adapts two packages namely the *Network Package and Events package* as shown in Fig 12. This data model is simple by considering the limitation of available spatial data. The Network package primarily comprises a low-level description of the transportation network that mainly include the transportation features like Road network, transport routes, Junctions, bus stops, bus terminals.

Figure 12: Data model packages for Visakhapatnam

Classes when combined they form packages which are essential for the data modelling and analysis. Feature classes are formed for spatial data whereas Object classes are formed for non-spatial or attribute data. The feature and object classes, their relationship is depicted in figure 10 and 11. The corresponding definitions of the feature and object class are given in table 8 and 9.

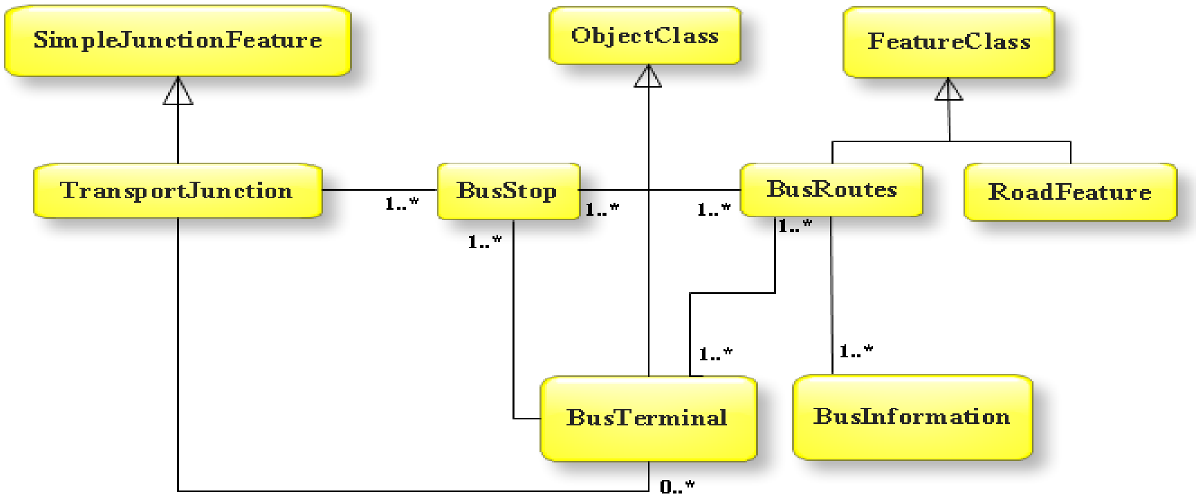

Figure 13: Conceptual design of the network package for Visakhapatnam case study

The below table presents features and object class definitions for Network Package

Object/Feature Class	Object/Feature Class Definition
SimpleJunctionFeature	A simple feature class representing simple spatial feature of transport network.
ObjectClass	A list of tables representing non-spatial data related to any transport network.
FeatureClass	A spatial feature representing points, lines, or polygon on transport network.
TransportJunction	A feature that bounds a Route Link or any significant point of interaction between transport routes.

Object/Feature Class	Object/Feature Class Definition
RoadFeature	Any linear object intended to represent a right-of-way for transportation activities
BusStop	A point where passengers can board or alight a public transport.
BusTerminal	One or more stops point close to each other. It is also a type of TransportJunction representing a hub location for bus travel where passengers can board busses, transfer between busses, and obtain travel information.
BusInformation	Records of all buses registered to carry transport business as city buses.

Table 8: Object and Feature class definitions for the conceptual design of the Network Package

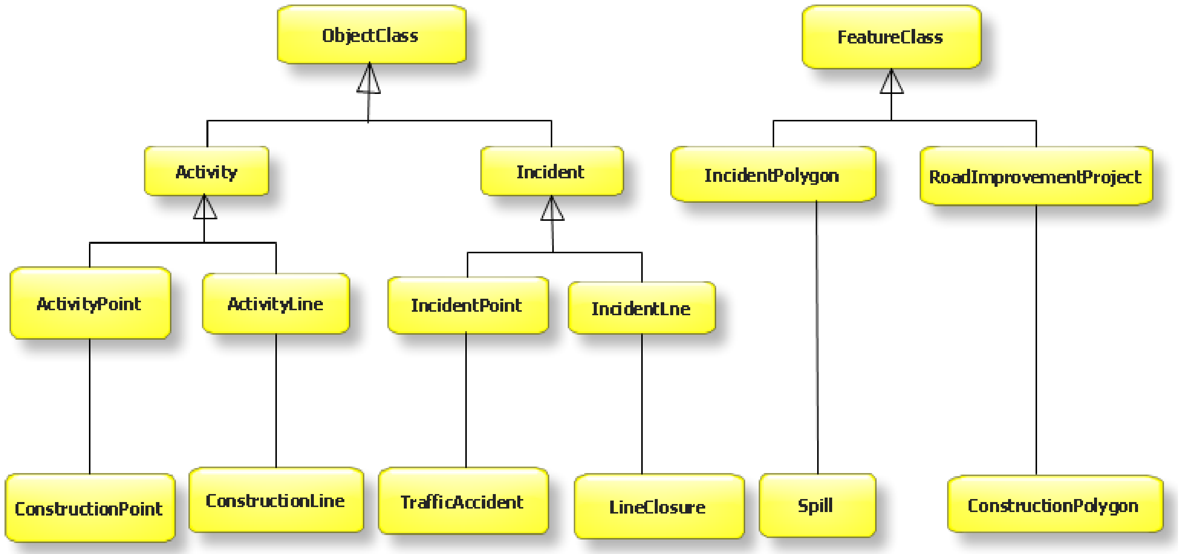

Figure 14: Conceptual design of Events Package: Feature and Object Classes (Butler, 2008)

The below table shows the Feature/Object Class definitions for the events package

Feature Class	Feature Class definition
Activity	An Activity is one of several types of feature that represents a planned operation. Activities are linearly referenced to the network. Activities can have point, line, or polygon spatial representations.
Incident	Any type of unplanned, transient occurrence with a reference to the Transport Network.
ActivityPoint	The abstract feature class for any Activity that has a point spatial representation
ActivityLine	The abstract feature class for any Activity that has a linear spatial representations

Feature Class	Feature Class definition
ConstructionPoint	A construction activity with a point spatial representation, referenced to the transportation network.
ConstructionLine	A construction activity with a linear spatial representation, referenced to the transportation network.
IncidentPoint	Any type of Incident with a point representation
IncidentLine	Any type of Incident with a linear representation.
TrafficAccident	A type of IncidentPoint representing a transient, unplanned occurrence that must be maintained in the database.
LaneClosure	A type of IncidentLine representing the transient, unplanned closure of a lane on a BusRoute or RoadFeature due to a TrafficAccident or other Incident.
Spill	A type of IncidentPolygon representing the area affected by an Incident such as a toxic spill or oil spill from a TrafficAccident on a TransportRoute.
RoadImprovementProject	An object class representing any information about road construction project undertaken on RouteFeature or Transport Network.
ConstructionPolygon	A construction activity with a polygonal spatial representation, referenced to the transportation network.

Table 9: Object and Feature Classes definition for the Events Package

3.4.2 Logical Model Design:

A logical data model is a typical type of model which shows the detailed representation of the organization's data which is independent of data management technology and described in business language. It is typically represented as a diagram, organized in terms of entities, relationships with underlying definitions. The purpose of logical design is to translate the conceptual schema design into a logical schema customized to the specified database's management system. A logical schema is a description of the structure of the database that can be processed by the database management software; it includes attributes for each class or entity and data types for each attribute. Therefore, a logical data model is the blueprint for designing and creating a physical geodatabase (Baynon-Davies 2004, Butler 2008). In this case, the designed logical schema is processed in the ArcGIS geodatabase model. In fulfilling this, a logical design has been created using ArcInfo UML model toolset template that is integrated into the ArcGIS-ArcInfo software, and were developed using Microsoft Visio software. Thus, the conceptual schema is mapped into logical design as presented in figures 12 & 13, and whose entity descriptions were exemplified in tables 9 & 10 respectively.

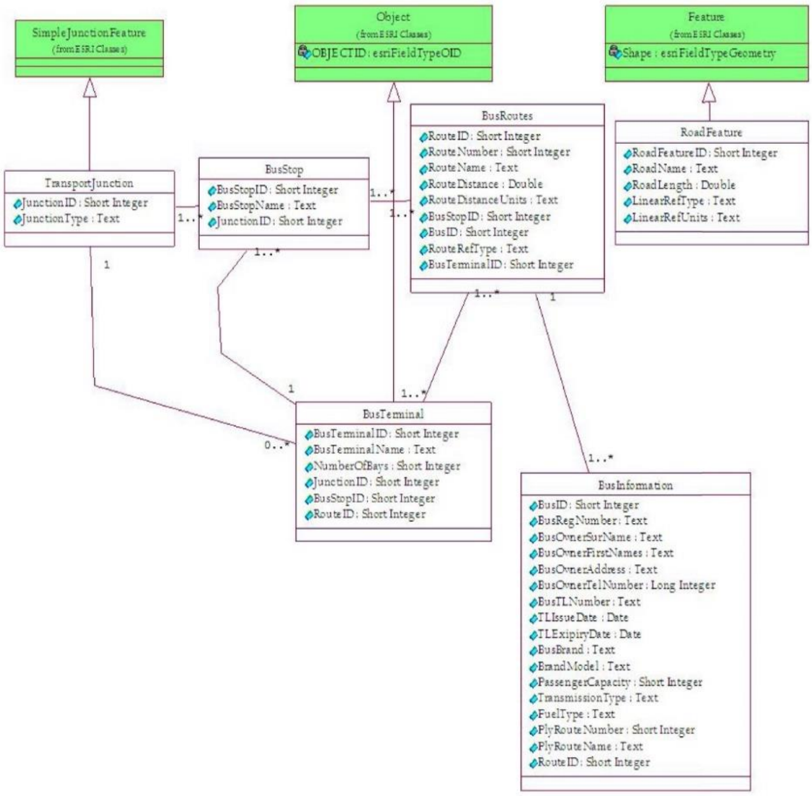

Figure 15: Logical design of the Network package developed for the Visakhapatnam city

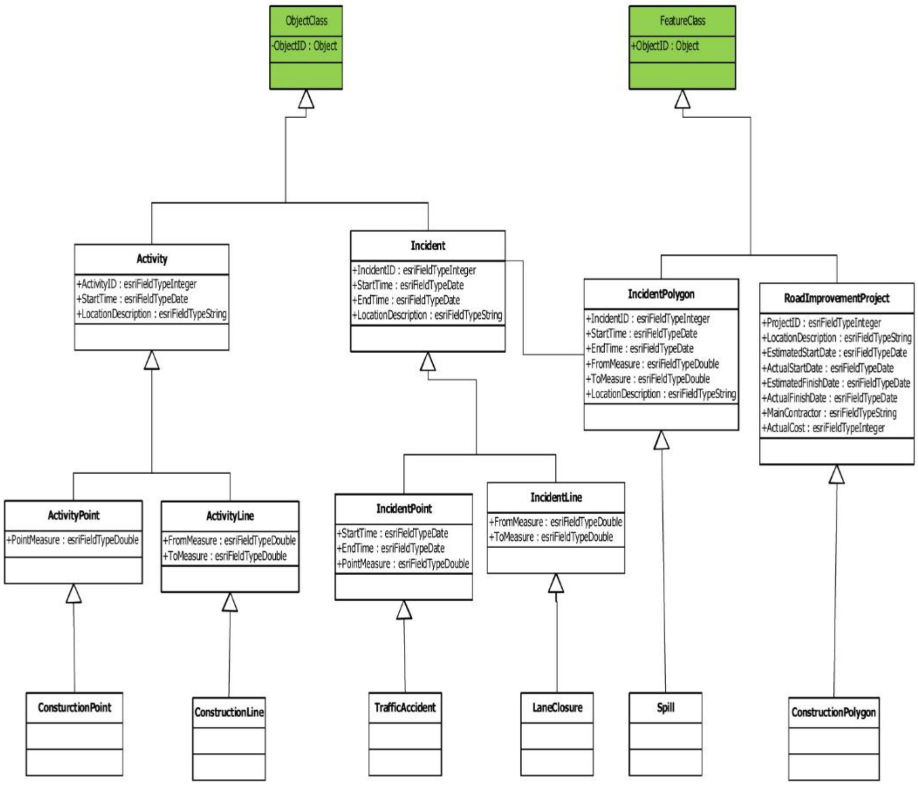

Figure 16: Logical design of the Events package developed for the Visakhapatnam city case study.

3.5 Geodatabase and its concepts:

A Geodatabase can be defined as a collection of geographic datasets like Feature classes, Raster data, attribute tables. It is the native data structure for Arc GIS. A geodatabase provides the ability to

- Leverage data relationships
- Enforce Data Integrity
- Create Intelligent features

Geodatabase is a set of geographic datasets of various types held in a common file system folder, a Microsoft Access database, or a multiuser relational database management system. A basic geodatabase concept is the dataset. It is the primary method used to organize and use geographic information in ArcGIS products.

3.5.1 Why should we use a geodatabase?

- All GIS data is in a File GDB or RDBMS
  –Supports continuous, large datasets
- Built on the simple feature model
  –Open access (OGC, C, COM, SQL)
- Business rules, topology, networks
  –Data Integrity
- Versioning work flows
  –Long transactions
  –Distributed data management
  –Archiving (history)

3.5.2 Advantages of Geodatabases:

- Central location for features and attributes
- Ability to create behavior
  – Grouping features into subtypes
  – Creating spatial and attribute validation rules
- Persistent relationships between records
  – Referential integrity
- Stored connectivity between lines and points
- Many users editing database at one time
  – File geodatabase and enterprise geodatabase
- Scalable

3.5.3 Types of Geodatabases:

Arc GIS have three types of geodatabases namely:

I. Personal Geodatabases: In this type of geodatabases all files are stored in a Microsoft Access data file. It mainly consists of only single user editing. It has size limit of 2GB. It is designed only for use by one or few people.

II. File Geodatabases: In this type of geodatabases files are stored as folders in a file system and is designed for use only by one or few people.

III. Arc SDE Geodatabases: In this type of geodatabases files are stored in an enterprise DBMS. It supports multi user editing via versioning and requires Arc Info or Arc Editor to edit.

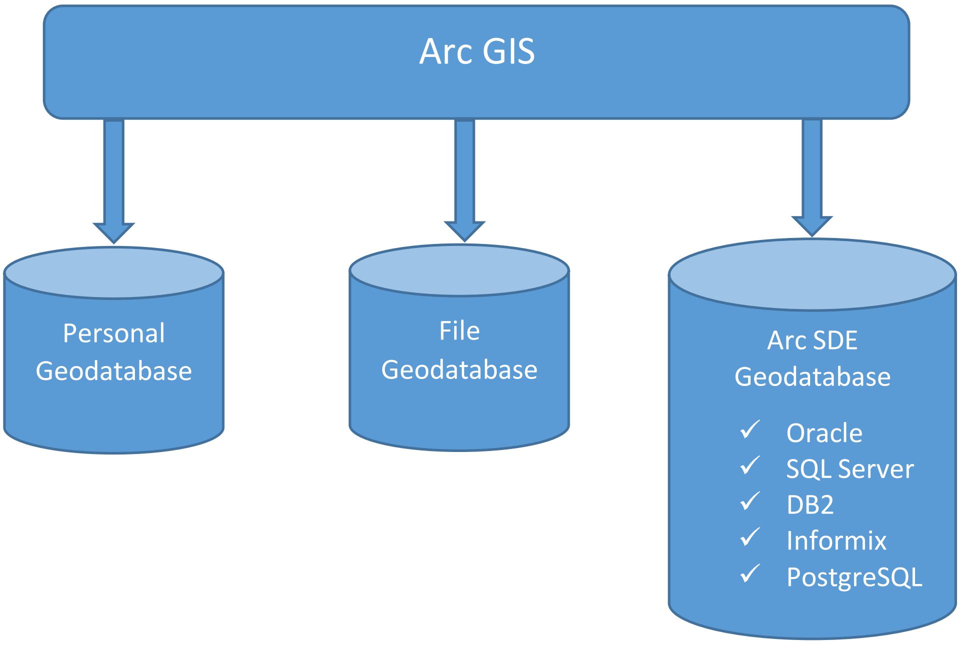

Figure 17: ArcGIS Geodatabase types (ESRI, 2007b)

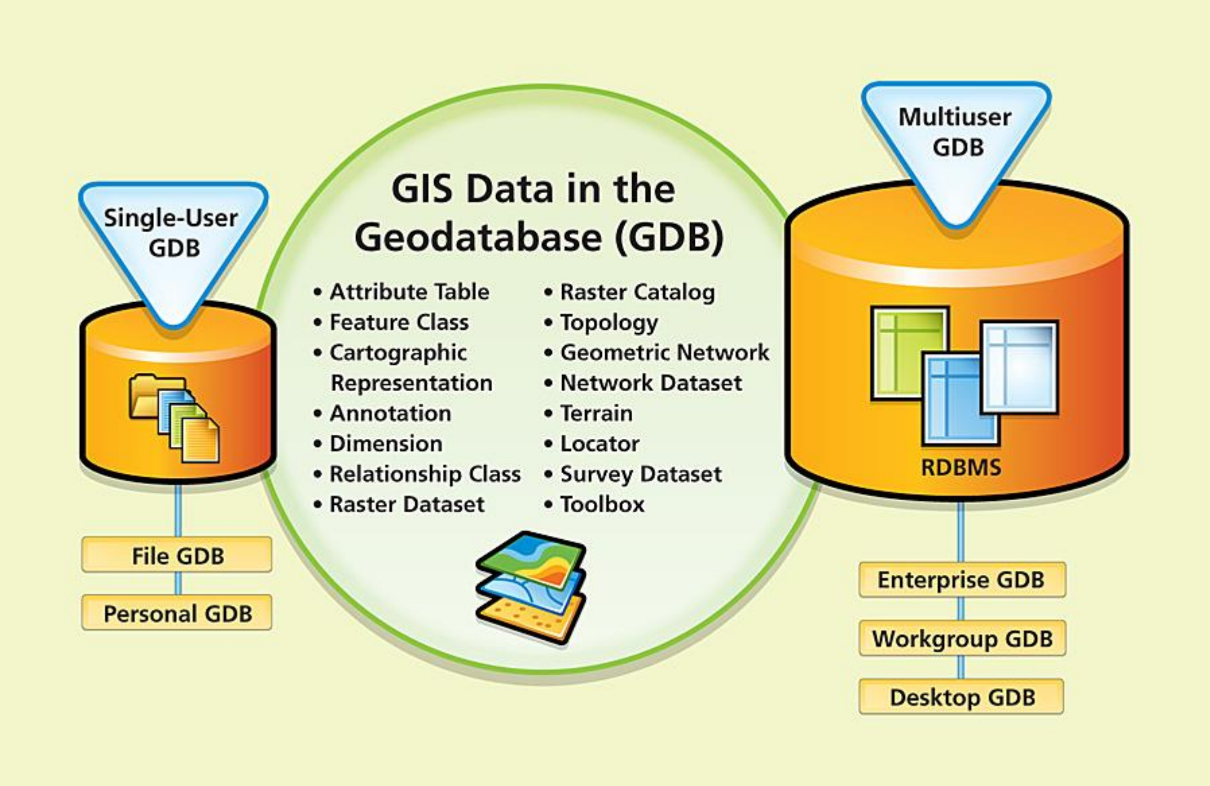

Fig 18: Geodatabase types and GIS Data in it.

3 Types of Geodatabases…

	Personal GDB	File GDB	SDE GDB (3 editions)
Storage format	Microsoft Access	Folder of binary files	DBMS
Storage capacity	2 GB	1 TB per table*	Depends on edition
Supported O/S platform	Windows	Any platform	Depends on edition
Number of users	Single editor Multiple readers	Single editor Multiple readers	Multiple editors & readers
Distributed GDB functionality	Check out/check in replication	Check out/check in replication	Replication (all types) & versioning

*** By default; option to have 256 TB per table**

Fig 19: Geodatabases Categorization based on parameters (ESRI,2007B)

3.5.4 Dataset Types in Geodatabase:

The geodatabase consists of three primary data set types as shown in figure 19

I. Feature Class

II. Raster Datasets

III. Tables

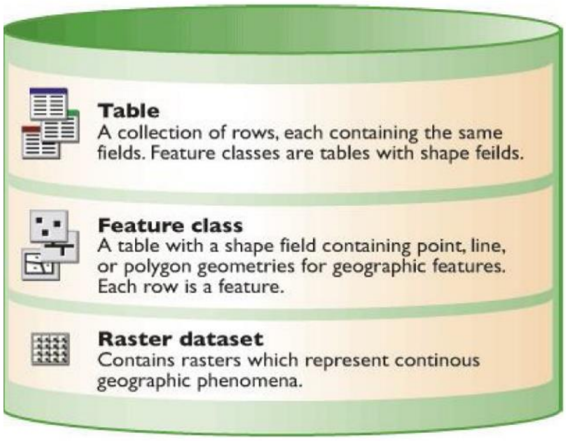

Figure 20: Primary dataset types in geodatabase (ESRI, 2008)

The geodatabase has been created such that there is a well-organized and systematic data management with common projection systems within the feature data sets and all the feature classes have the same reference system.

3.5.6 Creating Geodatabase in ArcGIS-ArcMap:

The GIS-T data model which has been proposed actually consists of two packages implemented for Visakhapatnam Public Transit Planning and operations. The two packages discussed in the earlier section are Networks Package and Events Package respectively. However in this project only the Networks package has been implemented and only four feature classes were populated with data. A personal geodatabase was manually created in ArcGIS as shown in the figure. This mainly consists of creating the personal geodatabase, feature dataset, feature class, and personal geodatabase tables. Attribute information has been added corresponding to the type of data that has been stored.

3.5.6.1 Creating Roads and BusRoute Feature Datasets:

Road feature and bus route features of the steel city Visakhapatnam were created by onscreen digitization of the google maps of the Visakhapatnam area. The study area under consideration has been downloaded through the classic google maps and it has been used as a base map for all the digitization purposes. The base google map taken is up to the newest extent considering all the latest changes. However there can be any minor changes occurred to the roads. The road set which has been digitized comprises all road classes, namely regional roads, national highways, main roads, street roads. However road distinction has not been done by representing each type with different color. All the roads are represented with same color. The bus route feature dataset mainly comprise of all the major bus routes through which buses make the public transport facilities possible and most of them have been digitized by having prior knowledge and personal experience with the city. The following maps in figure 21 depict portion of the digitized road feature dataset, and figure 22 illustrates the portion of bus route feature dataset of Visakhapatnam city.

3.5.6.2 Creating Transport Junctions Feature Class:

Transport Junctions feature class were created from a base road feature dataset. Transport Junctions mainly comprise of all the road intersections, street intersections, bus stops, bus terminals and road or street dead ends. The map in figure 23 illustrates some of the important created transport junctions.

3.5.6.3 Network Dataset creation:

Network dataset creation from major roads was one of the important input for carrying out the network analysis. It is created by navigating to the geodatabase and right clicking on the feature data set and selecting the network dataset option and there by adding all the feature classes that are desired for being in the network dataset. Two network datasets have been created (Vskp Road network and BusRoutes Network dataset) were created and illustrated in the figure 24(a) and (b). The Visakhapatnam road network datasets incorporates all the feature classes that are created in the geodatabase like (transport junctions, RoadFeature, BusRoutes), while the BusRoute network dataset incorporates BusRoute and Bus Stops Terminal classes. Principally, Network Datasets comprises of junctions and edges of the feature class formed at every junction of feature class and at the vertex of polylines. The two figures presented below shows the created Network Datasets.

Figure 21: Part of Road feature dataset of Visakhapatnam City

Figure 22: Part of Bus route feature dataset of Visakhapatnam city

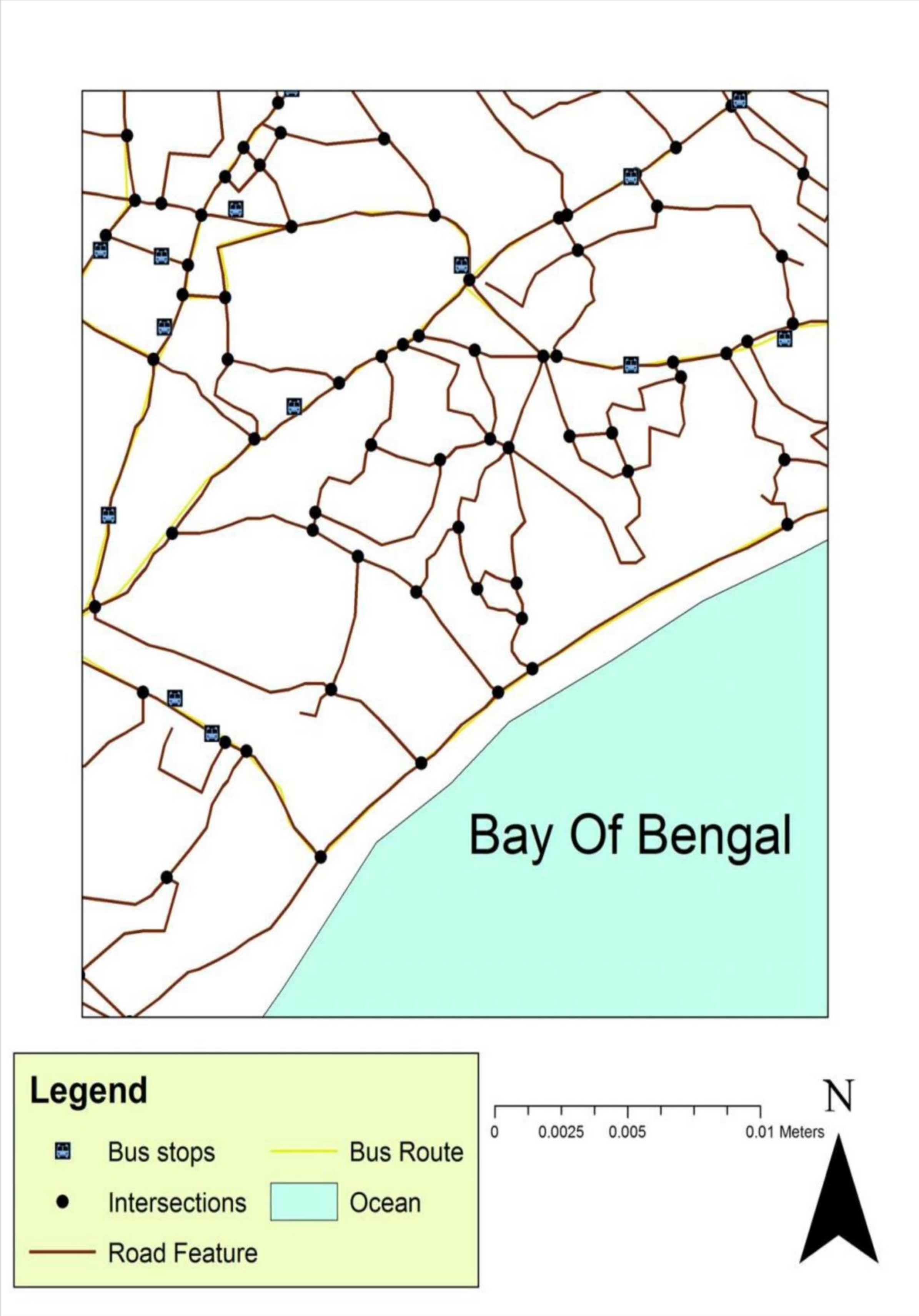

Figure 23: Part of Transport Junctions within road feature dataset

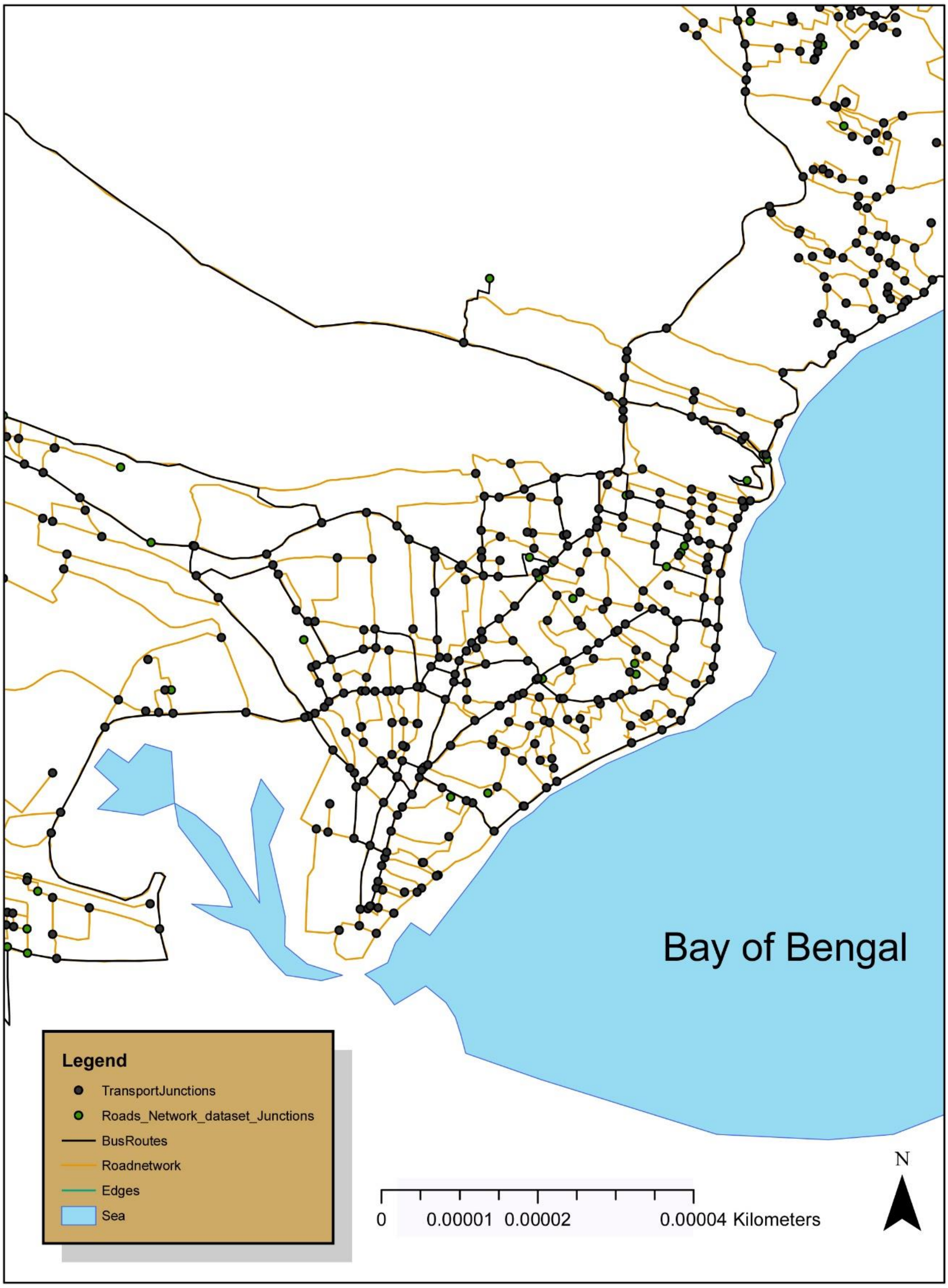

Figure 24(a): Road Network Dataset for Visakhapatnam

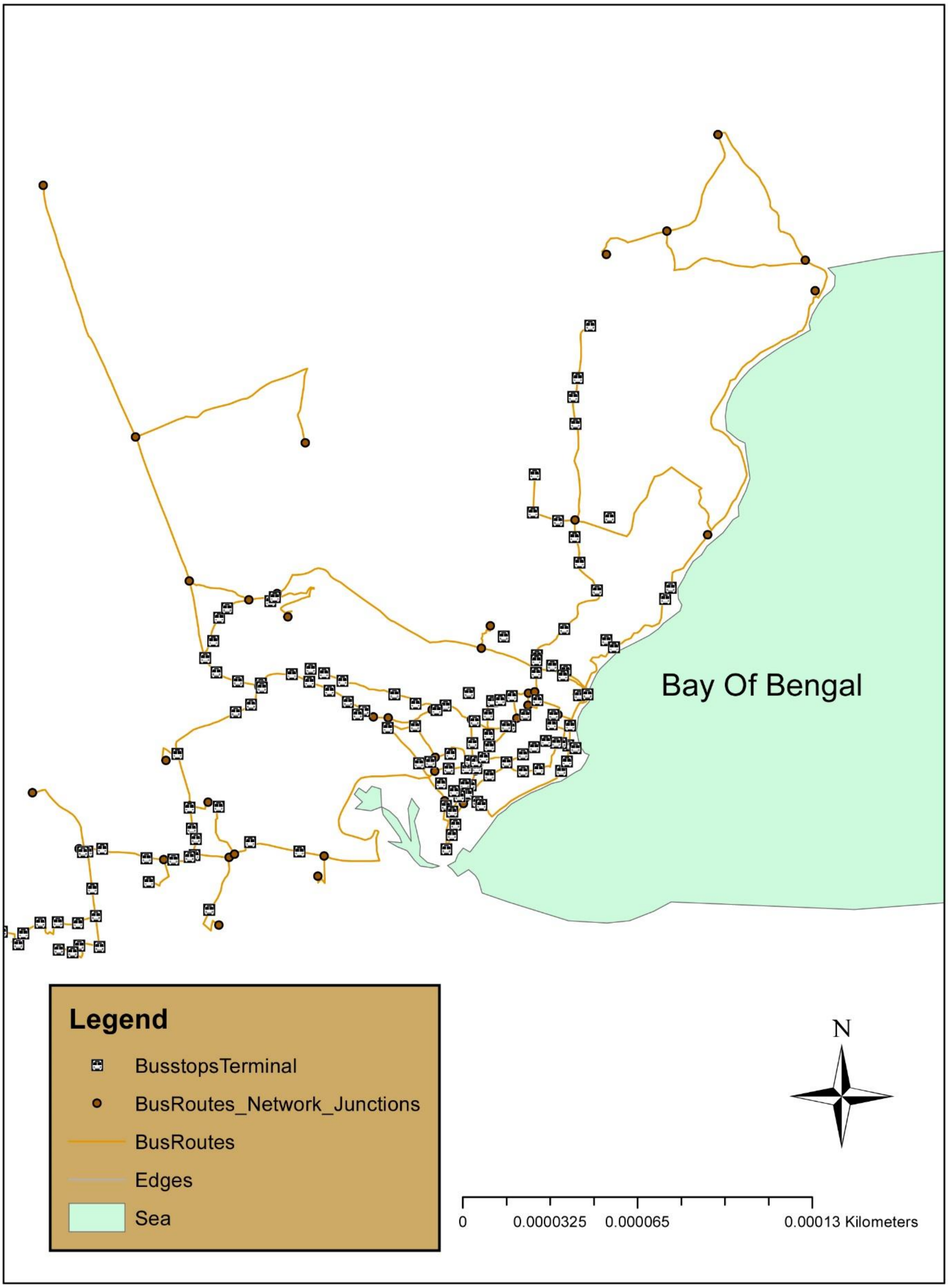

Figure 24(b): Bus Route Network data set for Visakhapatnam

3.5.6.4 Creating Attribute Information:

During the course of making a geodatabase tables of the present feature classes in the feature datasets, the attribute information is given only up to a certain extent due to the lack of availability of data information. The bus route attribute information like the bus number, bus owner etc. have been given and also the digitized road feature information like length has been given. There are only a few data that were populated in the geodatabase for prototyping and implementation of the created model. The main aim was generally to check for an instance whether the designed data model implementations has been achieved or not.

3.5.7 Network Analysis Application:

Network data structures were one of the earliest representations in geographic information systems (GIS), and network analysis remains one of the most significant and persistent research areas in geographic information science (GIScience). Network analysis is a way to solve network problems such as finding the best route, finding the closest facility, and identifying a service area around a location, OD cost matrix analysis, Vehicle routing problem, location-allocation. This section details two network applications that have been done; namely, finding the closest facility (Closest Bus Stop to hospitals), and identifying a service area around hospitals' location.

The closest facility is the nearest facility which can be an emergency vehicle (Ambulance or fire engines), hospital facility, fire station. In case of any incident such as accident or fire mishaps along the route, rescuers in general search for the closest hospital or emergency vehicle to an incident point. On the other hand people travelling through the public transport wants to know the closest bus stop to a network location or facility such as hospital, tourist places etc.

For carrying out a simple network analysis on bus routes a hospital layer was created and it was used along with the bus stops network so as to find out the closest bus stop to a designated network location. In general the procedure which was used here is the utilization of the graphic pick tool in the network analyst extension which facilitates the creation of point of interest and the closest bus stops were automatically determined based on the shortest distance from a number of bus stops, where in this case hospitals are selected as point of interest.

Service area is that area around a facility which can be served by the facility. For example if we have an area of about 1000m from a hospital, it helps in providing the service for the nearby people who are residing within the specified zone of 1000m. Similarly a grocery shop, restaurants, hotels helps in providing the necessary service to the people in that area which has been specified within that ring of the measurement. The service area is determined by on the basis of distance from the facility. The area that has been created is a polygonal buffer after giving a specific distance criteria in which a certain community of people must be served.

3.6 Results:

The process of building transportation geodatabase for Visakhapatnam has several results that are found in sections 3.5.6.1 through 3.5.6.4 in this report. From conceptual design to physical design of the geodatabase, and its prototype implementation gives some kind output of the project that fulfil the goals and objectives of this project.

3.6.1 GIS-T Data Model:

One of the objectives in this project was to design a GIS-T database for public transport route planning and operations for Visakhapatnam City. In order to come up with a functional database, a database model has to be developed. In the project, a GIS-T database model has been developed and implemented in ArcGIS 9.3

The developed geodatabase consists of feature classes and object classes. The former are tables holding spatial data, and the latter are tables mainly for non-spatial data. In implementation through prototyping, all tables were created in ArcGIS and partially populated with data, specifically, spatial data in feature classes. However, populating object class tables was not possible, almost all attributes remained with null values, this makes the need for the future work to ensure the database is comprehensive and fully populated with associated data, be it spatial or non-spatial.

The developed GIS-T database model is not comprehensive due to several reasons among them are the lack of both spatial and non-spatial data, which are vitally important in building-up geodatabases. In addition, lack of specific and well properly organized transportation data for Visakhapatnam City hinders the comprehensively of the desired GIS-T.

When reviewing the UNETRANS data model, it was found that UNETRANS model was developed to fit the US and other developed world transportation infrastructural environments, this is not the case for Visakhapatnam, Andhra Pradesh or any other Sub-Asian counties where its transportation infrastructures are not yet stable and not comparable to that of developed world like USA. Therefore, the GIS-T database for Visakhapatnam, though customised based on some part of the UNETRANS data model reflects the real and actual environment of roads network in Visakhapatnam city, and availability of both spatial and non-spatial data related to transportation.

3.6.2 Network Analysis Results:

Two examples of network analysis applications based on simulated incidences are presented in figure 25, figure 26 and figure 27. Figure 25 shows the route to the closest hospital facility from a simulated accident location. The example in figure 25 does not take into consideration information about two ways or one way nor does it consider time. It would be better to consider time if available, however, for this case, only distance is used. The analysis of Service area can be done but due to the software constraints, it is not incorporated in our report.

3.7 Conclusions:

In this chapter a comprehensive design of GIS-T data model for Visakhapatnam City has been dealt in a broader perspective which helps in serving as a basis for future road maps. More work need to done with a special emphasis on availability of required data, format and organization of the data in an interoperable manner. This chapter has completed the major tasks which are outlined in the objectives of this project. In the following chapter, the main conclusions, hypothesis verification and future works are discussed.

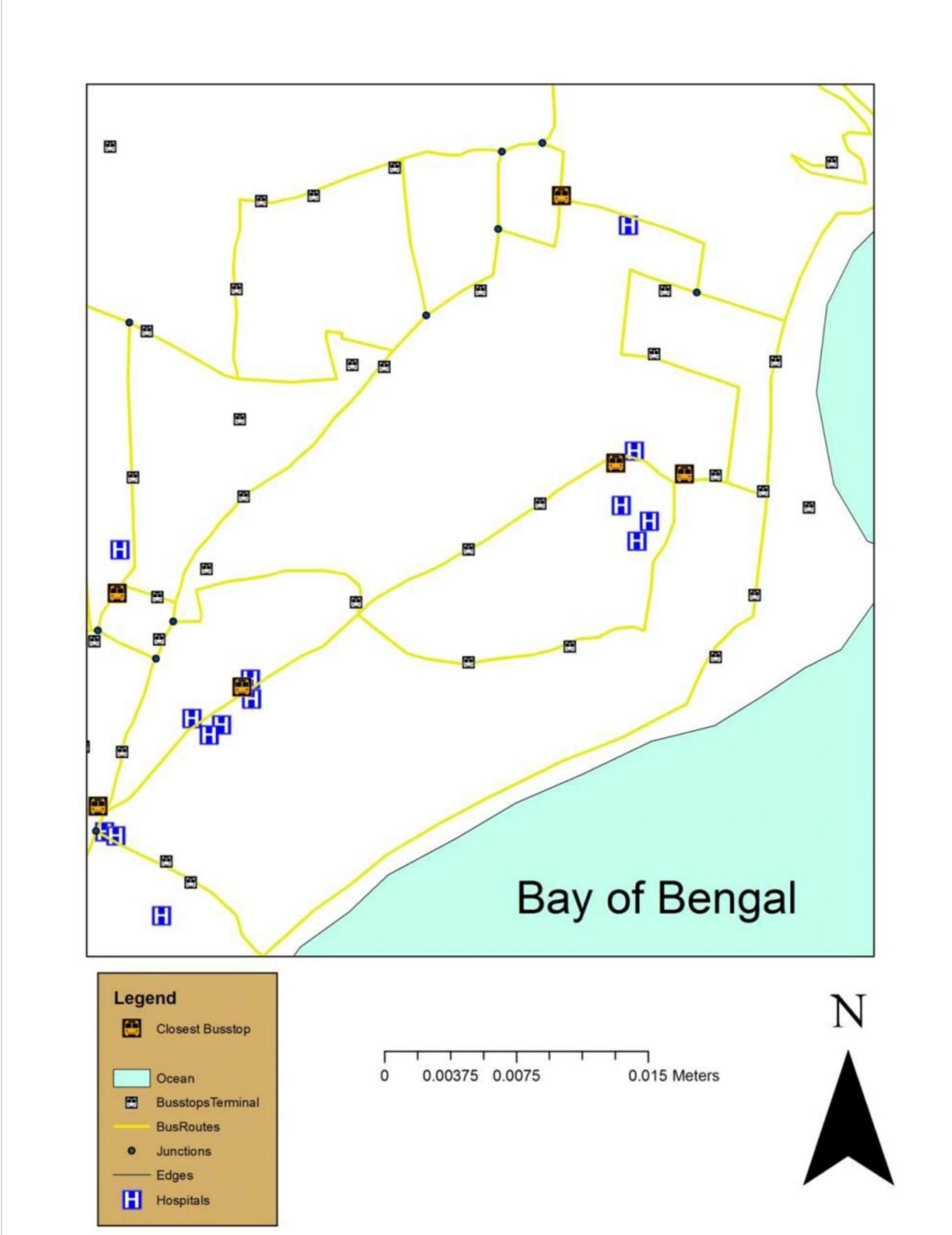

Figure 25: An example depicting the closest bus stops to the hospitals

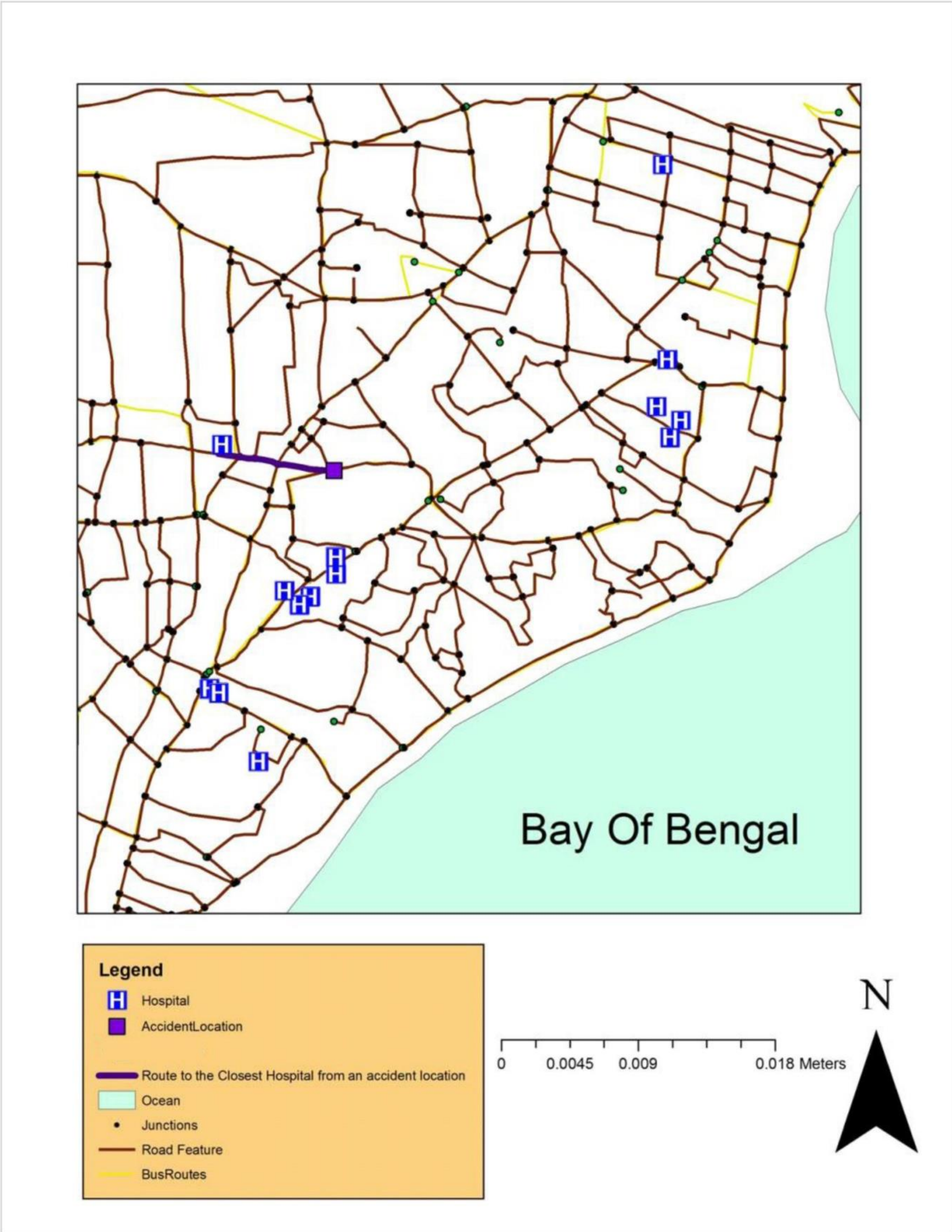

Figure 26: An example showing routes to nearest hospitals from a simulated accident location on a network

4. CONCLUSIONS AND RECOMMENDATIONS

This chapter gives a brief overview of the conclusions and recommendations as a whole for the entire project which are detailed in chapters one, two and three. The conclusions which are made here are purely based on our analysis work carried out for the project and obtained after a thorough and conceptual review of literature.

4.1 Important Conclusions:

The major objective of as listed in section 1.3 were to review and make analysis of the existing GIS-T data model especially the UNETRANS and implement it for the design of a GIS-T data base design for public transport planning and operational analysis in Visakhapatnam city and to apply the design through the concept of prototyping.

The conclusion about these is that all objectives have been achieved, few-selected GIS-T data models (the focus was on UNETRANS) were reviewed & studied in detail, and customized GIS-T data model made out of it for Visakhapatnam city. The designed and implemented database is not full and comprehensive system, but a mere prototype, which can be further, improved, and expanded.

Due to non-availability of enough spatial and non-spatial data, there exist in the prototype many null values in the geodatabase tables; all these need to be collected, documented, and implemented. A network analysis on selected application was done to find the routes to existing hospital facilities within the city.

4.2 Verification of research questions and hypothesis

This research argued for two research questions and three hypothesis as stipulated in sections 1.4 and 1.5 respectively, and which are discussed in subsequent sections.

4.2.1 Verification of research questions

The major question addressed in this project was to know which package and classes in GIS-T data model can support public transport planning and operations for Visakhapatnam. This question is answered after review of the UNETRANS data model. It is our opinion that two packages are required to support GIS-T data model for Visakhapatnam, the packages are the Network and Events package. The prototype in the project is implemented using one package only (the Network Package). The other two sub-questions are answered as follows based on a detailed review of the UNETRANS data model

I) UNETRANS is a comprehensive GIS-T model that caters for both uni-modal and multi-modal transport systems, therefore, its full implementation for Visakhapatnam city will require an infrastructural setting that resembles the classes and features in the model itself. In fact, the data model as a whole is not suitable for implementation unless customized and use part of the packages and classes from UNETRANS to reflect the real situation of Visakhapatnam infrastructure and availability of spatial data.

II) UNETRANS data model was developed in the US, so it fully reflect the US infrastructural settings, open access to spatial data as well as organized and harmonized spatial data. This is not the case for Visakhapatnam city.

III) With regard to whether the available spatial data that can fit into the UNETRANS data model, it can be concluded that, UNETRANS data model requires complete spatial data for its full implementation, the data that may not available for Visakhapatnam.

Thus, the available geodata does not fit in the current UNETRANS GIS-T data model.

4.2.2 Verification of research hypothesis

Three-research hypothesis argued in this project are justified for as follows:

i. The first hypothesis contended that it is possible to build an effective transportation data model for Visakhapatnam based on part of UNETRANS GIS-T data model. This hypothesis is accepted. Through customization, part of the UNETRANS data model components may be used to build an effective data model for Visakhapatnam. The designed and implemented prototype in this project is an example of the positivity of the hypothesis.

ii. The second hypothesis claimed that: Building an effective GIS-T data model requires comprehensive spatial data and technology. This hypothesis is also accepted. An effective and exhaustive GIS-T data model will require extensive spatial data, but also, the right technologies in terms of hardware, software, and human ware. However, this does not mean that a simple GIS-T data model like the one developed and prototyped in this project may not be effective to some extent based on available fragmented data.

iii. The third and last hypothesis said that, Lack of well-documented and organized transportation data is a hurdle to effective GIS-T database design and implementation. This argument is true for the following reasons: In Visakhapatnam City, Spatial Data Infrastructure is not in place yet. Spatial data is highly fragmented in different organizations and government entities. It is not known, which and what type of spatial data is available and in which format or standards. This is a major bottleneck to effective implementation of GIS for transport planning in Visakhapatnam city.

4.3. Limitations

This section details the limitations and future work required for same project. The information provided is based on what has been done so far and the encountered shortcomings. The development and design of the GIS-T for Visakhapatnam city was based on the limited available spatial and non-spatial data. Thus, the developed GIS-T database is not comprehensive.

4.4 Recommendations

Based on the work done in this project and challenges faced during implementation, some of which were limitations of available spatial and non-spatial data, the following recommendations are advanced for effective and comprehensive design and implementation of GIS-T for Visakhapatnam City:

I) In order to have well collected and organized spatial data related to the transportation sector, there is a need to have a spatial data infrastructure for Visakhapatnam city, which can make available all spatial data for the city. This will facilitates and make easy use of standardized data for various activities including development of GIS-T for the city;

II) Technological developments that are happening in the geospatial technology field require a considerable investment in hardware, software and proper training to manage and develop GIS-T for the city. Therefore, decision makers need to be aware of the importance of the GIS-T for decision-making process, in addition, should be aware of the benefit of having such a geodatabase in support of urban transport planning systems.

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