Design and implementation of an internet based spatial decision support system (SDSS) for freight management

Srikanth Venkata Palem

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A Thesis

entitled

Design and implementation of an Internet based Spatial Decision Support System (SDSS) for freight management

by

Srikanth Palem

Submitted as partial fulfillment of the requirements for

the Master of Arts in Geography and Planning

Advisor: Dr. Peter S. Lindquist

Dr. Mark Vonderembse

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Graduate School

The University of Toledo

August 2004
An Abstract of

Design and implementation of an Internet based Spatial Decision Support System (SDSS) for Freight Management

Srikanth Palem

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The University of Toledo

August 2004

Growing freight has been a major concern for the transportation planning community. Increasing freight movements by all modes of transportation across the nations has lead to congestion and inadequate infrastructure. There is a rising need for internet based freight management spatial decision support systems (SDSS) exploiting the latest Geographical Information Systems (GIS) and Remote Sensing (RS) technologies that can assist the transportation planning community in making informed decisions about freight related issues consisting of congestion, demand and capacity. The system being an online or web based system has the advantage of being accessed from anywhere thus making it an easy tool for sharing information across different regions. This can also be
utilized for asset management, data dissemination and to model alternative freight management plans and “what if?” scenarios. There is no established framework to date for the development of such systems.

A pragmatic approach is taken in this study to design and develop a conceptual framework for an internet or web based freight management spatial decision support system (SDSS). Different components, features and technology that are required to create such systems were discussed in detail along with a variety of development and implementation strategies.

The developed framework was utilized in creating a freight management SDSS for the Upper Midwest Freight Corridor Study currently underway at The University of Toledo encompassing the states in the Midwest. This has given an opportunity to look at the feasibility of implementing such systems and the difficulties faced. The freight management SDSS is currently online and is anticipated to be used by Department of Transportation officials, urban and transportation planners and homeland security officials in making informed decisions. Thus, the conceptual framework developed in this study can be used as the rudimentary framework for creating a robust freight management SDSS in the future.
Dedicated to my parents and sister, Ravindranath, Bhagyalakshmi and Padmini who have encouraged me in all ways to grow and experience the challenges in my life.
Acknowledgements

I would like to acknowledge all of those who made this thesis possible. I am particularly grateful to Dr. Peter S Lindquist and Dr. Kevin Czajkowski for their invaluable guidance and encouragement throughout the preparation of this thesis. I am also grateful to Dr. Mark Vonderembse and Dr. Jiwan Gupta for the willingness and contribution as thesis committee members. Finally, I wish to acknowledge my debt to the many kindnesses I have received from my friends and fellow researchers.
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Chapter One  

Introduction  

1.0 Overview  

This study focuses on the design and implementation of an internet based Spatial Decision Support System (SDSS) on the World Wide Web (WWW) for freight management and planning. A SDSS is a suite of computer programs with components consisting of GIS, databases, simulation models, decision models, and user interfaces that assist a decision maker in making informed decisions (Densham and Goodchild, 1989). There is currently no established framework for an internet based freight management SDSS. The transportation planning and decision making community needs more robust tools to address the ever increasing problem of congestion, demand and capacity (Harvey, 1995). Further, this could also be used to look at alternative freight management plans.

The framework and design of the SDSS depends on the envisioned end product. The rudimentary framework of an internet based freight management SDSS can be very complicated with inbuilt heuristic models, visualization tools, user interfaces, report generators, geodatabases to analyze and formulate
decisions. On the other hand it can be simple in terms of functionality and may lack many of the above elements and include a powerful visualization tool for analyzing data. There are many well established SDSS’s in different domains of sciences, the majority being used for environmental modeling and spatio temporal analysis of both spatial and non spatial data (Fedra, 1995).

A successful SDSS for freight management should be capable of allowing the users to examine the spatial and temporal nature of freight movements across all modes of transportation. In built travel demand forecasting models, capacity analysis and estimation, route choice, deterministic and stochastic assignments, and flow analysis should be part of it, allowing users to model “what if?” scenarios and look at different management alternatives. Robust data report generators and database management facilities including data editing and capturing, inbuilt models for advanced transportation network analysis and advanced spatial analysis should also be present. The system being an internet based SDSS, the user has the advantage of using it remotely from anywhere in the world at any point of time with minimum computer hardware installation.

Some of the components like route choice which form an essential component of SDSS are already available as commercial products in the market, see Figure 1.1. These components are used by individual people and logistics companies around the world to derive shortest and optimized routes for
personal travel and fleet management. None of them have the capabilities to look and analyze freight movements from a regional or national perspective, further they are not capable of “what if?” scenario analysis. Thus there is no established standards or framework to integrate all the specified capabilities into one SDSS.

Figure 1.1 Simple online routing application (Source:ESRI)

There are many issues with designing and standardizing the framework for creating a ideal internet based SDSS, these include the end users requirements, algorithms or models that are to be incorporated within the SDSS, compatibility issues with various components including software and hardware and cost implications.
The end users for these kind of systems may essentially consist of transportation planners, DOT (Department of transportation) officials, stakeholders, homeland security officials and many other individuals interested in looking at freight movement issues at regional and national scales. Further, they might not be proficient with the usage of GIS or analyzing the spatial data or lack the technical knowledge on using the system. The models or algorithms that could be incorporated depends on the end users again. For example, a transportation planner might be interested in analyzing the transportation networks using network analysis tools. A policy maker might be interested in visually analyzing thematic maps and spatial relationships to understand the relation between different variables that are of interest.

### 1.1 Need

Recent technological advances in spatial sciences and information technology have enabled the development of high quality SDSS (Tarantilis, Kiranoudis, 2002). They constitute a new scientific area of Geographic Information Systems (GIS) and Remote Sensing applications developed to support semi-structured or unstructured decisions, paying much attention to the spatial dimension of data to be analyzed such as the location, shape, and relationships among geographic features (Fedra, 1995). Freight traffic has been growing rapidly for decades. The origins of this growth are in the dramatic changes in industrial production and distribution that have occurred in recent decades. These include globalization,
which result in longer supply chains, and hence longer hauls and more freight
Ton-km (Morlok, 1999). Domestic freight that was moved by all modes
combined (measured in Ton-km) increased by 65% from 1970 to 1995 across the
USA (Morlok, 1995) (Figure 1.2). The thick lines in the figure show the truck
flows on that particular route, this is calculated using AADT (Annual Average
Daily Traffic). Level of Service (LOS) often referred to as the operating
characteristics of road decreases with increase in AADT. It is clear that the
capacity of the freight transportation system is becoming an increasingly
pressing issue. Consequently, in most urban areas, increases in transportation
system capacity cannot match the corresponding increases in the volume of
vehicles (Cerverto and Hanson, 1995). The increasing ubiquity and complexity
of freight congestion combined with its severe negative impacts suggests the
need for new tools to analyze and predict congestion patterns.

These tools are important both for tactical operations and strategic
planning. Also important is the ability to perform “What If?” scenario modeling
to assess the robustness of tactical plans subject to unplanned incidences (e.g.,
accidents, bridge closings) and their effects on congestion patterns (Miller, 1995).
Successful decision making requires the integration of geographic theory, data,
simulation models, and expert judgment to solve travel demand forecasting
models. Many indicators such as capacity, flows, administrative considerations
such as vehicle loads, limits, performance metrics, population density, economy,
Figure 1.2 Road network in the continental USA (Source: FAF network and ESRI data)

Thickness of route indicates the volume of traffic on the route
average income of the populace and other spatially diffused phenomenon help in predicting the travel demand patterns. A freight management SDSS would be very useful for transportation planners/DOT officials, policy makers, stakeholders and homeland security advisors in making informed decisions. This could ultimately prove to be an effective spatial analysis tool in modeling the freight movements. Further, this could reveal the freight congestion patterns.

1.2 Why Internet based or WWW?

The world wide web (WWW) is the most recent new medium to present and disseminate geospatial data and solutions. Why is the WWW an interesting medium to present and disseminate geospatial data? The answer is that information on the web is virtually platform independent, unrivalled in its capacity to reach many potential users at minimal costs and update with ease frequently. There are different approaches to develop the overall framework;

Figure 1.3. Basic web publishing (Source: Web cartography, Menno-Jan kraak and Allan brown 2001)
a web based, hypertext system; a GIS, with embedded macros; a single software and with routines for each model; or stand alone package for each model. The option of web based structure was chosen because it offered the greatest flexibility for independent model development and testing, and facilitated the updating and refinement of individual models. It also enabled the incorporation of a disparate array of contents for the presentation and operation of models, centrally updateable data repository and world wide access. This approach has the advantage of using widely available, standard and low cost computing (Figure 1.3). There are many new and upcoming GIS and RS web technologies that are yet to be exploited to the full potential. There are two different ways to publish maps on the web one being dynamic and the other being static. For this study in specific, we require dynamic mapping as it offers the ability to conduct spatial analysis and browse different datasets. The majority of technologies are being developed for dynamic mapping however these offer very little ability to customize to user requirements. This study also looks at potential web GIS technologies that can be used for creating web based GIS tools.

1.3 Problem statement

A pragmatic approach is being made in this thesis to establish a standardized framework for freight management SDSS (Spatial Decision Support System), the conceptual, technical and hardware parameters developed in this study could further be used to advance the development of more sophisticated
SDSS and data dissemination tools on the internet or the world wide web. The study also looks at the different components available for creating such systems. This can also be later on integrated with real time data such as GPS, weather, satellite imagery and other relevant databases to monitor freight movements in real time and to create a more robust SDSS capable of real time planning. In the near future it is of utmost importance for officials to have better tools to monitor and maintain the quality of freight movements as it still remains the major component of traffic flow across the world. Further, better algorithms for travel demand forecasting can be developed and incorporated for forecasting traffic flows.

1.4 Design objectives for SDSS

In order to accomplish the design and implementation of ideal internet based freight management SDSS, the following key objectives in are to be considered (Table 1.1). A standardized architecture for interoperable technology and exchange of spatial and non-spatial data is necessary. The ability to rapidly share and apply geospatial information for decision making is important as it involves cooperation among a broad range of organizations operating across many jurisdictions. This is considered a very essential component in a multi-user decision making environment.
<table>
<thead>
<tr>
<th>OBJECTIVES</th>
<th>Status</th>
<th>Final Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Standardized open GIS framework for SDSS</td>
<td>TBI</td>
<td>N/A</td>
</tr>
<tr>
<td>2. User friendly interfaces</td>
<td>TBI</td>
<td>N/A</td>
</tr>
<tr>
<td>3. Implementation of remote sensing technology for monitoring transportation</td>
<td>TBI</td>
<td>N/A</td>
</tr>
<tr>
<td>4. Data standards implementation</td>
<td>TBI</td>
<td>N/A</td>
</tr>
<tr>
<td>5. Database management system (DBMS) with advanced data querying and editing abilities</td>
<td>TBI</td>
<td>N/A</td>
</tr>
<tr>
<td>6. Spatial analysis tools (dependent on the user analysis) such as identify tools, buffer analysis, dynamic multi layer mapping facility etc</td>
<td>TBI</td>
<td>N/A</td>
</tr>
<tr>
<td>7. On the fly Map production and display facility (report generators)</td>
<td>TBI</td>
<td>N/A</td>
</tr>
<tr>
<td>8. Potential bottleneck Identification in the study area for immediate decision making</td>
<td>TBI</td>
<td>N/A</td>
</tr>
<tr>
<td>9. Data sharing capabilities (data repository)</td>
<td>TBI</td>
<td>N/A</td>
</tr>
<tr>
<td>10. SDSS Implementation and evaluation</td>
<td>TBI</td>
<td>N/A</td>
</tr>
</tbody>
</table>

_TBI- To be implemented      N/A- Not applicable_

**Table 1.1 Design objectives for the freight management SDSS**

Open GIS consortium (OGC, 1994) is a non-profit organization that is leading the development of standards for geospatial and location based services,
these standards can be readily adopted from OGC or could be used to find the geospatial technologies that are compliant with the OGC standard. The next most important feature of a high-quality SDSS is user interface. User interfaces are very important as they constitute the medium of interaction between the decision maker or the user and the system. As mentioned in the previous paragraphs the users for these systems consist of technical and non technical users not aware of GIS systems, considering this as a criteria the user interfaces are to be designed with user friendly features like easily comprehensible fonts, labeling, popup tools with help etc. Implementation of remote sensing technology, and to identify the potential uses of this technology in the freight management SDSS constitutes another objective of this study.

Another key component of the system is to establish and maintain data standards across all the data contents of the system. This is a very essential part of data management. This allows for keeping the database concurrent, further a full scale database management system is necessary to accommodate easy file sharing and editing and updating over the internet at a centralized data repository. Spatial analysis tools form a vital module of an SDSS, these are essential for analyzing the data. It is imperative that without any tools to analyze the data the system remains impractical for use in the decision making process. Along with analysis tools it is necessary to have strong data reporting facilities. These are essential for conveying the results of the analyses to other interested
audiences. We have so far seen the important components of the objectives, the next step of the process is to look into the various components in more detail.

1.5 Design objectives for database

The database forms an essential constituent of the SDSS. Keeping in view that the SDSS is specialized for freight management, the following layers of data are necessary to compliment the decision making process (Table 1.2). All the data layers are to be prepared from the available datasets. Consistency in the database is of utmost importance, later in the study more information will be given on the database design as to how the data normalization is carried out. Database contents are derived on the need of the system. The data can be divided into two categories spatial data and non spatial data. While spatial data consists of major networks of highways, rail and waterways (Polyline features), major nodes of ports, airports, intermodal terminals (point features), state and county boundaries (Polygon features), hydrology and water bodies, tract and block group level data. The general attributes for the networks consist of capacity, flows, regulations and performance. Capacity, in general, is defined as maximum number of vehicles or persons that can pass through a point or a region of interest. Flow can be defined as the traffic flow on a segment at a given time.
<table>
<thead>
<tr>
<th>Database contents</th>
<th>Status</th>
<th>Final Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Build the network (Highways, Rail, Waterways)</td>
<td>TBI</td>
<td>N/A</td>
</tr>
<tr>
<td>2. Build Major Nodes (Ports, Airports, Intermodal Facilities)</td>
<td>TBI</td>
<td>N/A</td>
</tr>
<tr>
<td>3. Generate attributes for network and nodes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. capacities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. Flows</td>
<td>TBI</td>
<td>N/A</td>
</tr>
<tr>
<td>c. Regulations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. Performance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Link network- flows, capacities and regulations to economic activities in the region</td>
<td>TBI</td>
<td>N/A</td>
</tr>
<tr>
<td>5. Link network- flows, capacities and regulations to population characteristics in the region</td>
<td>TBI</td>
<td>N/A</td>
</tr>
<tr>
<td>6. Incorporate remote sensing backdrop</td>
<td>TBI</td>
<td>N/A</td>
</tr>
<tr>
<td>7. Thematic mapping of variables</td>
<td>TBI</td>
<td>N/A</td>
</tr>
<tr>
<td>8. Base layers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. States</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. Counties</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. Tract level data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. Block group level data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>e. Hydrology and major water bodies</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 1.2 Database creation objectives*
Non spatial data can consist of attributes for these layers and other supporting auxiliary data such as demographics etc. Non spatial data adds value to the spatial data to a large extent as it allows the user to analyze the relationships between different variables. More data layers will be added on a need basis as the database is more refined in the next stages.

1.6 Objectives for implementation and evaluation of SDSS

Implementation and evaluation of the SDSS consists of the steps specified in the Table 1.3 below. This stage of the study could be considered the crux. Extensive beta testing of software modules, models or algorithms, tools etc are part of this process. Beta testing involves finding the loop holes in the code, security issues etc. All the components so far listed in the previous paragraphs are compiled to form the final SDSS. This stage also involves choosing the right hardware and software resources for developing the SDSS.

1.7 Organization of the report

This report is organized into chapters one through four. Chapter one as seen so far introduces the concept of Spatial Decision Support Systems (SDSS). It also defines the need and the objectives of the study. Chapter two consists of literature review, explanation of terminology and conceptual underpinnings of different components that make up an online or internet based freight
<table>
<thead>
<tr>
<th>Implementation and evaluation of SDSS</th>
<th>Status</th>
<th>Final Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Selection of programming and scripting languages</td>
<td>TBU</td>
<td>N/A</td>
</tr>
<tr>
<td>2. System configuration i.e., server side technology and client side technology</td>
<td>TBU</td>
<td>N/A</td>
</tr>
<tr>
<td>3. Front and back end platforms</td>
<td>TBU</td>
<td>N/A</td>
</tr>
<tr>
<td>4. Prototype development and testing includes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Prototyping service</td>
<td>TBU</td>
<td>N/A</td>
</tr>
<tr>
<td>b. Fixing bugs in the code and optimization</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. Clearing security loopholes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Finalizing the freight management SDSS</td>
<td>TBI</td>
<td>N/A</td>
</tr>
</tbody>
</table>

*TBI- To be implemented TBU- To be utilized N/A- Not applicable*

**Table 1.3 Implementation and evaluation of SDSS**

management SDSS. Chapter three discusses the design framework of SDSS, justification of the design frame work, study area and implementation of the system in the study area. Chapter four being the last consists of results and discussion. Further, appendices are also be provided at the end to elucidate complex procedures and terminology that are of importance to this study. A basic idea of essential components of a freight management SDSS and the
different phases of the development involved are understood. The objectives and components listed in the tables will be justified in the final results after the design and implementation phase.
Chapter Two

Background

2.0 Introduction

There are many kinds of specialized SDSS’s developed to aid decision makers in solving spatial problems. Most of these systems are developed as separate stand alone applications. There is a variety of information available on these systems and the generic framework on which they were developed. Thus far there isn’t any kind of generic framework developed for an online freight management SDSS. This chapter describes all the fundamental components and methodological concepts that are part of the generic SDSS and also lists other components and technologies that could be essentially embedded into the online SDSS.

2.1 Spatial Decision Support Systems (SDSS)

The concept of decision support system (DSS) is based on the seminal work by Simon and associates in 1950s and 1960s (Simon, 1960). The SDSS concept has evolved in parallel with DSS (Densham and Goodchild, 1989). The need for development of spatial decision support systems (SDSS) has been associated with the need to expand the GIS capabilities for tackling complex, ill defined, spatial decision problems (Densham and Goodchild, 1989). Decision
making in time and space is a highly complex process of choosing among alternatives to attain an objective or a set of objectives under constraints. DSS literature contains a substantial body of theory and a large number of application. Extensive research in DSS has been done by Bonczek, Holsapple, Whinston, (1981).

The major characteristics of spatial decision problems usually consist of more than one decision maker (or interest group) involved in the decision making process and a large number of decision alternatives to choose from and spatially variable outcomes of the decision alternatives. Some of the criteria may be qualitative while others may be quantitative. The decision makers have different preferences with respect to the relative importance of evaluation criteria and decision consequences. Due to these reasons the decisions are often surrounded by uncertainty.

2.2 Major phases in the decision making process

According to Simon (1960) any decision making process can be structured into three major phases (Figure 2.1). The first phase being ‘intelligence’ where you look for a problem or an opportunity for change. The intelligence phase involves searching or scanning the environment for conditions calling for decisions; this phase requires an exploratory analysis of the decision situation. GIS can play a vital role at the initial stage of the decision making. The system can help in coordinating decision situation analysis through its ability to integrate and explore data and information from a wide array of sources.
Figure 2.1, Decision making phases
(Source: NCGIA, Core curriculum, UCSB)

It can further effectively present information in a comprehensive form to the decision makers. The second phase is ‘design’ to look for decision alternatives. The design phase involves inventing, developing, and analyzing a set of possible decision alternatives for the problem identified in the intelligence phase. A formal model is typically used to support a decision maker in generating the set of alternatives. While an increasing number of GIS are described as systems for supporting the process of designing and evaluating spatial decision alternatives, most commercially available GIS lack the kinds of spatial analysis and modeling required by decision makers.
The capabilities of GIS for generating a set of alternative decisions are mainly based on the spatial relationship principles of connectivity, contiguity, proximity and overlay methods. In current GIS environments, models for generating decision alternatives operate in the background, detached from the users insights and qualifications.

The final and third phase is ‘choice’ where the decision maker usually chooses the best alternative based on his expert knowledge. The choice phase involves selecting a particular decision alternative from those available. Each alternative is evaluated and analyzed in relation to others in terms of a prespecified decision rule; the decision rules are used to rank the alternatives under consideration. The ranking depends upon the decision maker’s preferences with respect to the importance of the evaluation criteria. Critical for use of GIS in the choice phase is the capability of incorporating the decision maker’s preferences into decision-making processes.

2.3 GIS and SDSS

A GIS is defined as a system of hardware, software, data, people, organizations, and institutional arrangements for collecting, storing, analyzing, and disseminating information about areas of the earth (Dueker, 1989). GIS have limited capabilities of supporting the design and choice phases of the decision making process. The systems provide a very static modeling environment and thus reduce their scope as decision support tools—especially in the context of problems involving collaborative decision making. GIS’s fall short of the goals of
SDSS for a number of reasons. Analytical modeling capabilities often are not
part of a GIS and many GIS databases have been designed solely for cartographic
display of results; SDSS goals require flexibility in the way information is
communicated to the user. The set of variables or layers in the database may be
insufficient for complex modeling. Data may be at insufficient scale or
resolution. GIS designs are not flexible enough to accommodate variations in
either the context or the process of spatial decision making (Simon, 1960).

2.4 SDSS framework

The essential framework for a SDSS consists of analytical modeling
capabilities, database management systems (DBMS), graphical display
capabilities, tabular reporting capabilities and the decision makers expert
knowledge.

Geoffrion’s definition of a SDSS requires 6 characteristics. It should be able
to solve ill or semi structured problems, i.e. where objectives cannot be fully or
precisely defined (Figure 2.2). Have an interface that is powerful and easy to use,
flexible in allowing models defined by the user and help the user to explore the
solution space by using the models in the system to generate a series of feasible
alternatives. Capability to support a variety of decision making styles, and easily
adapted to provide new capabilities as the needs of the user evolve. Problem
solving is considered an interactive and recursive process in which decision
making proceeds by multiple passes, perhaps involving different routes, rather
than a single linear path.
In addition, in order to effectively support decision-making for complex spatial problems, a SDSS will need to provide for spatial data input, allow storage of complex structures common in spatial data, include analytical techniques that are unique to spatial analysis and provide output in the form of maps and other spatial forms. The decision making process is considered to be iterative, integrative and participative in nature; It is iterative because a set of alternative solutions are generated which the decision maker evaluates, and insights gained are input to, and used to define further analyses. It is participative because the decision maker plays an active role in defining the problem, carrying out analyses and evaluating the outcomes. It is integrative.
because value judgments that materially affect the final outcome are made by
decision makers who have expert knowledge that might be integrated with the
quantitative data in the models.

Armstrong and Densham’s (1990) version of SDSS suggest that five key
modules are needed in a SDSS. A database management system, analysis
procedures in a model base management system (MBMS), a display generator, a
report generator and user interface. GIS database management systems are
designed to support cartographic display of vector and raster data sets. Database
of an SDSS must support cartographic display, and analytical modeling.
Database must permit the user to construct and exploit complex spatial relations
between all different types of data at a variety of scales, degrees of resolution
and levels of aggregation.

One approach to implement analytical modeling into the GIS and remote
sensing systems is to develop libraries of analytical sub-routines which permit a
large number of models to be made accessible very quickly, because existing
programs can be patched into a system. The second approach is to create small
pieces of code, each of which solves a step in an algorithm. Graphical and	abular report generators should be capable of high resolution cartographic
displays for both vector and raster data. The full range of tabular reports that are
normally associated with each of the above include statistical graphics and
thematic maps. The user interface must be easy to use. The move to graphical
interfaces for operating systems provide an opportunity for system designers to
develop more intuitive interfaces by using a graphical display for communication between decision maker and system.

### 2.5 Geographical nature of transportation planning

Transportation planning has many similarities with the academic discipline of geography in general and with transportation geography in particular. The traffic generation (production and attraction) phase of the process is usually a series of studies involving what was called areal association studies in the mid 20th century, wherein traffic generation is viewed as a function of characteristics of the traffic analysis zones. Land use models in transportation planning process seek to understand and predict the location of current and future activities. Many of the early land use models used in planning had their roots in geographic models of urban structure. Trip distribution is the same as spatial interaction in geography. The gravity model is the cornerstone of this entire body of literature, be it geography or transportation planning. Even the assignment process is geographical and deals with optimal (shortest) travel distance, time, or cost networks. It should be apparent that transportation geography is very similar to transportation planning, with the former often providing the foundation for applications in the later.

### 2.6 Transportation management and planning

Transportation planning is relatively a new field. In the United States indications of transportation planning can be traced back to the pre-World War II decades, but this was usually done by some private entity. The Detroit
metropolitan area traffic study (DMATS) is considered one of the first classical transportation studies undertaken in the United States. This study developed trip generation rates based on different land use categories and forecasted future trip rates as a function of forecasted future land use (Figure 2.3). Land use models are generally concerned with the factors generating economic activities, that are correlated with transportation requirements. For instance, by using a set of economic activity variables, such as population and level of consumption it is possible to calculate the generation and attraction of passengers and freight.

![Figure 2.3 Components of a Transportation/Land use system](Source: adapted from “transportation geography on the web”, Hofstra University, 2004)

Similarly, spatial interaction models are mostly concerned about the spatial distribution of movements, a function of land use (demand) and
transportation infrastructure (supply). They produce movement estimates between spatial entities, symbolized by origin-destination pairs, which can be disaggregated by nature, mode and time of the day. Transportation network models are used to evaluate how movements are distributed over a transportation network, often of several modes, notably private and public transportation. They provide traffic estimates for any given segment of a transportation network.

2.7 Importance of transportation sector in the economy

Transportation is a very important part of the economy of most developed nations, and it is well represented in the United States by the purchases of all transport related goods and services. The major component in this case is personal consumption of motor vehicles and parts, which in 1997 accounted for $269.5 billion. It was followed very closely by personal purchases of transportation services, at $240.3 billion. With transportation's total contribution to GDP of $905 billion, personal transportation accounted for more than 56% of this sector’s contribution to GDP (BTS, 2001). Early data for 1999 indicate that transportation accounts for 10.6% of GDP (Figure 2.4). Economic growth in an economy can result from an increase in just about any variable that can affect demand. An increase in the population of an area may stimulate demand resulting in growth even though there is no change in the production process. The movement of new industries into an area may also result in economic growth. These conditions stimulate the flow of freight movements, and hence
the need for a better freight management is necessary to keep the economy stable.

![Figure 2.4. Components of US gross domestic product (GDP), 1999 (Source: Transportation geography, Ed 02)](image_url)

### 2.8 Network Analysis

Network analysis is one of the most frequently used components of a GIS and underpins much of GIS use in the utilities and transportation sector. Once a road system, a river catchment basin, or a pipeline system has been digitized, a GIS should quickly be able to answer questions such as ‘what is the quickest way from A to B?’ (routing). The response algorithm can be made more complicated by adding impedance on to major route ways. Another important use of network analysis is the allocation of resources to predefined centers, normally based on
minimizing total distance traveled. Badillo (1993) provides a comprehensive list of application areas of network analysis, these include car navigation systems designed to give up to date information as to how to avoid the latest road works or accident hold-ups, and global positioning systems, which keep precise tabs on the locations of fire engines or ambulances so that the nearest vehicle can always be dispatched and response times improved (Ward, 1994). Peel (1993) also provides a useful case study of the use of a GIS to ease traffic congestion in the heart of London by prioritizing flows during peak periods.

2.9 Congestion

One of the major problems faced by the highway transportation systems today is congestion which results from number of factors, including slow moving traffic, low speeds, fast moving vehicles, high speeds, volume of traffic, capacity, weather conditions, highway incidents etc. Congestion is the impedance vehicles impose on each other, due to speed flow relationships, in conditions where the use of the transport system approaches its capacity (Figure 2.5). Commuters through their modal choice, are recursively influencing the development of the urban transport systems. The European conference of ministries of transport (ECMT) has described congestion as a “traffic condition in which vehicles are constantly stopping and starting and in which vehicle concentration is high while flow speeds are low” (ECMT, 2000). In a study of 300 metropolitan areas of united states in 1990, Abanninga (1999) found that travel times varied considerably across the country (Figure 2.6 and 2.7).
Figure 2.5. Vicious circle of congestion (Source: adapted from “transportation geography on the web”, Hofstra University, 2004)

Travel times were the least in the cities of the west north central states and the highest in the cities of the middle Atlantic states.

Figure 2.6. Traffic conditions in Major American Cities, 1982-1997
(Source: Texas transportation institute(1999) )
2.9.1 Measuring congestion

Over the last few decades considerable effort has been expended trying to measure congestion. Lomax, Turner, and Shunk (1997) identified several different measures of congestion. (Table 2.1) These indices can be used to evaluate the current conditions of the road segments and could be further used to arrive at a solution to decrease the congestion levels.

2.9.2 Congestion tools

The problem of urban traffic congestion has been a major issue concerning the transportation departments across major regions of the world. As a result, there is no shortage of proposed solutions. Possible actions to relieve and reduce
### Congestion indices

1. Travel rate (minutes necessary to traverse one mile)

2. Delay rate (actual minutes per mile less acceptable minutes per mile)

3. Total segment delay (delay rate of 2xvehicle volume on the segment)

4. Corridor mobility index (Passenger volume x average speed divided by normalizing factor)

5. Relative delay rate (delay rate divided by accepted travel rate)

6. Delay ratio (delay rate divided by actual travel rate)

7. Congested travel in vehicle miles (congested segment length x traffic volume summed for all segments)

8. Congested roadway miles (sum of all congested segments in miles)

<table>
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<th>Table 2.1. Congestion Indices for measuring congestion</th>
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Traffic congestion can be categorized (Dunphy, 1991) (Table 2.2). These actions could be implemented to reduce the congestion on a road segment.

#### 2.10 Intermodal Freight System

Transport of goods using more than one mode of transport is considered intermodal transportation. Different modes of transport consists of transfer by road, rail, water and air. Within the last forty years major efforts have been made to integrate separate transport systems through intermodalism. Intermodality enables economies of scale within a transportation system where modes are used in the most productive manner.
Possible actions to reduce congestion

1. Traffic signal improvement
2. Expanding the road system
3. Provision of sub urban transit
4. Prompt motor vehicle clearance
5. Travel demand management approaches
6. High occupancy vehicle lanes
7. Provision of light rail transit
8. Land use strategies
9. IVHS (Intelligent Vehicle highway system) or ITS
10. Telecommuting
11. Congestion pricing and toll roads
12. The do nothing alternative!

Table 2.2. Possible actions to reduce congestion

2.11 Remote Sensing as a tool for transportation:

Remote sensing is the science of acquiring information about the Earth’s surface without actually being in contact with it. This is done by sensing reflected or emitted energy and processing, analyzing, and applying that information (Figure 2.8). Remote sensing applications in the transportation domain is still a new concept; research is being done across the world to look at the feasibility of creating transportation applications using remote sensing.
There are many remote sensing platforms that are capable of being used for transportation sector. Choosing among the right remote sensing instrument platform depends on the four fundamental properties of spatial resolution, spectral resolution, radiometric resolution and temporal resolution. Spatial resolution of the sensor refers to the size of the smallest possible feature that can be detected (Figure 2.9 and 2.10). High resolution imagery is usually desired in transportation corridor studies (Jensen et al, 2002) (Figure 2.11). However with increase in spatial resolution the data becomes more expensive.
Spectral resolution describes the ability of a sensor to define fine wavelength intervals. The finer the spectral resolution, the narrower the wavelength range for a particular channel or band. Many remote sensing systems record energy over several separate wavelength ranges at various spectral resolutions. These are referred to as multi-spectral sensors. Advanced multi-spectral sensors called hyper spectral sensors, detect hundreds of very narrow spectral bands throughout the visible, near-infrared, and mid-infrared portions of the electromagnetic spectrum.
Their very high spectral resolution facilitates fine discrimination between different targets based on their spectral response in each of the narrow bands. The radiometric resolution of an imaging system describes its ability to discriminate very slight differences in energy. The finer the radiometric resolution of a sensor, the more sensitive it is to detecting small differences in reflected or emitted energy. And finally, The ability to collect imagery of the same area of the Earth's surface at different periods of time is known as temporal resolution. Spectral characteristics of features may change over time and these changes can be detected by collecting and comparing multi-temporal imagery.
Some of the high spatial resolution remote sensing platforms capable of being used for transportation studies are IKONOS with 1 m spatial resolution, Quick Bird with 0.61 spatial resolution, Orbview 3 with 1 m spatial resolution, and finally SPOT with 10 m spatial resolution. Imagery from these platforms can be used with other auxiliary data to perform corridor wide transportation and land use/land cover change analyses. This can further be utilized in highway design and asset management.

DOT (Department of Transportation) has identified the importance of remote sensing technologies and applications to transportation. It includes traffic surveillance, monitoring and management, environmental assessment,
integration and streamlining, transportation infrastructure management, hazards, safety, and disaster management. Efficient management of flow is critical to efficient transportation, it is expensive and difficult to achieve the desired regional coverage using conventional methods to calculate flows. Remote sensing imagery and real-time satellite systems can be used to obtain a better quality traffic flow data with more coverage for improving estimates in traffic flows (Figure 2.12). Airborne and satellite platforms offer the potential to obtain wide spatial coverage not offered by ground based sensors and provide a potential for monitoring regional spatial transportation flow conditions.

Figure 2.12 Traffic monitoring of trucks and automobiles on a segment of interstate highway. (Source: DOT and NASA)

Remote sensing technology can further be used for Digital Elevation Model creation (DEM) (refer Figure 2.13), Land use/land cover classification (LULC) (Figure 2.14), Topographic detail extraction, centerline extraction, asset management (Figure 2.15) and hazards. The different auxiliary products developed using remote sensing technologies such as DEM's, LULC maps, asset information can be seamlessly integrated into freight management SDSS along
with GIS and other data to give decision makers more choice in the process of decision making. Thus, remote sensing technology has the potential to be a major component of the SDSS.
2.12 Geospatial Data Dissemination

The largest, current application of distributed GIS is geospatial information dissemination. Distributed GIS makes it easier to disseminate information such as land use plans, zoning information, environmental information, and traffic information. It can also foster information sharing and exchange among different departments and agencies. This information can then be used by transportation planners in the development of transportation plans or by land use planners to make land use plans.

2.13 Internet GIS

Internet GIS is an exciting research and application direction in Geographic Information Systems (GIS), and represents an important
advancement over the traditional desktop GIS. It has been widely accepted in governmental agencies and educational institutions and among geospatial data producers and vendors. The increasing popularity of internet, from on-line surfing to e-commerce to interactive chatting, has made the internet an integral part of our society (Figure 2.16). The internet is a modern information relay system that connects hundreds of thousands of telecommunication networks and creates an “internetworking” framework. Internet GIS is a research and application area that utilizes the internet and other internetworking systems to facilitate the access, processing and dissemination of geographic information and spatial analysis knowledge. The internet is affecting GIS in three major areas: GIS data access, spatial information dissemination, and GIS modeling/Processing.

The internet provides GIS users easy access to acquire GIS data from different data providers. GIS data warehouse/clearinghouse and digital libraries are two common forms of internet data access systems. The U.S. Geospatial Data Clearing house activities under the Federal Geographic Data Committee (FGDC) in the united states has been working to build a distributed archive of information for universal access (http://www.fgdc.gov). The internet also enables the dissemination of GIS analysis results and spatial information to a much wider audience than does traditional GIS.
Further, the internet is becoming a means to conduct GIS processing. It enhances the accessibility and reusability of GIS analysis tools by dynamically downloading or uploading GIS processing components. In the future, GIS users could work on GIS data interactively by using their web browsers without installing GIS software on their local machines (Figure 2.17).
The client or the user usually interacts with the web server through a browser and the server acts as an intermediate tier logic to interpret the user request and passes it to the map server, in turn the server receives the data from the map server and sends it to the user’s browser. Access to and transfer of GIS data over the internet are the first steps toward true internet GIS. Online data access allows GIS users who have stand alone GIS software installed on their local machine to access and transmit GIS data across the internet. This method of use of the internet is efficient for data access, but the users ability to view and analyze the data is limited by his or her desktop GIS software. The ability to access GIS analysis functions to conduct GIS analysis anywhere over the internet is the next important step.

2.14 GIS technology: from centralized to distributed GIS services

Like many other new fields, there is no general agreement on the term to describe GIS programs based on the internet. Several names are used, such as internet GIS (Peng and Beimborn, 1998), GIS-online, Distributed Geographic

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**Figure 2.17  Basic components of Internet GIS** (Source: Adapted from Internet GIS, 2000)
Information (DGI) (Plewe, 1997), and Web based GIS, or simply Web GIS (Figure 2.18).

These different terms are similar but sometimes have different meanings. Figure 2.18 shows that distributed GIS allows for high interactivity and high functionality making it a viable solution for creating robust online SDSS for decision makers.

![Figure 2.18. Evolution of distributed GIS](Source: Adapted from Internet GIS, 2000)

### 2.15 What next?

Each of the individual components of a SDSS was explored in detail in the preceding pages. Further, the technology and terminology related with a SDSS was also investigated to understand the methodological underpinnings that lie beneath each component. It is seen that there are potentially many components that can be used as a viable tool to create the perfect SDSS for freight
management. These include congestion tools, network analysis, remotely sensed imagery etc. The tools that are to be included in a SDSS depends on many factors such as the availability of technology, pricing of technology and advantages and disadvantages of different software and hardware components.

Apart from the components, the fundamentals of Internet GIS were also closely observed as these would be important in designing the framework for the online SDSS. “Freight management” itself is a broad term, for example a freight management SDSS for a small region consisting of a county or a state will be very different from the one that supports a corridor wide perspective. It has different significance with the scale of the study or the support area. In the next few chapters a methodology will be developed for the design and implementation of the freight management SDSS. The developed frame work will be generic in terms of the system design and component model, which can be customized depending on the needs of the end user. This will further be implemented in real time to look at the feasibility of standardizing the framework for future development of advanced freight management SDSS.
Chapter Three

Methods

3.0 Introduction

The conceptual framework being developed in this study is a generic framework that could be used to assemble a freight management SDSS. This can also be customized accordingly with the user requirements. Other tools and components can also be added to create a more viable solution that aids in decision making.

3.1 Design of SDSS

Based on well founded principles, A typical web based SDSS should follow a multi tier or n-tier architecture for the deployment of applications and components (Peng, 1998). The elements of a typical system consist of user or the decision maker, interface, application logic, mapserver and the data. With the system being an internet based system, the audience for such systems vary to a great extent, every user need not be a decision maker.

3.1.1 Base framework for a generic online SDSS

The interface is the main component of the system where the decision maker actually interacts with the system (Figure 3.1). The next important component is the logical layer which consists of all the processes that are essential for carrying out the analyses; it consists of all the GIS-T tools, GIS
spatial analysis tools and other tools such as report generators. Database is another important component of SDSS. All the above components are interlinked through plausible linkages to form a seamless system. The system is designed as a client server based system, to take advantage of the evolving distributed GIS technology. The computer that makes a request is called client and the computer that processes and fulfills the request is called server. The three elements namely interface, logical layer and the database play their important roles. Typically the interface layer handles decision makers input. Its logical layer processes the users requests, utilizing the inbuilt analyses capabilities and the database. The relationship between these three elements is that one element makes a request to the other element and the other element then fulfills the requests.

Figure 3.1. Conceptual framework and components of a web based SDSS
Shan and Earle (1998) define this concept as the client/server computing model. These components can reside on the same machine or different machines. If they reside on a mainframe machine it is called mainframe application with centralized computing. This is considered the base framework for the development of an online SDSS and the architecture will be customized as to incorporate all the required tools to make it a freight management SDSS.

3.1.2 User

The generalized qualities of a potential freight management SDSS user are derived to establish further requirements of the system. The user in this case could be an official from DOT Urban planner, homeland security official or an individual interested in these kinds of systems. The system can be potentially used to look at the prevailing freight movements, analyze data and apply algorithms, decision making, maps and report generation and data sharing. Further this could be used to model what if? scenarios and effects of alternative freight management plans.

3.1.3 Interface and logical layer design

The interface should be easy to use in terms of navigation from one control to another, user and web friendly colors, large area of visualization and help menus. The interface layer should be capable of giving the user the opportunity to browse through the different datasets that are available (Figure 3.2).
The interface should consist or connect the user to all the GIS tool box functions like spatial overlay analysis, on the fly projection tools, query based selection, geocoding, identify tools, buffer analysis etc. Apart from these tools, as mentioned earlier it should also have the essential GIS-T (GIS- transportation) tools that are necessary for carrying out transportation analyses. They include route optimization algorithms like traveling sales man problem, shortest route calculations and vehicle routing problem, spatial interaction models, network flow problems, travel demand models, facility location, capacity calculation, level of service calculators and land use transportation interaction models. These models are to be essentially built into the logical layer and are accessed through
the interface (Figure 3.3). A modular structure approach is desired for logical layer, which is simple to build upon by connecting to relevant, independent research and models, either deepening or broadening the content of the logical layer.

![Figure 3.3 Components of logical and Mapserver layer](image)

The logical layer should be flexible enough to allow for addition of algorithms and customization at a later stage. The models should be capable of working with most of the standard data formats including vector, raster and tabular data. The logical layer should be built around client/server architecture. This allows for the deployment of logical layer on the client side or on the server side. This feature is very useful when there is a need for large and steady
computing resources. The client can download the component and run the analysis on local machine.

3.1.4 Mapserver

A map server is a major component that fulfills spatial queries, conducts spatial analysis, and generates and delivers maps to the client based on the user’s request (Figure 3.3). The map server provides specific traditional GIS functions. The output of the mapserver can be defined by the user depending on the need.

3.1.5 Dataserver

A dataserver serves spatial and nonspatial data, in a relational or nonrelational database structure. A client application such as a web client or a map server gains access to the database through the SQL. SQL is an international standard language and is available in different versions with different vendors and databases. Therefore database middleware is usually used to access the different databases. There are three major database middleware, ODBC (Open Database Connectivity) originally developed by Microsoft, Java database connectivity (JDBC), Object linking and embedding database (OLE DB) and Active X data object (ADO). Through one of these middleware, the client can query, retrieve, and even modify records in the database server.

3.2 Justification of Design

The specified conceptual technical framework can be considered the rudimentary base for the development of such systems. There are many variables that are to be considered before going further to implement such
systems. The first being user requirements. Each component can be customized depending on the need of the user.

The modular architecture provides flexibility in terms of technology and cost to a great extent. Any other components can be added to the current framework and integrated with a minimum of difficulty. The client/server based technology paves the way to advance the design into a fully distributed SDSS. Most of the components are available commercially from various vendors, there are also some free source components available for non profit usage.

The system being an online or internet based system, it can take advantage of the common means of presentation, ease of access by local or international users, standard low cost computing environment, rapid streamlined incorporation of model revisions and updated management. Model confidentiality can be maintained by the use of CGI (Common Gateway Interface) scripts or indirect presentation of results us using intermediate lookup tables.

The next step in this process is to apply the framework to a real world problem. This will give us more input as to how the framework can be improved in terms of technology and the components.

3.3 Implementation of SDSS

The Upper Midwest Freight corridor study currently underway at The University of Toledo is studying different aspects of freight movements including capacity, performance measures, administrative issues, demand, usage
and best practices. The Upper Midwest Freight Corridor Study was given shape by The University of Toledo, University of Wisconsin and University of Chicago, along with other major stakeholders and state DOT’s (Department of Transportation) to study freight movements and congestion patterns at a regional scale level encompassing the states of Ohio, Wisconsin, Minnesota, Indiana, Iowa, Michigan, Illinois and Canadian provinces of Ontario and Manitoba.

Keeping in view the vast area that’s being covered in the study, the need for development of an internet-based spatial decision support system was felt to disseminate the results of this study to a larger group of audience consisting of transportation planners, DOT officials, policy makers and stakeholders for decision-making purposes.

The need for a specialized SDSS was taken as an opportunity to implement the conceptual framework created thus far. A complete system from ground up will be designed and implemented to serve this purpose. This will give us an opportunity to test the efficacy of the framework in a real-world situation. This could ultimately prove to be an effective spatial analysis tool in modeling the freight movements across the seven states, further this could reveal the freight congestion patterns and could then be used to evaluate alternate freight management plans.
3.4 Study Area

The Midwest is bound by the great lakes and the Ohio, Mississippi river valleys. Upper Midwest region consists of Ohio, Wisconsin, Minnesota, Iowa, Indiana, Michigan and Illinois. This study also includes parts of Canada namely Manitoba and Ontario provinces to some extent (Figure 3.4). Upper Midwest Freight Corridor plays a vital role in the movement of domestic and international freight in the region and across the contiguous US. The primary corridor falls along with I-90/I-80/I-94 which are major highways that run parallel to the Upper Midwest.

The transportation system in the region is multimodal consisting of major highways, rail roads, inland waterways, the great lakes, pipelines, intermodal facilities, and major cargo handling airports.

3.5 Study objectives

Major objectives of the study revolve around documenting and analyzing the multimodal freight transportation system in the corridor. Create a viable coalition building through regular communication and data sharing. Identification and documentation of prevailing conditions and needs across all modes of transportation for the entire region.
Figure 3.4 Upper Midwest Freight Corridor Study area
Components of the study consists of performance metrics, best practices, clearinghouse of efforts, demand/usage, capacity, and administrative issues. Each of these components is considered critical to the regional freight effort, refer Appendix A.

3.6 SDSS needs evaluation

The study being multi jurisdictional- multi state with a regional approach, there was no established system to share the results of this study among stakeholders, transportation agencies, freight shippers and carriers, officials from state DOT’s, urban planners and home land security officials and other individuals for decision making purposes. There is also a need for the research partners and other individuals to share information among each other for research needs. Further, there was also a growing need to conveniently visualize the transportation infrastructure, demographic, economic and socio economic characteristics driving the freight movement system.

At this juncture an online freight management SDSS would allow for all the needs to be addressed. The next step in the process is to select the appropriate technology and to develop different components of the SDSS basing on the earlier developed conceptual framework. Finally, the system should be designed and implemented in a timely manner to compliment the needs.
3.7 Functional component Analysis

The immediate functions of the SDSS are to provide dynamic mapping and visualization system, file sharing system, database system capable of advanced editing, report generators, and flexibility to further include specialized models for capacity etc and distributed GIS (U).

![Figure 3.5 Functional component Analysis of Upper Midwest freight corridor study SDSS](image)
The next step in the process is to choose technology for the development of framework components which can offer the above mentioned functional features.

### 3.8 Technology selection and Implementation

Technology selection is the most important phase of implementation, technology is volatile and changes rapidly. There are many factors to be considered before selection, such as compatibility, flexibility in terms of architecture, and cost implications. Several commercial vendors offer a wide variety of technology choice to select from. After testing several component technologies (Figure 3.6), ArcIMS® from ESRI was chosen as the mapping and visualization technology, MS SQL SERVER 2000 from Microsoft for database management, ArcSDE® as middle tier component to store spatial databases in RDBMS, Java® VM and Apache® Tomcat as servlet engine for ArcIMS® , Microsoft IIS® as the web server , Windows 2000 Server for FTP sharing (File transfer protocol) and system installation.

The programming environment for these systems consisted of Visual basic ® for model and stand alone application development, Map Objects® for mapping in standalone applications, Javascript® for ArcIMS® viewer customization, HTML® for interface design and ArcXML® for ArcIMS® customization. Further, several graphic editing software like Adobe Photoshop® were used to create and render some parts of the user interface. The SDSS is implemented on a Windows 2000® platform with MS IIS® (Internet Information Server) and system installation.

...
ArcIMS® was installed along with required components such as JAVA VM® and Apache Tomcat ®.

ArcSDE ® is installed on top of MS SQL to take full advantage of storing spatial data in RDBMS (Relational database management systems). ArcXML® coding was used to connect ArcIMS ® spatial server with the ArcSDE ® SQL database (data repository). More information about the design of database is presented in the succeeding pages. There are essentially two major interfaces for the client, he or she can download the raw spatial and non spatial data from the FTP (File Transfer Protocol) and vice versa or use the mapping and visualization interface to look at the results, analyze and generate reports. When a user sends in a request through the mapping and visualization interface it passes through
the fire wall to the ArcIMS spatial server, ArcIMS spatial server in-turn requests it from the SQL server and posts back the data to the interface.

3.9 Database

Database in general is a broad term and could be defined much more precisely depending on data stored and the purpose. Database in this study will be referred as data repository. A data repository could be defined as file sharing data library consisting of spatial and non-spatial data in a usable format. Acquisition and integration of data forms the single largest contribution needed to support SDSS. The design and implementation of the data repository lays the path to an easy integration and dissemination of data.

The data repository for the Upper Midwest Freight Corridor study has been designed as an online data server with distributed GIS/Internet GIS. Access to the file server can gained through FTP (File Transfer Protocol) and is located on the web at ftp://gisag99.uhw.utoledo.edu/ user name and password are required to gain access to the data. The server currently also serves as a data repository for remotely sensed images from different satellite platform apart from other data. All the research partners of the project have access to the file server for research purposes.
3.9.1. Data repository technical specifications

The following specifications were implemented for creating the data repository. The data repository is situated on a Apple® G4 Xserve® file server with ATAboy2® RAID (Redundant Array of Inexpensive Disks) system connected to the World Wide Web (WWW) in the GISAG Lab (Geographic Information Science and Applied Geography lab) at the department of Geography and planning, The University of Toledo. RAID LEVEL 5 is implemented for maximizing "High data reliability and Highest Transfer capacity" along with frequent data backups. The current disk space on the server is 4 terabytes and more space can be added on need basis. Before using GIS to represent the data, it is important to take time to design the database. A good database design is the keystone to have a working database that does what you want, effectively, accurately, and efficiently. There are two alternatives for storing Geospatial and non spatial data together, they are a flat file systems and spatial databases. These are explained in detail in the following paragraphs.

3.9.2 Flat File GIS Systems

The easiest way to store spatial and non spatial data is using a flat file. ArcView from ESRI, for example, saves geographic data in a shape file (*.shp), index file (*.shx) and attribute file (*.dbf). Shape file contains the map features (point, line, area) and primary identifier attribute which is a table of database. Then you can join tabular data to another database that has same
primary-keys (e.g. the zip code, street name) with the shape file. This system lacks security and management system and certainly not to be used for client-server architecture and is recommended for data collecting.

3.9.3 Spatial Data Repositories

Spatial Data Repositories allow the storage and management of all the Geospatial and non spatial data including raster formats in one single relational database. This architecture is a far move from traditional concept of GIS database in which spatial data is stored in a proprietary graphic format and tabular attributes are stored in a separate database table. The general concept for spatial database is presented in the Figure 3.7. The major advantages of this system include high performance with large databases and robust data administration tools for data manipulation and analysis. They also provide better opportunities to integrate spatial data with other information that organizations may store in a relational database, creating a "data-warehouse".

![Figure 3.7 Spatial database storage format](Source: ESRI)
This system allows open architecture for managing GIS data and allow access with multiple client software for data query suitable for Client/server architecture.

3.9.4 Data layers

ESRI ® Shapefile is considered the de-facto spatial data format standard for this project. Some of the non spatial data included tables and other data in ASCII text or MS excel format and they were either spatially joined to the shape files or maintained separately basing on the need. Satellite images were acquired for some major cities in the state of Ohio comprising of Columbus, Akron and Cincinnati from the IKONOS platform with one meter resolution. These were also stored in the same database. Significant time and resources have been dedicated to assemble data from diverse sources that included both private sector data sets, and federal sources consisting of Bureau of transportation statistics (BTS), Federal Highway Administration (FHWA), Corps of engineers, ESRI, State transportation departments and metropolitan planning organizations etc, refer Appendix B. The major data sets of the database consist of linear networks, point data layers, base area layers (Figure 3.8, 3.9, 3.10, 3.11 and 3.12). Linear networks comprise of highways, rail roads, and waterways. Point data layers comprise of ports, airports and intermodal facilities.
Figure 3.8 Highways in the Upper Midwest Freight Corridor Study
Figure 3.9 Railroads in the Upper Midwest Freight Corridor Study
Figure 3.10 Waterways in the Upper Midwest Freight Corridor Study
Figure 3.11 Airports in Upper Midwest Freight Corridor Study
Figure 3.12 Intermodal connectors in the Upper Midwest Freight Corridor Study
Similarly, base area layers consist of state boundaries, county boundaries, tract level data, block group level data, hydrology and major water bodies. Each layer is compiled out of either a combination of datasets acquired or clipped out of large data sets. Selected highways were included in the corridor depending on the criteria formulated by researchers of the Upper Midwest freight corridor study, refer Appendix B for more details.

General attributes for all the layers were populated, these included capacity, flows and Level of Service (LOS). LOS describes the operating characteristics of a highway, the value of LOS ranges from A to F where A being best and F being worst operating conditions. Additional attributes comprising of economic activities in the region were joined to general attributes of layers to gain a better understanding of the driving force behind the freight flows.

Similarly other data sets from Demographics PLUS®, Geolytics® were also linked to study the demographic characteristics of the region. These additional attributes were separately populated into the shapefile databases for different regional scales comprising of block groups, tracts and county levels.

Dot density maps showing different variables for all regional scales were also created to study the influence of those variables on the freight movements. Lack of standardization in the reporting of transportation related data among these organizations lead to data incompatibility issues. As a result much time was allotted for investigating and cleaning up the data. Data reconciliation
techniques were utilized to standardize the database. More detailed information on data reconciliation techniques are provided in Appendix C.

Different custom tools were developed in VBA (Visual Basic for Applications) by other researchers for data manipulation depending on the need. Attributes were edited and normalized for inconsistencies. The data layers were re-projected to Lambert equal area azimuthal projection with central meridian at -89 centered on southern Wisconsin and reference latitude at 43, using feet as the coordinates and projected unto the WGS 84 ellipsoid using the NAD 83 datum. This custom projection was chosen to facilitate correct representation of land and water masses across the Upper Midwest region.

All the data layers were populated into the database using the ArcSDE command line interface. The data can be readily accessed over both the user interfaces i.e. mapping system and FTP.

3.10 Interface development

The online SDSS interface is intuitively designed keeping in mind the potential users, refer Figure 3.13. Every link, all icons and other elements of the SDSS give the response that one logically expects. Well designed buttons and symbols help the users in navigating the site with ease. The tool box was developed using ArcIMS® platform from ESRI®, each tool is customized into a pop up tool for easy use. The interface itself is built as a light weight client, so
that users with low computer system resources can take advantage of the product.

Large visualization area is provided for two reasons, the first being the user does not need to pan or zoom into an area often to look at map as it covers an optimum area. The second reason is internet bandwidth, if the bandwidth is low the user might face trouble using the system as it takes longer times to download the map image, with large area the zoom in rate is faster as the client downloads the image prior to a larger extents using a customized Javascript®

A wide variety of tools were incorporated within the system (Figure 3.14), these include feature identification tools, zoom in, zoom out, panning, report generators, SQL query builder, buffer tools, report or map print console, hyperlinks, multi units to choose from, measuring tools, feature select tools, legend tool and find tools.

Sensitivity tolerances of tools such as zoom in rate and zoom out rate, feature selection tolerance etc were all optimized with custom scripting to offer the best result with the area of study. Further custom scripts were written to enhance the visualization on any screen resolution. The custom script checks the user resolution and then loads the interface at optimum resolution. At present the functionality works best with Microsoft internet explorer 5.0 and above.
Figure 3.13 Online SDSS user Interface Version 2.0

Dataframe- layers of data available

Tool Box/ pop up tools

Large Mapping and visualization area

Lat/Long and units
Figure 3.14 Online SDSS tool bar features
Dataframe has been customized to show data layers in groups. When working with multiple layers, often it gets confusing to select and unselect a particular layer. With the customized dataframe (Figure 3.15) the user can expand the layer tree to see different layers of the group. There is also a check box provision to select and unselect a layer from the current analysis. This kind of dataframe is easy to use and space saver when it comes to displaying layers. These are some of the salient features of the SDSS interface.

Figure 3.15 Online SDSS dataframe features
3.11 Final Implementation

The SDSS is implemented as per the provided specifications and is being hosted from The University of Toledo’s GISAG lab (Geographic Information Science and Applied Geography) facilities. The system can be accessed remotely from anywhere in the world. However, internet bandwidth may affect the quality and time it takes to load. It serves the purpose without any flaws in the Upper Midwest freight corridor study. The current version of the SDSS is versioned as 3.0 and can be accessed through a web browser at

HTTP://131.183.84.117/website/midwest alternately this can also be accessed through a hyperlink from The University of Toledo, research site located at www.midwestfreight.utoledo.edu

3.12 Summary

The conceptual framework developed in this thesis forms the rudimentary beginnings of an online freight management SDSS. This could further be developed to incorporate a wide variety of tools depending on the user needs. The technology adapted to implement the framework for the Upper Midwest Freight Corridor study is not a compulsion. The framework is flexible enough to be tried with different components. The following chapter looks at some of the findings from this study.
Chapter Four

Results

4.0 Results

The result of this research can be divided into two categories, one being the design of the conceptual framework for developing a web based freight management SDSS and the other, implementation of this conceptual framework for a real world problem. The objectives set forth before creating the framework are to be evaluated in order to assess whether the final framework meets the goals (Table 4.1). A standardized GIS functionality was implemented in the conceptual framework, the map server component in the implementation phase brings all the essential GIS capabilities to SDSS. The map server can also be customized depending on the user needs. The interfaces of the SDSS are designed intuitively with user friendly features, this was discussed in the previous chapter. Support for remotely sensed imagery was provided in the conceptual framework, it was also implemented separately to show the feasibility of using it as a viable tool for transportation studies.

Data standards were set forth prior to the study. This included the essential layers or data that is necessary to support a online freight management system. This is further demonstrated by the actual creation of the comprehensive
database (Table 4.2) for The Upper Midwest Freight Corridor Study. All the objectives were met in the conceptual design framework and were also successfully implemented in The Upper Midwest Freight Corridor Study online SDSS.

<table>
<thead>
<tr>
<th>OBJECTIVES for framework</th>
<th>Status</th>
<th>Final Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Standardized open GIS framework for SDSS</td>
<td>Implemented</td>
<td>✓</td>
</tr>
<tr>
<td>2. User friendly interfaces</td>
<td>Implemented</td>
<td>✓</td>
</tr>
<tr>
<td>3. Implementation of remote sensing technology for monitoring transportation</td>
<td>Partially Implemented</td>
<td>✓</td>
</tr>
<tr>
<td>4. Data standards implementation</td>
<td>Implemented</td>
<td>✓</td>
</tr>
<tr>
<td>5. Database management system (DBMS) with advanced data querying and editing abilities</td>
<td>Implemented</td>
<td>✓</td>
</tr>
<tr>
<td>6. Incorporate spatial analysis tools (dependent on the user analysis) such as identify tools, buffer analysis, dynamic multi layer mapping facility etc</td>
<td>Implemented</td>
<td>✓</td>
</tr>
<tr>
<td>7. On the fly Map production and display facility (report generators)</td>
<td>Implemented</td>
<td>✓</td>
</tr>
<tr>
<td>8. Potential bottleneck Identification in the study area for immediate decision making</td>
<td>Implemented</td>
<td>✓</td>
</tr>
<tr>
<td>9. Data sharing capabilities (data repository)</td>
<td>Implemented</td>
<td>✓</td>
</tr>
<tr>
<td>10. SDSS Implementation and evaluation</td>
<td>Implemented</td>
<td>✓</td>
</tr>
</tbody>
</table>

Table 4.1 Objectives of SDSS framework
<table>
<thead>
<tr>
<th>Database contents objectives</th>
<th>Status</th>
<th>Final Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Build the network (Highways, Rail, Waterways)</td>
<td>Incorporated</td>
<td>✓</td>
</tr>
<tr>
<td>2. Build Major Nodes (Ports, Airports, Intermodal Facilities)</td>
<td>Incorporated</td>
<td>✓</td>
</tr>
<tr>
<td>3. Generate attributes for network and nodes</td>
<td>Incorporated</td>
<td></td>
</tr>
<tr>
<td>a. capacities</td>
<td>Partially/ regulations</td>
<td></td>
</tr>
<tr>
<td>b. Flows</td>
<td>And performance</td>
<td>✓</td>
</tr>
<tr>
<td>c. Regulations</td>
<td>Not included</td>
<td></td>
</tr>
<tr>
<td>d. Performance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Link network- flows, capacities and regulations to economic activities in the region</td>
<td>Incorporated</td>
<td>✓</td>
</tr>
<tr>
<td>5. Link network- flows, capacities and regulations to population characteristics in the region</td>
<td>Incorporated</td>
<td>✓</td>
</tr>
<tr>
<td>6. Incorporate remote sensing backdrop</td>
<td>Partial</td>
<td>✓</td>
</tr>
<tr>
<td>7. Thematic mapping of variables</td>
<td>Partial</td>
<td>✓</td>
</tr>
<tr>
<td>8. Base layers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. States</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. counties</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. Tract level data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. Block group level data</td>
<td>Incorporated</td>
<td>✓</td>
</tr>
<tr>
<td>e. Hydrology and major water bodies</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.2 objectives of database
The development of the freight management SDSS (Table 4.3) is a continuing process and the developed system has been refined and revised several times depending on the researchers and users needs. The changes from version to version can be seen in the figures listed below.

As the upper Midwest freight corridor project progressed more detailed and accurate datasets were created. Important calculations and other information such as LOS (Level of service) etc were added to the existing datasets. All the variables included in the database objectives were also added to the final datasets. Dot density maps were also created for the variables that are...
important. These variables included county, block group and tract wise manufacturing, warehousing, transportation etc. Administrative policies and other relevant data are still to be included along with the current data online. This will be done when Upper Midwest Freight Corridor Study project reaches a consensus as to what data should be included.

The current freight management SDSS can be utilized in analyzing the data as shown in the preceding figures. It can also be used to look at the current transportation infrastructure in the upper Midwest region. Level of service (LOS) has been calculated for all the selected networks consisting of highways, railroads, airports and waterways to a major extent by the researchers. As mentioned earlier LOS is described by alphabets A to F, where “A” represents the best traffic flows and “F” represents worse conditions or frequent or heavy congestion. Other data such as demographics and economic data were included as separate layers, these could be used to analyze the economic and demographic variables that affect the freight movement dynamics in the region.

Different spatial analysis tools are also available for the user. These include buffer analysis, feature identification tools, SQL query tools, custom scale tools, Measuring tools, legend and layer toggle, panning, hyperlinks, selection tools and report generators for producing reports and these are described in the following pages.
The above figure shows the initial system interface and feature selection facility in the Upper Midwest Freight Corridor Study SDSS. Geographic features can be selected basing on a common attribute criteria or a bounding box or area.

The above figure shows the selection of roads in Illinois state road network using a bounding box. The advantage of feature selection lies in the ability to perform spatial analysis such as buffering etc on the selected features and to highlight important areas in a larger area. The initial interface doesn’t have layer tools. As the number of data layers increased, the layers weren’t visible in the layers list. This was resolved by creating specific tree structures for each type of geographic feature, this can be seen in the following figures.
The above figure (Figure 4.2) shows the user interface of the current version of the SDSS versioned as Ver 3.0. This updated version has better layer manipulation facilities and better labeling and annotations. Major layer categories can be seen in the right most corner of the figure. The major categories of the layers are subdivided into base layers, intermodal facilities, road networks, rail road networks and thematic mapping variables that can be plotted as dot density maps.
The above figure (Figure 4.3) shows the expanded layer trees on the right side of the figure. This facility gives flexibility to users when they are analyzing large number of datasets. The layer tree can be expanded and collapsed by clicking on the main layer title. Further, the user has the option to toggle between the layer visibility, invisibility and overlay of other thematic variables.
The above figure (Figure 4.4) demonstrates the automatic layer scaling and visibility. The user can drag a bounding box to zoom in to a particular area of interest using the zoom in box and zoom out using the zoom out box tool. As the user zooms in the number of layers visible increases and the degree of feature detail also increases. The default map display consists of the whole Upper Midwest Freight Corridor study area with county level detail. The default display also consists of the Level Of Service (LOS) thematic maps for road networks and rail road networks.
The above figure (Figure 4.5) demonstrates the feature scaling, as the user zooms in further more detailed information is provided. Further, pop up tools provide easier interaction with the system as they can be moved irrespective of the map display. Web and user friendly colors are used to depict the geographic features and to build the user interface. Automatic labeling allows for labeling the layers basing on the scale which can be seen in the above figure.
The above figure (Figure 4.6) demonstrates the ability of the SQL (Structured Query Language) pop up tool utility. Using the SQL query the users can select or analyze geographic features basing on their attributes or characteristics. In the above example a road feature is selected basing on the Level Of Service (LOS) factor. Due to large datasets the querying process might take longer intervals to display the results, which is quite common with the ArcIMS platform.
The results from a SQL query are usually returned in a pop up window with hyperlinks to those features selected. The user can click the hyperlink to automatically zoom onto the feature of interest. This is demonstrated in the figure below (Figure 4.7). Most of the tools are inbuilt functions of ArcIMS platform, each of those are then customized to the user requirements.
The above figure (Figure 4.8) demonstrates the buffer analysis tool. Buffer analysis is used for identifying areas surrounding geographic features. The process involves generating a buffer around existing geographic features and then identifying or selecting features based on whether they fall inside or outside the boundary of the buffer. For example as show in the figure, buffer analysis is used to look at the road networks that are actually affected by a road segment with high traffic volume.
The above figure (Figure 4.9) shows the report generator facility in the system. This tool can be used to create custom map layouts depending on the user requirements. The user can choose the title, scale, area of interest and legend to be displayed on the layout. This can be directly printed or saved to a hard disk.
The above figure shows the spatial overlay tool in the SDSS. One basic way to create or identify spatial relationships is through the process of spatial overlay. Spatial overlay is accomplished by joining and viewing together separate data sets that share all or part of the same area. The result of this combination is a new data set that identifies the spatial relationships. This helps the decision maker in spatially visualizing the variables.
The whole system can also be accessed through other software’s like Arc Catalog, Arc Explorer with an internet connection apart from an internet browser. All the anticipated requirements and objectives framed earlier were satisfied in the final product version 3.0.

The Upper Midwest Freight Corridor Study is still underway at The University of Toledo along with other research institutions and will continue to improve upon the presently established freight management SDSS. In the near future the current system will be fully integrated with other capabilities and would follow the distributed computing model architecture. The current system location i.e., the IP address for the SDSS and the FTP will be changed depending on current university policies from time to time. The new location will be continuously updated and can be accessed through The University of Toledo project website at www.midwestfreight.utoledo.edu.
Chapter Five

Conclusions

5.0 Conclusions

The general conclusions to be drawn from this research are that freight management decision making can benefit significantly from the development of an online or internet based spatial decision support system that include GIS, GIS-Transportation and quantitative tools.

The internet based freight management SDSS architecture developed in this study lays the rudimentary conceptual and technological framework for reporting, visualizing and disseminating freight movement data across large regions for decision making purposes. This online SDSS framework fills in the gap for a decision support system that’s widely and easily available to the decision making community. Through a web browser, the decision maker can retrieve crucial information without having to go through exhaustive and expensive training of spatial technologies.

The Upper Midwest Freight Corridor Study SDSS is developed keeping in view the user requirements. More advanced tools can be developed basing on the user needs. This system can be used to look at the current freight operating conditions in the Upper Midwest region. The current infrastructure assets were
also compiled into the database which include road type, lanes etc. Other important variables such as demographics, economic indicators can be visualized within the GIS. This is a single resource that supplies the decision maker with multiple sources of data.

Although efforts are well under way to incorporate decision making and analytical tools into full featured desktop packages, a more promising approach follows from the evolution of SDSS from desktop to internet based systems. This evolutionary path is faster and easier to implement with upcoming technologies that include JAVA®, .Net®, XML® and GML® based programming architecture. The advantage of the conceptual frame work lie in the modular architecture of the SDSS which readily accepts any plug-in or component as part of the logical layer and makes it readily available to the decision maker.

Numerous guidelines are available for planning and implementing this kind of technology. However, development and implementation processes must be considered with in a larger context that includes issues related to the organization as a whole where it is used for decision making.

Some of the other issues concerning the database of the SDSS involves providing access to proprietary and historical data that may be stored in different locations and different forms throughout the organization. The next issue involves the ability to maintain and analyze these data to identify hidden patterns. Similarly, the need to distribute data and processing to many different locations.
To develop and implement this kind of freight management SDSS, different aspects of the system design are to be clearly dealt before going any further with the implementation, a system design and information architecture planning is required. It includes analysis of users of such systems and their requirements, type of problems the system should solve and the models or algorithms that are needed to solve the problems and other features that the user might think are important in the decision making process.

Although this kind of planning is not without its pitfalls and problems, the benefits of effective and efficient development and implementation of a internet based freight management SDSS justify the effort. This study paves the way for research and development of more robust, intelligent and user-friendly online SDSS that could one day become an essential tool to the transportation planning officials, urban planners and other officials in the transportation planning process.
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Springe10/22/2003r Verlag. ISBN 3-540-62518-6

APPENDIX A

(Source: Upper Midwest Freight Corridor Study, draft report, 2004)

Performance Metrics:

Performance metrics can be defined as the condition or conditions that are important to the movement of freight and the operation of transportation system as it moves freight. These are essential in creating a better transportation system.

Best Practices:

There are many multi jurisdictional projects related to freight transportation that are now underway like I-10 freight study. A review of those experiences is necessary to capitalize on those experiences, to avoid possible failures and replicate successes.

Clearinghouse of efforts:

There are many multi jurisdictional freight corridor studies that are underway or completed in the past. As part of improving the true base of experience these other studies must be compiled and made available to the transportation decision making community.

Demand Usage:

Proper understanding and analysis of how the transportation system is being used is important. The objective of this kind of analysis is to give the stakeholders useful information on how goods move to, from, and within the region of study.
Capacity:

Demand management and usage decisions depend on a clear understanding of the freight capacity on different modes of transportation along and feeding into the corridor where necessary. Together with the Demand/Usage information, capacity information leads to the analysis and mitigation of bottlenecks in the region.

Administrative Issues:

Inconsistencies in the prevailing regulations and administrative processes lead to duplication of efforts and poor travel efficiencies. Identification of inconsistencies and analyzing their impacts are necessary to lead regional participants to money saving opportunities for cooperation that does not sacrifice travel safety or overstress the physical infrastructure.
APPENDIX B. SELECTION OF HIGHWAYS

(Source: Upper Midwest Freight Corridor Study, draft report 2004)

This appendix documents the procedure implemented by the research team in selecting the Highways. The process and guidelines included the following stages:

1. Direct connection to Intermodal terminals

Routes that are directly connected with major intermodal terminal were selected except when such route was far from meeting the traffic volume criteria discussed below.

2. ADT, Truck ADT, and truck percentage of ADT

These three variables were used jointly to determine whether the route is considered to be a regionally significant freight route, and also whether the route is likely to be experiencing congestion from truck traffic. The 50 percentile of the truck volumes for all the links (i.e. national network) included in the Freight Analysis Framework's 1998 truck ADT data is 1890 trucks per day. This figure was used to judge the significance of a route as a truck route.

3. Potential to serve as the alternative route to I-80/90/94

There were several sub-criteria for determining whether a route has the potential to serve as the alternative route to I-80/90/94. First, the route must be able to accommodate freight flow at the regional scale. This requires the route to show continuity through the significant portion of the study area. Exception was
made for the urban routes such as beltways and bypasses that can provide local but considerable congestion relief in the urban areas. Second, the route must cater to the same demand as the I-80/90/94 corridor does. When necessary, the select link analysis function of the GeoFreight software was used to analyze the origins/destinations of the freight transported on the route in question. I-70 corridor was excluded from the network based on the finding that most of the shipments on the route come from or go to Southwestern part of the U.S. while the I-80/90/94 corridor serves Northwestern part.

4. Connectivity

In some cases, routes that served as the critical connector to other major freight corridors, such as I-70 and I-74, were included in the study network even if they did not meet other criteria.

5. Proximity to manufacturing activities measures in terms of value added

From an economic growth standpoint, it is clear that highways in close proximity to manufacturing will experience major truck traffic pressure. In most cases, not meeting one of the guideline did not determine the fate of a route. Rather, the routes that were excluded usually suffered from a combination of several shortcomings.
APPENDIX C. DATA RECONCILATION

(Source: Upper Midwest Freight Corridor Study, draft report, 2004)

**Data incompatibilities:**

Significant time was catered to compile the geospatial data from diverse sources that consisted of proprietary and public data sets. Federal data sources included BTS, FHWA, NHPN etc. The research team cleansed the data to eliminate any inconsistencies that were present in the data. Due to varying data standards among the different organizations, very few datasets were compatible with others. The different datasets were later on compiled into a common comprehensive database for the Upper Midwest Freight Corridor Study, the techniques used to compile the database was given in the following paragraphs.

**Data reconciliation:**

The data obtained for the study was derived from various sources. Most of the datasets had different georeferencing system which include projections, coordinate systems, ellipsoid etc. Common georeferencing parameters were developed and implemented to bring the data into common georeferencing system. All the data layers were reprojected into Lambert’s Equal Area Azhimuthal centered on southern Wisconsin using feet as the coordinates and projected onto the WGS 84 Ellipsoid using the NAD 83 datum. This process did not eliminate problems completely. Other problems included improper alignment of network data even with common georeferencing parameters. Due
to these problems when data was overlaid they would not match or align. These problems can be attributed to different segmentation standards of networks that were implemented during the actual creation of data. These were again explained in detail in the following paragraphs.

1. Dynamic Segmentation Problems

Data reporting standards differ from one another, leading to problems with data alignment and overlay analysis. The networks are subdivided into links or sections of different length, as a result attributes from one network to other networks cannot be directly compared. This can be overcome by subdividing the network lengths from all networks basing on common characteristics such that they can be compared.

2. Conflation Problems

Data networks often do not align geometrically over one another, resulting in braided effect. It further complicates the process of transferring the attributes from one network to other. This accomplish successful transfer of attributes from one network to other, snapping of segments either basing on center or nodes is desired. The research team was able to overcome these issues by re segmenting both road and rail networks into minute one-mile segments.

3. Creation of comprehensive network

The comprehensive network was created using selected segments from 1:100,000 National Highway Planning Network (NHPN) and the 1:100,000 FRA railroad network. These were again subdivided into half mile segments using a
segmentation algorithm developed by The University of Toledo research team. These segments were then assigned a midpoint using common primary key in the attributes.