**TISCSoft: A Decision Support System for Transportation Infrastructure and Supply Chain System Planning**

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**Abstract**

We describe an ongoing research effort on the development of a decision support system (DSS), called TISCSoft, that is designed to facilitate critical decisions related to transportation infrastructure planning in the public sector and supply chain planning in the private sector. This DSS implements mathematical models developed as part of a recently completed research effort titled Freight Movement Model (FMM) for the State of Oklahoma. We also explain how the results of the FMM model will be used to support and enhance the solution to supply chain (SC) system planning problems pertaining to the logistical network. A unique feature of TISCSoft will be its scenario-based decision analysis capability using a combination of interactive scenario definition and off-line execution of freight flow models. TISCSoft will also support training and education of transportation and supply chain professionals and classroom instruction through associated case studies.

1. Introduction

Realizing the need for proper planning tools to support decisions related to the nation’s transportation infrastructure, state DOTs (Departments of Transportation) in the US have initiated research efforts to develop models for predicting freight movement. Freight Movement Model (FMM) for the State of Oklahoma is one such effort initiated by the Oklahoma DOT in 2003 [17, 28]. The FMM project has resulted in one of the most comprehensive and innovative freight flow movement models because of its multi-level (entire nation to state to county) and multi-modal nature with decision and scenario analysis capabilities. The ongoing DSS research effort makes the results (models and methodology) of the FMM effort accessible for transportation professionals and decision makers. Furthermore, TISCSoft will also support supply chain planning problems by implementing new research that uses the results of the freight movement projections to simplify and improve the supply network design problem.

1.1. Transportation planning

The FMM project resulted in a prototype system that predicts freight movement by commodity type and by mode across the nation and, with more detail, within the State of Oklahoma for multiple future years. This prototype addresses several key issues in freight movement and public transportation planning. Examples are infrastructure planning, security, safety, and mobility. (1) Infrastructure Planning. FMM predicts the volumes of freight flow on state and national highway segments. This information is valuable for planners and policy makers in the state government as they can use the freight flow model as a tool to study the impact of their policy decisions with respect to the highway infrastructure. (2) Security. If a transportation emergency (e.g. a bridge collapse or a natural disaster) were to happen that renders part of the infrastructure unusable for a protracted period of time, FMM can be used to predict how the freight flow patterns (volumes and routes) could change because of the transportation network disruption. (3) Safety. More accurate modeling and planning of passenger traffic and freight flows is needed to better understand highway capacity related issues. In addition, the management of freight flow is critical to the safety of the general public on the federal highway system. Within FMM, flow assignment with capacity consideration will identify congested links, which, when linked with freight accident information, could help shed light on freight-related safety issues. (4) Mobility. Understanding and forecasting freight flow is a critical component of any multi-modal movement of goods. The FMM effort addresses multi-modal freight movement. For example, considering link capacity in highway flow assignment will enable us to locate congested segments and help decision-making related to the location of multi-modal transportation hubs to alleviate highway congestion.
1.2. Supply chain system planning

Nowadays, commercial companies not only consider transportation to account for the immediate cost of moving goods from one location to another, but they also view the transportation process as a part of the larger logistics concept. According to this concept, capital requirements related to easy and fast market access might be more important than the direct transport costs. Firms are also aware of the importance of quick response times, reliable and on-time delivery and freight sustainability issues. These observations have caused us to rethink the traditional approach where supply chain planning and freight flow modeling are treated as two independent problems with the former focusing on product level movement at the firm level and the latter dealing with aggregate flows at the commodity level on a state or national scale. A more careful examination reveals meaningful linkages between the two problems. To better predict transportation times in a supply chain network, we would need accurate estimates of congested travel times on highway segments, one of the key outputs of the freight movement model. Our novel approach combines the macro view of aggregate level freight flow on US highway network with the micro view of product movement due to individual supply chain networks.

The rest of the paper is structured as follows. Section 2 presents a brief review of existing work on decision support for transportation planning and supply chain system planning. Section 3 presents the objectives of the DSS effort. Section 4 presents an overview of the TISCSoft environment and includes a brief summary of the FMM methodology. We conclude in Section 5 by briefly discussing ongoing work on the development of a bio-fuels case study.

2. Literature review

We first review previous efforts on providing decision support for transportation planning and then discuss available modeling efforts to support supply chain planning. This is similar to the two-level classification related to freight transportation decision-making mentioned in [18]. (1) Operational Level. This type of freight transportation decision-making is at the firm level and usually applied for optimization purposes. (2) Strategic Level. In contrast to the operational level, strategic decision-making is an aggregation of firm-related decision making. Based on the survey by Eom et al. [11], DSSs have been applied in the area of freight transportation both at the operational and strategic levels.

2.1. Decision support for transportation planning

Transportation planning, particularly transportation infrastructure planning, is one of the most important planning functions of the public sector at the national, state, and local levels. The major activities of transportation planning include efficient movement of commodities (freight) and people (passenger) at various spatial scales, by various modes, for different purposes, and through careful consideration of critical issues, such as, safety, health, sustainability, and mobility.

At this strategic level, the DSSs are used to help policy makers obtain insight into the impact of freight flow volumes on the transportation infrastructure for long-term planning purposes. Some examples of decision-making at the strategic level are the influence of central distribution centers on the patterns of transportation and mode share, competition between ports, and consequences of multi-modal transport policy on utilization of the different networks. Many strategic freight transport DSSs apply the 4-step conventional model [9] (see Section 4.1 for further details). The most common and critical component of freight transportation DSSs ([6], [21]) is a Geographical Information System (GIS) based interface. GISs have the querying, manipulation, overlaying, visualization, and spatial decision analysis capabilities for spatial data and its associated attribute data.

A key development in using decision support systems for freight transportation was the “GeoFreight Intermodal Freight Display Tool” released by the Bureau of Transportation Statistics (BTS), Federal Highway Administration (FHWA) and the Office of the Secretary in 2003. GeoFreight is the first comprehensive DSS with various visualization functions for national, regional, and state level freight movement by highway, rail, water, and air networks. The users can query, select, display, and print freight flows at various scales with customizable symbols. GeoFreight is based on Freight Analysis Framework (FAF), a comprehensive freight database developed jointly by Battelle Team, Rehee Associates, Wilbur Smith Associates, Oak Ridge National Lab, Global Insight for Federal Highway Administration (FHWA) at the U.S. Department of Transportation, and Office of Freight Management and Operations ([13], [14]). FAF has been developed and modified over the past few years, including FAF1, which was based on private and proprietary data for the base year 1998 and future years 2010 and 2020; FAF2.1 and FAF2.2 [14], which were released in 2006 and cover freight flow for the base
year 2002 and future years from 2010 to 2035 at five-year intervals.

Macharis and Bontekoning [24] presented several decision problems in intermodal freight transportation and identified opportunities for operations research based decision tools. Crainic et al. [8] developed Strategic Planning of Freight Transportation (STAN), an interactive freight transportation DSS. STAN provided the decision maker with a tool for multi-product, multi-modal freight flow analysis to evaluate and compare alternative policies. Brand et al. [5] discussed the Strategic Transport-Energy-Environment Decision Support (STEEDS). STEEDS assisted policy makers in exploring the influence of different transport technologies under various exogenous scenarios and policy options on market take-up, as well as in assessing the energy and environmental impacts of these technology mixes. Finally, transportation network capacity assessment and scenario simulation, for both goods and passenger transport, are often a focus of decision analysis (see e.g., [1], [4], [27], [29], [32], [35]).

2.2. Decision support for supply chain system planning

Most of the literature on supply chain planning focuses on developing optimization models or stochastic models at the product level. The works of Lee and Billington [20], Cohen and Lee [7], and Ettl et al. [12] are some examples. Lee and Billington [20] developed an optimization model to meet the needs of the manufacturing managers at Hewlett-Packard in managing the material flows in their decentralized supply chains. Cohen and Lee [7] developed a framework for linking decisions and performance throughout the material-production-distribution supply chain. Their model could support analysis of various manufacturing material/service strategies. They also discussed a prototype software implementation. Ettl et al. [12] developed strategic level decision-making models for large supply chain networks. They focused on optimization with service level constraints along with a queueing model to take into account the stochastic nature of a supply chain network.

Gayialis and Tatsiopoulos [16] developed a DSS for vehicle routing and scheduling for an oil company. The DSS combines a supply chain management (SCM) application with a GIS and integrates it with an enterprise resource planning (ERP) software. The objectives of this tool are to optimize the use of the distribution network, transportation cost reduction, and customer service improvement. Vannieuwenhuyse et al. [34] studied the use of an interactive online DSS in making decisions for transportation mode selection. Locklear [22] studied the utilization of a DSS for reverse logistics of product take-back. This DSS uses GIS as a main tool for helping decision makers to better understand the logistics system and enables them to quantify the impact of their decisions. Moynihan et al. [25] developed a DSS using simulation techniques for planning logistics and distribution activities, and measuring their impact on overall corporate profits.

Longo and Mirabelli [23] presented an advanced modeling approach and a simulation model for supporting supply chain management. An advanced modeling approach was used to develop a flexible, time efficient and parametric supply chain simulator starting from a discrete event simulation package. The simulator was used as a decision making tool capable of analyzing different supply chain scenarios by using an approach based on multiple performance measures and user-defined set of input parameters.

Recently, Needy et al. [26] have developed a software-based test platform that optimizes and simulates a user-defined supply chain for products that are being (re)designed. They study the impact of product design and redesign on the supply chain structure with an aim of quantifying the impact so that these results can be used in the product design phase to better understand the tradeoffs between the benefits and costs of the different supply chain alternatives. The supply chain optimizer treats the problem at hand as a network optimization problem where it addresses some strategic issues like which facilities to open or close, how much of a product to produce, which transportation mode to use, etc. The solution from the optimizer is fed into a simulator built using the Arena simulation package. While the optimizer was used to assess the performance of the supply chain network under static parameter values, the simulator takes into account the randomness that is prevalent in the real world.

Tavasszy et al. [33] also proposed the integration of logistics behaviors of operators at the operational level into a strategic freight model. The model describes logistics chain at three levels: production, inventory, and multimodal transportation. At the production level, the main aim is to develop a better view of the future freight flows related to the production and consumption structure. The inventory level model links trade relations to transportation relations by considering distribution center/warehousing services. At the third level, a multimodal network with different modes connected by transshipment facilities is considered.
3. DSS project objectives

The primary objective of the ongoing DSS effort is to design and develop a decision support software environment (TISCSoft) that can assist planners and policymakers in making critical decisions related to transportation infrastructure planning in the public sector and supply chain system planning in the private sector. In addition, to support supply chain planning problems, research is underway to develop a methodology to use the results of the freight movement projections to simplify the supply network design problem.

TISCSoft will allow users to analyze, query, select, display, and print freight flows as in GeoFreight. However, there are many aspects of the TISCSoft DSS that distinguishes it from other similar efforts.

- To support the planning functions of a state DOT (Oklahoma in our case), the freight flow modeling has to be done at the county level. This requirement led to a novel approach [17, 31] that uses a code-mapping scheme between commodity types and industrial sectors to split MSA (Metropolitan Statistical Area) level data (used in FAF2) to county-level data for use in the FMM methodology.

- Existing transportation DSSs use pre-computed freight flow projections that are based on an assumed set of demographic and economic forecasts and a given transportation network structure. While these projections support basic analysis needed for infrastructure planning, they are not capable of supporting scenario analysis involving either changes in demographic and economic projections or infrastructure changes such as major transportation network disruptions caused by man-made (e.g. I-40 bridge collapse) or natural (e.g. Hurricane Katrina) disasters. TISCSoft will support scenario analysis in an asynchronous mode through a combination of interactive scenario definition and off-line execution of freight flow models.

- TISCSoft will also provide support for supply chain network design problems by using congested travel times on the highway segments provided by the FMM model to obtain more realistic transportation costs and times to serve as an input to the supply chain optimizer module. In addition, the shortest-time paths from the FMM model would yield a simplified logistical network for the supply chain optimizer.

- The use of DSSs and associated freight movement models is still a relatively new concept in transportation infrastructure planning. Hence, TISCSoft also includes an education/training module for current and future transportation professionals.

4. Overview of TISCSoft

In this section, we present an overview of the TISCSoft DSS environment. Figure 1 shows the current architecture of the TISCSoft environment. It shows the major software modules and the key data sources and repositories. We will briefly describe each module and discuss how it relates to the DSS objectives presented in the previous section.

![TISCSoft Architecture Diagram](image)

**Figure 1. TISCSoft architecture**

4.1. FMM module

The FMM module represents the implementation of the various models developed as part of the FMM methodology (shown in Figure 2), which is an adaptation of the four-step Urban Travel Demand Model originally developed for passenger transport [17, 28]. We briefly describe these four steps below.

4.1.1. Freight generation. The objective of freight generation is to determine the tonnage of a particular commodity type (there are a total of 43 commodity types) that is produced at an origin (called "production") and consumed at a destination (called...
“attraction”). Using the FAF2 freight data [13] and socio-economic data (e.g. population, personal income, and employment by industry) for 114 MSAs in the US, regression models to calculate the freight attraction and freight production at each MSA for each commodity type were obtained. These regression models can then be used to predict the freight attraction and production at each MSA by commodity type for any future year for which the socio-economic forecasts are available.

4.1.2. Freight distribution. The freight distribution step distributes the freight production and attraction at an MSA to all other MSAs. The inputs to the distribution model include the freight attraction and production data from the freight generation step, and an MSA level friction factor matrix. A distance-based friction factor was used within a doubly constrained gravity model [17]. The gravity model has been implemented in VB.NET. The output of this step is the amount of freight flow between any two MSAs by commodity type.

As mentioned in the previous section, to support the transportation planning functions of a state DOT, county-level detail is necessary. Hence, a novel combined regional-state approach was developed as part of the FMM effort. The MSA level freight flows were split to yield county-level freight flows using county and MSA level socio-economic data as the basis. In the case of Oklahoma, freight flow data for three MSAs was split among 77 counties.

4.1.4. Freight flow assignment. The major purpose of a freight assignment model is to determine the patterns of freight-flow movement between the given O-D (origin-destination) pairs on a transportation network. Within the FMM methodology, freight assignment is done using a novel shortest-time path approach. Freight flow between an O-D pair is assigned to network segments of the shortest congested travel time (determined using a volume-delay function) path starting with the O-D pair with the highest total freight flow volume. This approach is believed to closely model shipper and carrier behavior as they transport goods.

In this approach, the freight flow is assigned to transportation network segments one O-D pair at a time. The flow volume for the chosen O-D pair is assigned to all links on the network and the volume-delay function is used to calculate the congested travel-time on each link. Solving the shortest path problem with the congested travel-time data on the links would yield the shortest congested travel time path. The flows on the links that are not part of this path are reinitialized to the previous values. The next O-D pair is chosen and the above procedure is continued until all the O-D pairs are assigned a shortest congested travel time path.

The input to the freight flow assignment step includes the network structure data and link data (capacity, length, etc.) and results from mode split. The output includes the total flow volumes and congested travel times on highway segments and shortest time paths for all O-D pairs. The freight assignment model is solved using a commercial package such as FICO Xpress Optimization Suite.

4.1.3. Mode split. The third step splits the distributed flow between MSAs by the different modes (highway, railway, and waterway). For this DSS effort, we first computed the mode split percentages for each commodity type for the base year and assumed that the mode sharing pattern in future years will be the same as that in the base year. The input for this step includes the results of the freight distribution step and the historical data on mode split percentages based on the FAF2 data [13], and the output is the freight flow between MSAs by commodity type and by mode.

4.2. Input/Output module

The data needed for the various models used by the FMM methodology requires a variety of socio-economic data that have to be retrieved from many different public sources, mostly through the Web. Examples of sources are the US Census Bureau and BLS. This data is typically not in a form or format that is readily usable by the FMM models. After the relevant data is extracted from the source in the proper
format, the data has to be cleansed to address issues such as missing data and inconsistent data. Furthermore, some of the data may not be available at the right level of granularity (state level data available, but not MSA level). Hence, appropriate transformation procedures have to be developed to derive data at the required level of detail. Furthermore, some level of translation or transformation may be necessary as data is exchanged between the various models used within the FMM methodology. The input/output module is responsible for all such data extraction, preparation and transformation steps. Data (both input and output/results) within TISCSoft is typically stored in databases (MS Access) or spreadsheets (MS Excel).

4.3. Supply chain planning module

This module includes the implementation of an optimization model for supply chain design that was developed as part of an NSF-funded research effort [26]. The supply chain optimizer treats the problem at hand as a network optimization problem where it addresses some strategic issues like which facilities to open or close, how much of a product to produce, transportation modes, etc. The problem is formulated as a mixed integer linear program (MILP). The model considers a profit-maximizing firm and a finite planning horizon, which can be separated into multiple time periods. It also addresses various types of transportation modes and multiple facility types including supplier, manufacturer, distribution center and customer site.

The objective function is to maximize a firm’s profit while constrained by facility capacity if a facility is open, service level agreement and minimum deployment percentage of a link. In the model, practical considerations such as tariff and duty, volume discount agreement, inventory and lead-time are also incorporated. Both fixed and variable cost elements (e.g., transportation costs, purchase costs, and inventory costs) are included in the objective function. In the supply chain optimizer developed for the NSF project [26], the estimated travel time and cost from one location to another are assigned by the firm and do not take congestion into account. However, for the implementation within TISCSoft, the impact of congestion on travel times will be considered, which is in keeping with the current emphasis on sustainability and low-carbon supply chains.

The results of the freight flow assignment yield congested travel times on highway segments and shortest-time paths for all origin-destination pairs. These congested travel times on the highway segments will be used to obtain the transportation costs on the highway network, which will serve as an input to the supply chain optimizer. Similarly, the shortest-time paths generated by the FMM assignment model will be used to create a simplified logistical network for the supply chain optimizer.

4.4. Decision analysis module

A key feature of TISCSoft is the scenario-driven decision analysis capability. This module will provide policy-relevant and decision-critical scenarios for freight transportation and logistics decision makers. The following broad categories of scenarios will be supported.

- Transportation network disruptions for a prolonged time period because of natural (e.g., earthquake, hurricane, tornado, flood, and winter storm) and man-made (e.g., a gateway sea port shut-down by a workers’ strike, bridge collapse because of barge collision, and a terrorist incident) disruptions. This category of scenarios would result in a change in the transport network structure and/or potential shifts in production and/or attraction volumes at affected MSAs.
- Transportation and logistics policy impacts (e.g. locations of intermodal facilities and transport mode shifts).
- Socio-economic changes (e.g. significant changes in population or employment). This category of scenarios would result in shifts in production and/or attraction volumes.

To support scenario-driven decision analysis a major requirement is to provide a user-friendly interface to guide the user through the scenario definition phase including the specification of transportation network changes and new economic or demographic data. This module will also include retro analysis of past disasters including the I-40 bridge collapse [3], Hurricane Katrina [2], and the Northridge Earthquake. Such “canned” scenarios would be valuable from the following perspectives. We would have a better understanding of the nationwide impact on freight movement due to local/regional incidents. One would also develop an appreciation for the type of freight flow analysis that can be performed using the FMM models available within TISCSoft. The scenario analysis would be supported by rich, intuitive freight flow analysis using a GIS-based interface.

4.5. GIS interface

TISCSoft has a GIS interface developed using the ArcGIS software. Users will be able to perform exploratory visualization of different types of data (e.g. freight flows, demographic, and economic). For example, a user can visualize the demand data on a
map as shown in Figure 3. Figure 3 shows the different source sites for chemical production and the larger the dot, the more the production of chemical products. One of the main uses of the GIS type interface would be to visualize the freight flow volumes on the various highway segments. For example in Figure 4, the highway links carrying more that 500,000 kilo tonnes of freight per year in Oklahoma are highlighted. This type of visualization of data will be very helpful for decision-making when a user can easily identify patterns and critical links.

A user-friendly application for freight flow analysis and data visualization has been developed using ArcGIS Engine and VB.NET. Various queries have been developed to search and display transportation links with high flow volumes and high V/C (volume to capacity) ratios. Figure 4 shows a sample screen shot.

4.6. Training/Education module

This module is primarily designed to educate users on decision-making related to transportation and supply chain planning issues and also train/educate users on conducting freight flow analysis and designing supply chain networks. The main target audience of this module includes transportation/supply chain professionals and students majoring in transportation and logistics in disciplines such as industrial engineering, civil engineering, and regional & city planning. This module will include the following functions and features:

- Tutorial type material with easy organization/navigation of lessons including the FMM methodology and the supply chain design problem. The material will be organized in a Web page format with appropriate links to on-line resources.
- Self-testing and evaluation using on-line quizzes.
- Case studies including canned models and sample scenarios (derived from the analysis cases in the decision analysis module) with solutions.

4.7. TISCSoft model configuration and execution module

This critical module provides the essential linkages between the various modules and the user-interface. A TISCSoft user can have many objectives while using the environment; e.g. learning about freight movement modeling, analysis of freight flow projections, supply network design and scenario based decision analysis. This module contains the logic to invoke the right set of models, to allow the user to input pre-defined data or import new data, to facilitate data exchange between models, etc. A significant part of this module’s functionality will be related to the off-line execution of the appropriate FMM models for user-defined scenario analysis. For example, if the scenario involves changes only to the highway infrastructure (e.g. I-40 bridge collapse), then only the freight assignment model needs to be rerun to obtain the new freight flow volumes. If the scenario involves changes in economic or demographic forecasts then the entire set of FMM models will have to be executed (all 4 steps).

5. Ongoing work

The TISCSoft DSS effort is in the final year of a 3-year research effort. Current work focuses on the development and implementation of the methodology for supply chain planning. Simultaneously, a case-study on a bio-fuels supply chain is also being developed. The commercial viability of ethanol production requires a huge investment in the biomass distribution system, bio-refinery establishment, ethanol distribution system, and retail stations. As a proof-of-
concept, the DSS environment is expected to facilitate decision making related to transportation infrastructure planning for biomass feedstock and ethanol distribution.

### 5.1. Bio-fuels case study

Lignocellulosic biomass, such as switch grass and Miscanthus, has significant potential for the growing ethanol industry, by supplying large quantities of less expensive, high yield, sustainable, raw material. The delivery system of such biomass for a bio-refinery includes various operations like harvesting, baling, pre-processing, storage, transportation, and transshipment [15]. It is estimated that biomass supply accounts for 20 to 30% of the cost of ethanol and 90% of the biomass supply cost is associated with logistics processes [10].

A scenario optimization approach is being developed with the objective of minimizing total cost subject to local and regional conditions [30]. The model will help in making decisions regarding number of transportation, storage, and harvesting units required before and after frost, amount of switch grass produced, shipped, and stored in a time period, and number of inventory sites required to meet the demand in a time period.

The biorefinery that is the subject of our case study is a new facility located in southwestern Kansas that is expected to become operational in 2011. The case study will focus on the impact of the biorefinery on socioeconomic conditions (population, economy, etc) of Stevens County, Kansas. The biorefinery is expected to have significant impact on transportation infrastructure at the county and state levels as a result of the following activities. Biomass collection for which the region of influence will be source counties supplying biomass within a 50-mile radius from the biorefinery site; biomass storage in a region within a 30-mile radius of the biorefinery site; and worker commute within 50 miles of the biorefinery site.

The present transportation infrastructure may not be sufficient to meet the needs of the biorefinery and its biomass supply system. The truck flow volumes will increase significantly and may result in congestion on local highways. The case study will analyze the impact of increase in flow volumes on the region of influence with the present road infrastructure. The DSS project will facilitate decision making in relation to regional infrastructure planning to support the biorefinery and its biomass supply system.

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### 7. References


