OKLAHOMA TRANSPORTATION CENTER

ECONOMIC ENHANCEMENT THROUGH INFRASTRUCTURE STEWARDSHIP

A DECISION SUPPORT SYSTEM FOR TRANSPORTATION INFRASTRUCTURE AND SUPPLY CHAIN SYSTEM PLANNING

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16. ABSTRACT

This project makes the results (models and methodology) of the research and development efforts on freight movement modeling (FMM) and supply chain design carried out by faculty at OSU and OU available to transportation and logistics professionals. A web-based DSS called TISCSoft was developed to make the research results available to decision makers in a convenient on-demand format, while providing the researchers a mechanism to keep the models and results current.

TISCSoft has been designed to have the look and feel of a typical web-based software. Its home page provides some basic information to all users such as an overview of the DSS project, information about the research team, and links to sponsors and technical/data resources. Access to the DSS functionality is through a login procedure and currently there are three different user groups, namely, Research Team, Planner/Designer and Student. Users belonging to these groups have different access privileges based on their expected need for the various DSS functions. While users belonging to all three groups can analyze freight flows, only users belonging to the Planner/Designer group or the Research Team can access the supply chain network design and user-defined extreme event analysis functions. TISCSoft supports scenario analysis involving either changes in demographic/economic projections or infrastructure changes such as major transportation network disruptions caused by man-made or natural disasters. This is accomplished through a combination of on-line scenario definition and off-line execution of freight flow models.

The DSS also implements a novel approach for the design of supply chain networks. The congested travel times on the highway segments provided by the FMM model lead to more realistic transportation costs and times and serve as an input to the supply chain optimizer module. The DSS project also included a case study on the design of a biomass supply chain for switchgrass in western Oklahoma and southwestern Kansas. The supply chain model was extended to include the effect of weather patterns on the allocation and use of land and mechanical resources for a biomass supply chain by employing a scenario optimization approach.

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SI (METRIC) CONVERSION FACTORS

Approximate Conversions to SI Units

Symbol	When you know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	25.40	millimeters	mm
ft	feet	0.3048	meters	m
yd	yards	0.9144	meters	m
mi	miles	1.609	kilometers	km
		AREA		
in²	square inches	645.2	square millimeters	mm
ft²	square feet	0.0929	square meters	m²
yd²	square yards	0.8361	square meters	m²
ac	acres	0.4047	hectares	ha
mi²	square miles	2.590	square kilometers	km²
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft³	cubic feet	0.0283	cubic meters	m³
yd³	cubic yards	0.7645	cubic meters	m³
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.4536	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	degrees Fahrenheit	(°F-32)/1.8	degrees Celsius	°C
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.448	Newtons	N
lbf/in²	poundforce per square inch	6.895	kilopascals	kPa

Approximate Conversions from SI Units

Symbol	When you know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.0394	inches	in
m	meters	3.281	feet	ft
m	meters	1.094	yards	yd
km	kilometers	0.6214	miles	mi
		AREA		
mm²	square millimeters	0.00155	square inches	in²
m²	square meters	10.764	square feet	ft²
m²	square meters	1.196	square yards	yd²
ha	hectares	2.471	acres	ac
km²	square kilometers	0.3861	square miles	mi²
		VOLUME		
mL	milliliters	0.0338	fluid ounces	fl oz
L	liters	0.2642	gallons	gal
m³	cubic meters	35.315	cubic feet	ft³
m³	cubic meters	1.308	cubic yards	yd³
		MASS		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.1023	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	degrees Celsius	9/5+32	degrees Fahrenheit	°F
		FORCE and PRESSURE or STRESS		
N	Newtons	0.2248	poundforce	lbf
kPa	kilopascals	0.1450	poundforce per square inch	lbf/in²

A DECISION SUPPORT SYSTEM FOR TRANSPORTATION INFRASTRUCTURE AND SUPPLY CHAIN SYSTEM PLANNING

Final Report

July, 2013

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Executive Summary

This report documents the accomplishments of the project titled "A Decision Support System (DSS) for Transportation Infrastructure and Supply Chain System planning." This project is the culmination of several years of research and development on freight movement modeling (FMM) and supply chain design carried out by faculty at OSU and OU. The DSS research effort makes the results (models and methodology) of these efforts available to transportation professionals. After an initial implementation for the workstation environment, the research team switched to a web-based DSS to make the research results available to decision makers in a convenient on-demand format, while providing the researchers a mechanism to keep the models and results current.

The web-based DSS is called "TISCSoft" and has been designed to have the look and feel of a typical web-based software. Its home page provides some basic information to all users such as an overview of the DSS project, information about the research team, and links to sponsors and technical/data resources. Access to the DSS functionality is through a login procedure and currently there are three different user groups, namely, Research Team, Planner/Designer and Student. Users belonging to these groups have different access privileges based on their expected need for the various DSS functions. While users belonging to all three groups can analyze freight flows, only users belonging to the Planner/Designer group or the Research Team can access the supply chain network design and user-defined extreme event analysis functions. TISCSoft supports scenario analysis involving either changes in demographic/economic projections or infrastructure changes such as major transportation network disruptions caused by man-made or natural disasters. This is accomplished through a combination of on-line scenario definition and off-line execution of freight flow models. The DSS also implements a novel approach for the design of supply chain networks. The congested travel times on the highway segments provided by the FMM model lead to more realistic transportation costs and times and serve as an input to the supply chain optimizer module. The DSS project also included a case study on the design of a biomass supply chain for switchgrass in western Oklahoma and southwestern Kansas. The supply chain model was extended to include the effect of weather patterns on the allocation and use of land and mechanical resources for a biomass supply chain by employing a scenario optimization approach.

1 Introduction

This report documents the work accomplished during 2008-2012 in the project titled "A Decision Support System for Transportation Infrastructure and Supply Chain System planning." The project team consisted of Drs. Kamath, Ingalls and Jones at Oklahoma State University (OSU) and Drs. Shen and Pulat at The University of Oklahoma (OU). The project team's previous research on the development of a Freight Movement Model (FMM) for the State of Oklahoma provided most of the methodological foundation for this project. A decision support system (DSS) was built around the FMM models in order to facilitate critical decisions related to transportation infrastructure planning in the public sector and supply chain system planning in the private sector. The original version of the DSS was developed for a workstation environment. The team then switched to a web-based DSS to make the results of several years of research available to decision makers in a convenient on-demand format, while providing the researchers a mechanism to keep the models and results the decision makers access and use current.

The original FMM project resulted in a prototype system that had the capability to predict 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 addressed 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.

This DSS project could be seen as the culmination of several years of research and development on freight movement modeling (FMM) and supply chain design carried out by faculty at OSU and OU. The goal of the DSS research effort was to make the results (models and methodology) of the FMM effort accessible for transportation professionals and decision makers. Furthermore, the DSS also supports supply chain planning problems by using the results of the freight movement model projections to simplify and improve the supply network design problem. 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. 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.

In the current DSS implementation, users can analyze, query, select, display, and print freight flows. However, there are many aspects of our 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 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. The DSS performs scenario analysis in an asynchronous mode through a combination of on-line scenario definition and off-line execution of freight flow models.

- The DSS also implements a novel approach for the design of supply chain networks. The congested travel times on the highway segments provided by the FMM model lead to more realistic transportation costs and times and serve as an input to the supply chain optimizer module. In addition, the shortest-time paths from the FMM model yield a simplified logistical network for the supply chain optimizer.

1.1 Outline of the Report

Section 2 focuses on the FMM methodology and enhancements made to the FMM modules for the DSS implementation. This section begins with an overview of the FMM methodology and then summarizes the various enhancements made especially to the freight generation and freight assignment modules. In the freight generation module, the freight production and attraction models were refined and updated using the FAF2 data. The freight assignment module implemented a novel shortest congested travel time path method to assign freight flows to highway links. Section 3 describes the supply chain design part of the DSS which implements a novel approach for the design of the supply chain network that uses congested travel time information provided by the FMM results. Section 4 presents an extension of the basic supply chain model to include the effect of weather patterns on the allocation and use of land and mechanical resources for a biomass supply chain. A case study on the design of a biomass supply chain for switch grass in western Oklahoma and southwestern Kansas is presented. Section 5 provides an overview of TISCSoft, the web-based DSS that was developed. Brief descriptions of the various modules of TISCSoft are included in this section.

2 Freight Movement Model (FMM)

2.1 FMM Methodology Overview

The FMM methodology (shown in Figure 1) is an adaptation of the four-step Urban Travel Demand Model originally developed for passenger transport [1]. The four steps with the FMM methodology are briefly described below.

*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 [2] 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.

*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 to perform freight distribution [1]. The output of this step is the amount of freight flow between any two MSAs by commodity type.

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 [2], and the output is the freight flow between MSAs by commodity type and by mode.

As mentioned in Section 1, 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.

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 [3]. 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.

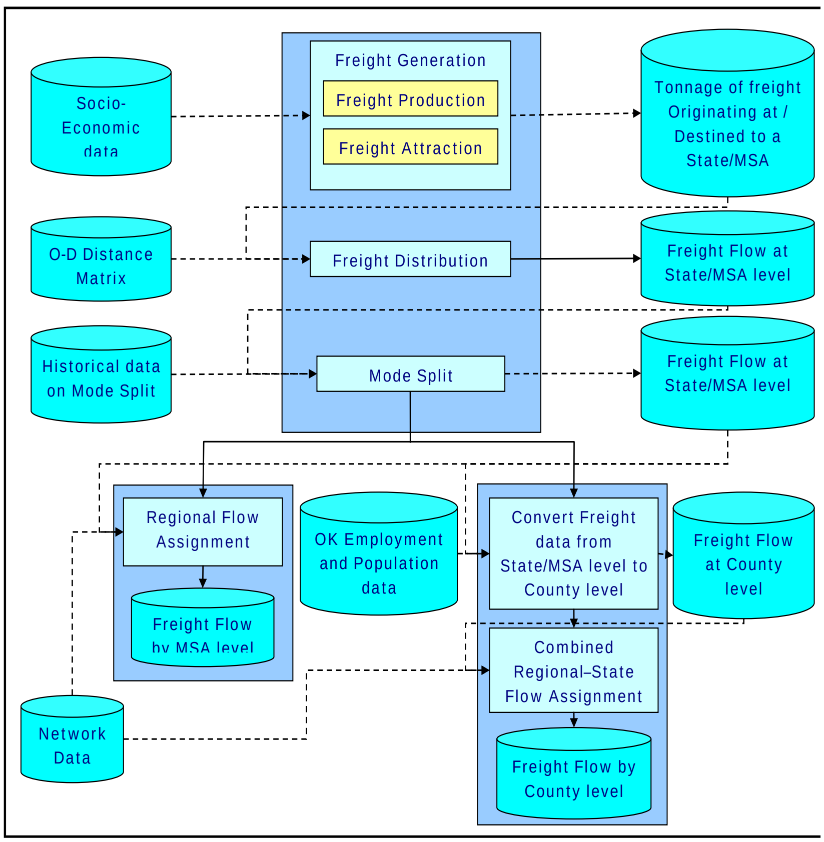


Figure 1: FMM Methodology

2.2 Freight Generation

Freight generation determines the tonnage amounts produced and consumed for particular commodities at different locations. The first phase of freight generation involves establishing the freight production and consumption locations on the highway transportation network. The production locations are nodes where freight is produced and consumption locations are nodes where freight is consumed. Socio-economic data- payroll wages, population, establishments, and employment- at the MSA level is the main input data to generate freight. The Freight Analysis Framework (FAF2) database [2] developed by the Federal Highway Administration (FHWA) has data for 114 MSAs, and this data serves as the data source for the freight flow data. Additionally, data is generated at the commodity level for the 43 Standard Classification of Transported Goods (SCTG) federal commodity codes for both freight production and consumption.

Data collection involves acquiring data for the 43 commodities identified under the SCTG commodity codes for the 114 MSAs. The dependent variable data is readily available for the 114 MSAs from the FAF2 database for each commodity; however, the independent variables data is much more difficult to obtain. The independent variables data is available from the U.S. Bureau of Labor Statistics (BLS) from three different tables at the MSA, Combined Statistical Area (CSA), and state levels. The SCTG commodities consist of different North American Industry Classification System (NAICS) codes. A code mapping procedure was developed and used to enable the grouping of different NAICS industry codes under the SCTG codes where 2-digit SCTG codes are mapped to 4-, 5-, or 6-digit NAICS codes based on relevancy [1]. This mapping aids in finding more accurate estimates of relevant measures such as the number of employees involved in producing any one commodity. The code mapping procedure is necessary to correctly group the NAICS industry codes into the proper SCTG codes for data collection. The BLS data consists of data for the NAICS industry codes. The code mapping is also used in disaggregating state-level production data to county-level production data using employment in the relevant industry as illustrated in Figure 2.

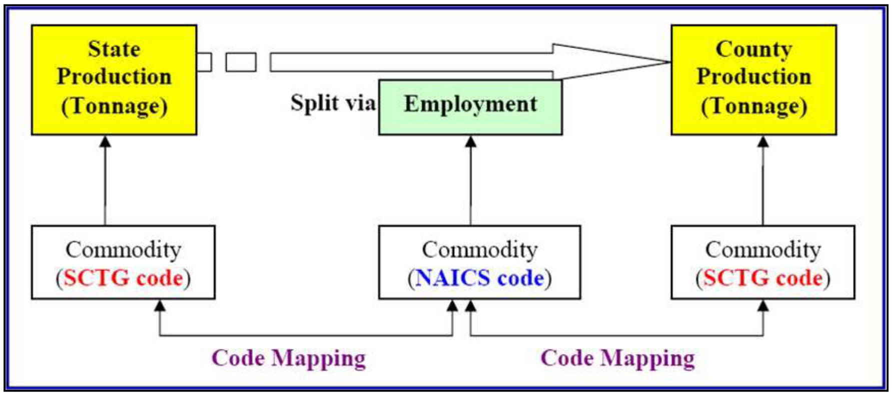


Figure 2: Use of the Code Mapping Scheme [1]

The CSA data available with the BLS did not have data for the NAICS industry codes at the 4-digit level; hence, this data was ignored. The 114 MSA data points consist of CSA, MSA, and the remainder of state data. After the tonnage data was collected for each MSA by commodity, the data was aggregated at the MSA level, which served as production and consumption tonnage for each MSA. The tonnage data was converted to truckloads using a payload factor for tonnage conversion developed by the U.S. Department of Transportation and the Federal Highway Administration. The payload factor is based on the following formula [4]:

$$TEF_{ijk} = B_{ijk}/w_{ijk}$$

where

TEF_{ijk} is the factor that converts tons of commodity to equivalent number of trucks

B_{ijk} represents the fraction of commodity i moved by truck type j with truck body type k; represents a tabular factor at the national level and is found in accordance to FAF2

w_{ijk} represents the mean payload of truck type j with body type k transporting commodity i; represents a tabular factor at the national level and is found in accordance to FAF2

The truckload data was used to establish freight distribution in the second phase. In order to better understand the code mapping process, an example considering freight production is illustrated using SCTG commodity 12, which is the Gravel and Crushed Stone commodity.

First, code mapping was done to determine the NAICS industry codes associated with SCTG commodity 12 for freight production. The code mapping process associated with Figure 2 was used to establish the mapping between the NAICS and SCTG commodity codes. NAICS codes 21231, 212321, and 327991 were mapped to SCTG commodity 12, and these codes were used to obtain the independent variables data for SCTG commodity 12. NAICS code 21231 involves stone mining and quarrying. NAICS code 212321 involves construction sand and gravel mining. NAICS code 327991 involves cut stone and stone product manufacturing.

Second, the number of establishments, number of employees, and payroll wages were obtained from the appropriate BLS tables for each MSA/CSA/state for NAICS codes 21231, 212321, and 327991, and this information was summarized in a table to establish the independent variables data. Table 1 shows an example illustration of NAICS 21231 code data for the number of establishments, number of employees, and payroll wages for the state of California involving various MSAs and CSAs within California.

Table 1: Independent Variables Data Associated with NAICS Code 21231 for California

Name	NAICS Code	Establish-ments	Employees	Wages
Los Angeles - Long Beach - Riverside, CA MSA	21231	6	386	$ 22,732,275
Los Angeles - Long Beach - Santa Ana MSA	21231	0	0	$0
Oxnard - Thousand Oaks - Ventura MSA	21231	0	0	$0
Riverside - San Bernardino-Ontario MSA	21231	6	386	$ 22,732,275
Sacramento- Arden-Arcade- Truckee, CA-NV CSA (CA Part)	21231	4	21	$774,581
Sacramento- Arden-Arcade- Roseville MSA	21231	0	0	$0
Truckee - Grass Valley MSA	21231	0	0	$0
San Diego - Carlsbad- San Marcos, CA MSA	21231	4	21	$744,581
San Jose - San Francisco - Oakland, CA MSA	21231	6	221	$14,089,727
Napa MSA	21231	0	0	$0
San Francisco - Oakland-Fremont, MSA	21231	6	221	$14,089,727
San Jose-Sunnyvale - Santa Clara MSA	21231	0	0	$0
Santa Cruz-Watsonville MSA	21231	0	0	$0
Santa Rosa-Petaluma MSA	21231	0	0	$0
Vallejo- Fairfield MSA	21231	0	0	$0
Remainder of California	21231	50	865	$41,903,456

Similar to sample data shown in Table 1, independent variables data was found for NAICS codes 212321 and 327991. After the establishments, employment, and wages data were obtained for NAICS codes 21231, 212321, and 327991, they were combined to produce one table for all 114 data points at the MSA level for SCTG commodity 12 involving freight production. In a similar fashion, the FAF2 database provided the dependent variables data for

NAICS codes 21231, 212321, and 327991, and the data was combined for the 114 MSAs for SCTG commodity 12 involving freight production. After the independent and dependent variables data were obtained for the 114 MSAs, the data was input into Minitab® to execute the regression. Table 2 shows a sample of the input data for the Minitab® software.

Table 2: Commodity 12 Production Input Data for Minitab®.

MSA	Dep Var	Establishments	Employment	Total Wages
AK	13,660.98	41	187	7,395,000
AL Birmi	8,412.33	10	210	8,097,000
AL Rem	14,623.72	117	2,574	121,035,000
AR	34,205.47	103	1,587	52,294,000
AZ Phoen	18,179.03	11	90	2,079,000
AZ Tucso	704.31	4	15	271,000
AZ Rem	3,169.79	67	1,350	41,366,452
CA Los A	58,250.79	30	1,024	61,764,000
CA Sacra	13,742.19	4	21	745,000
CA	18,039.74	46	650	24,843,000
CA San J	28,478.97	9	250	16,175,000
CA Rem	86,452.48	139	2,930	160,289,000

Lastly, after data was collected for the independent and dependent variables for each SCTG commodity, regression models were developed for each of the 43 SCTG commodities for both production and attraction. Figure 3 shows sample Minitab® regression results for the freight production model of SCTG commodity 12.

Regression Analysis: Dep Var versus Establisments, Employment, …

The regression equation is

Dep Var = 5291 -4.3 Establishments – 17.3 Employment + 0.776 Total Wages

Predictor	Coef	SE Coef	T	P
Constant	5291	1985	2.67	0.009
Establishments	-4.31	66.79	-0.06	0.949
Employment	-17.332	8.987	-1.93	0.056
Total Wages	0.7758	0.1645	4.72	0.000

S = 14293.7 R-Sq = 51.1% R-Sq (adj) = 49.8%

Figure 3: SCTG Commodity 12 Production Regression Results

2.3 Freight Distribution

The freight distribution phase involves distributing freight production and attraction at an MSA to all other MSAs. The freight production and attraction data are inputs to the distribution model along with a MSA level distance-based friction factor matrix. A doubly constrained gravity model was used to model freight distribution between production and attraction locations. The basic notion of the gravity model is that the flow from one location to another is positively proportional to the "pull" of the locations and negatively proportional to the impedance between the locations [1]. The doubly constrained gravity model ensures the flow conservation of production and attraction for each state/MSA [1]. The equation for the doubly constrained gravity model is given below [1]:

$$T_{ij} = A_i B_j O_i D_j \, F(d_{ij})$$

where

T_{ij} is the "Trips Distribution" between MSA i and MSA j

A_i , B_j are "Balancing Factors"

O_i is the production at MSA i and D_j is the attraction at MSA j

$F(d_{ij})$ is the "Friction Factor" associated with MSA i and MSA j

The doubly constrained gravity model was coded and executed as a Visual Basic Application (VBA) in Microsoft Excel. Trip distances between MSAs, balancing factors, MSA production and consumption data, and friction factors associated with the MSAs were determined and tabularized. The output result included the amount of freight volume flowing between any two MSAs by commodity type. The various steps in the implementation of the doubly constrained gravity model are as follows.

Step 1. Generate freight production and attraction data for each MSA. The freight generation regression models would be used in this step.

Step 2. Create the distance matrix, d_{ij}, the distance between MSA i and MSA j

Step 3. Create the friction factor matrix using an exponential function to compute the friction factors. The formula for the exponential function is:

$$F(d_{ij}) = e^{-.03 * d_{ij}}$$

Step 4. Make sure that the production and attraction are balanced for the MSAs. If the two are not balanced, then hold the production constant and adjust the attractions accordingly until production and attraction are balanced.

Step 5. Compute the trip distribution balancing factors A_i and B_j using the Bi-proportional algorithm. The expressions used for calculating the balancing factors are as follows:

$$A_i = 1/(\sum B_j D_j F(d_{ij}))$$

$$B_j = 1/(\sum A_i D_j F(d_{ij}))$$

The Bi-proportional algorithm works as follows.

The value of A_i is computed initially by substituting $B_j = 1$ into the A_i equation. Then the computed value of A_i is used to compute the value of B_j. The new value of B_j is then used to compute A_i and so on. This iterative process is repeated until convergence. The convergence rule used is based on the A_i values from two successive iterations and the B_j values from two successive iterations being "close" enough. The end result of convergence is a final trip distribution matrix between each pair of MSA locations.

2.4 Mode Split

Mode split involves the distribution of freight flows between MSAs by the different transportation modes (i.e. highway, rail, and water). The mode-split percentages for each SCTG commodity were determined for year 2002, and it was assumed that the transportation mode sharing among the different modes would be roughly the same for future years. The input for mode split includes the freight distribution results and the historical data on the mode split percentages based on the FAF2 [4]. The output is the freight flow between MSAs by commodity type and by transportation mode.

2.5 Freight Assignment

2.5.1 A New Freight Flow Assignment Heuristic

In this project, a new heuristic for assigning freight flows to highway network links was implemented. Within the FMM methodology, freight assignment is done using a novel shortest-congested time path approach [3]. 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 heuristic was further refined and completely implemented in this project. The heuristic uses an iterative approach that repeatedly solves a standard shortest path algorithm. Specifically, travel times are calculated based on the flow assigned to the network at iteration k. An all-or-nothing assignment is then made based on the fixed costs (i.e., congested travel times), and the next assignment is determined by combining the current flows with the all-or-nothing solution [3]. This procedure will terminate when freight flows for all O-D pairs are assigned to highway network links.

The following is an algorithmic description of the heuristic that was implemented. The O-D pairs are indexed from 1 to K in the descending order of O-D flow volume.

Model Notation & Parameters

A: set of all arcs

(ij): directed arc from node i to node j

Cap_{ij} : Capacity of (ij)

Ft_{ij} : Free flow time on (ij)

V_k: Freight flow between O-D pair $k = 1, 2, \ldots, K$

x_{ij} : Flow on (ij)

c_{ij} : Cost of flow on (ij)

p_{ij} : Passenger flow on (ij)

Heuristic

Initialize: $x_{ij} = p_{ij} \ \forall \ (ij) \in$ A

For $k = 1 \ to \ K$ do

Step 1: $x_{ij} = x_{ij} + V_k$

Step 2: $c_{ij} = Ft_{ij} \left[1 + \alpha \left(\frac{x_{ij}}{Cap_{ij}} \right)^{\beta} \right]$

Step 3: Solve the shortest path problem for the network with costs c_{ij} using Dijkstra's algorithm

Step 4: $x_{ij} = x_{ij} - V_k \forall$ (ij) that does not belong to the shortest path

2.5.2 Freight Flow Assignment Heuristics Implementation- Overview

The overall implementation process is summarized in Figure 4. The freight flow assignment problem involves the entire U.S. highway network, which is a computationally challenging problem. Hence, the implementation was divided into three stages as shown in Figure 4. The first stage, namely input data processing included data format conversion and data integrity check. The second stage included the implementation of the freight flow assignment heuristic. The third stage was on output data analysis, which included analysis and visualization of the results. In the remaining part of this section, these three stages will be explained in more detail.

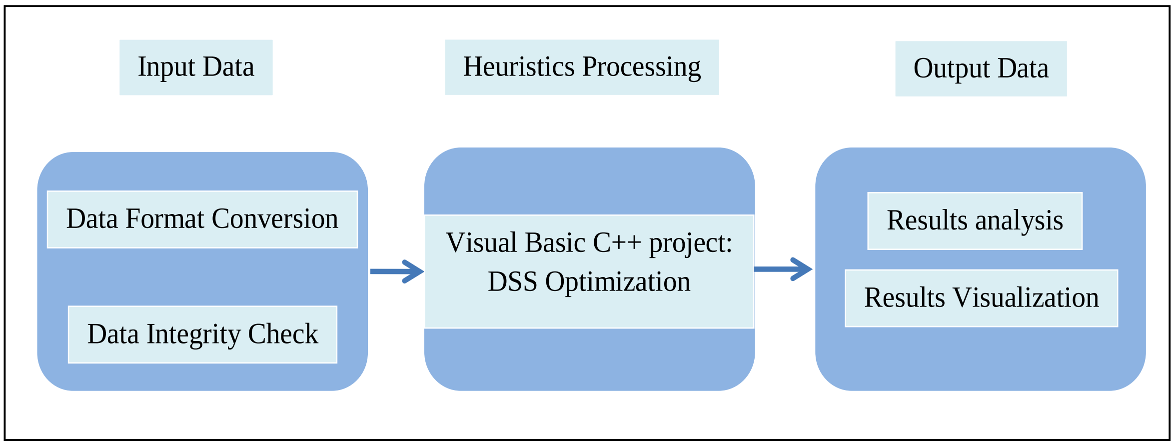


Figure 4: Implementation of Freight Flow Assignment Heuristic

2.5.3 Freight Flow Assignment Heuristics Implementation- Input Data Processing

Input data includes data about the U.S. highway network structure and O-D flow information. The highway network information was generated based on the FAF2 database [5]. O-D flow information was generated from the previous steps coded in the OD flow generation module. Figure 5 shows the details of the input data processing stage, which involves converting the FAF2 network into a directed network and performing the necessary integrity checks.

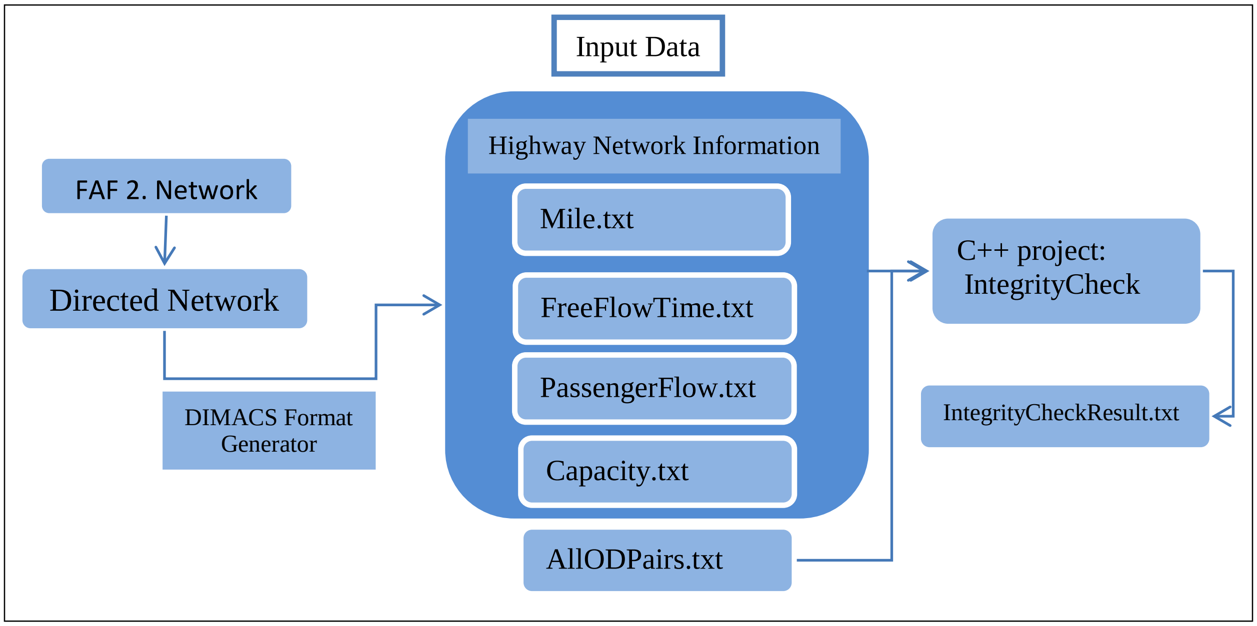


Figure 5: Input Data Processing

Data preparation started with the FAF 2.2 database; the data dictionary shown in Table 3 gives the names, definitions and data types of the variables stored in the FAF 2.2 database [5].

Table 3: FAF 2.2 Data Dictionary [5]

ID	Integer	Unique identification number
VERSION	Character	Used for maintaining consistency across data files containing alternate releases of the FAF.
AADT02	Integer	HPMS annual average daily traffic for year 2002
AADTT02	Integer	Year 2002 truck volume based on HPMS average truck percentage
FAF02	Integer	FAF 2.2 truck flow based on freight demand model and FAF 2.2 O-D database.
NONFAF02	Integer	Local truck traffic that is not part of FAF 2.2 flow
AADT35	Integer	Annual average HPMS daily traffic. Estimated using the HPMS traffic growth factor
AADTT35	Integer	Year 2035 truck volume based on HPMS average truck percentage and traffic growth
FAF35	Integer	FAF 2.2 truck flow based on freight demand model and FAF 2.2 O-D database
NONFAF35	Integer	Local truck traffic that is not part of FAF 2.2 flow
CAP02	Integer	Estimated capacity using HCM 2000 methodology
SF02	Real	Service flow volume/hour
VCR02	Real	2002 volume to capacity ratio
SPEED02	Real	2002 congested speed miles/hour
DELAY02	Real	2002 link delays in hour
CAP35	Integer	Estimated capacity using HCM 2000 methodology
SF35	Real	Service flow volume/hour
VCR35	Real	2035 volume to capacity ratio
SPEED35	Real	2035 congested speed miles/hour
DELAY35	Real	2035 link delays in hour

According to the data dictionary shown in Table 3, AADT02 is the total flow on each link in 2002 and AADTT02 is the total truck flow on each link in 2002. Based on our investigation [5] the units of attributes, which are of interest to the project, are summarized in Table 4. The length of links in miles and the speed limit of links in miles/hour were extracted from TransCAD FAF2 network [1].

Table 4: Units of Attributes in FAF 2.2

AADT02	Volume/day/link
AADTT02	Volume/day/link
CAP02	Volume/hour/link

Using the data gathered, a network database was created for use in the freight flow assignment step. Specifically, link capacity, link annual passenger flow, link free flow time, and the length of each link were of interest in this project. The undirected FAF2.2 network was converted to a directed network by replacing an undirected link between a pair of nodes by two directed links. In addition, the following requirements/constraints/assumptions were needed to ensure that the conversion process was successful.

- For node pairs with multiple (direct) arcs in the FAF2.2 network (e.g. a highway segment and a parallel service road segment), the arc with the largest capacity was retained and then replaced with two directed arcs.
- The annual capacity and annual passenger flow in a directed link are assumed to be half of those in corresponding undirected link.
- All U turns in the undirected network are discarded while constructing the directed network.
- All directed links in FAF2.2 are included in the directed network without any modification.

Table 5 shows the details of the link attributes in the directed network. It shows how the values of these attributes were derived from the data in the FAF2.2 database and also shows their units in the directed network database.

Table 5: Link Attributes in the Directed Network

Network Link Attributes	Calculation	Unit
PassengerFlow	Max{AADT02-AADTT02, 0} * 365 / 2	Volume/year/link
FreeFlowTime	Miles/ Speedlimit	Hour/link
Capacity	Cap02 * 24 * 365 / 2	Volume/year/link
Miles	miles	Miles/link

The directed network database includes 341,412 records, one for each of the 341,412 arcs in the network constructed. The total number of nodes in the directed network was 135,594. Table 6 shows the first 20 records in the directed network database. Each record shows the starting and ending nodes of the link, the link ID and values of the link attributes.

Table 6: Partial Data in the Directed Network Database

Start ID	End ID	ID	PassengerFlow365	CAP365	FFTIME	MILES
1988	1989	2353	276488	11576328	0.0173	1.0387
1989	1988	2353	276488	11576328	0.0173	1.0387
1990	1991	2354	86688	5983080	0.0361	2.1671
1991	1990	2354	86688	5983080	0.0361	2.1671
1992	1988	2355	293460	11576328	0.0725	4.3520
1988	1992	2355	293460	11576328	0.0725	4.3520
1993	1994	2356	78840	5829768	0.4281	25.6863
1994	1993	2356	78840	5829768	0.4281	25.6863
1991	1995	2357	125378	11817240	0.3589	17.9433
1995	1991	2357	125378	11817240	0.3589	17.9433
1996	1992	2358	219912	10976280	0.0238	1.4250
1992	1996	2358	219912	10976280	0.0238	1.4250
1997	1998	2359	187610	11755920	0.0213	1.2772
1998	1997	2359	187610	11755920	0.0213	1.2772
1999	2000	2360	114975	8155560	0.2147	12.8819
2000	1999	2360	114975	8155560	0.2147	12.8819
2001	1998	2361	231775	10971888	0.1652	9.9125
1998	2001	2361	231775	10971888	0.1652	9.9125
2002	2003	2362	193450	10735368	0.2234	13.4021
2003	2002	2362	193450	10735368	0.2234	13.4021
2003	2004	2363	179032	4940640	0.1064	6.3863

To facilitate the efficient implementation of the shortest path algorithm in the flow assignment heuristic, the network data had to be converted into the DIMACS format. The DIMACS format is widely accepted as the standard format for graph/network problems [6]. An input file in the DIMACS format usually includes the following three parts.

- **Comment line**. E.g.: **c** this is a comment;
- **Problem line**. The problem line is unique and must appear as the first non-comment line. E.g.: **p** max *n m;*
- **Arc descriptors.** E.g.: **a** SRC DST CAP/FLOW/COST.

A converter was coded in Visual Basic to convert the directed network data into the DIMACS format.

The DIMACS format converter produced the following four network input files for the heuristics implementation program.

- Capacity.txt
- FreeFlowTime.txt
- PassengerFlow.txt
- Mile.txt

These four files plus the O-D flow information constituted the input needed for the assignment flow heuristic algorithm. One final check had to be performed to guarantee that the directed network constructed was a simple network and that all entries such as capacity, passenger flow, free flow time and miles were nonnegative. A program in C++ named "IntegrityCheck" was developed to conduct the following tasks.

- Check for negative O-D flow, negative capacity, negative passenger flow, negative free flow time (to eliminated the possibility of negative cycles);
- Check for multiple or duplicate arcs between a single pair of nodes to make sure that the network is simple.

The input files for the IntegrityCheck program are the input files that have been prepared for the program implementing the assignment heuristic.

2.5.4 Freight Flow Assignment Heuristics Implementation – Heuristic Implementation

In the flow assignment heuristic algorithm, the critical step is step 3, which requires solving a shortest path problem on a large-scale network with 135,594 nodes and 341,412 directed arcs. Based on O-D flow information from the freight flow generation step, it was noted that there were 34,400 OD pairs in total. This means the shortest path algorithm had to be executed on a large-scale network, 34,400 times. Such a task is computationally expensive in both run time and storage space. To accomplish this challenging task, the team took advantage of Dijkstra's shortest path program available in the Boost Graph Library (BGL) [6].

The BGL function library provides a comprehensive graph algorithm framework. It includes program code for solving standard graph problems like the shortest path problem, maximum flow problem, and minimum spanning tree problem. Besides, the BGL is written in ANSI Standard C++ and compiles with most C++ compilers.

In our implementation of the assignment heuristic, the C++ project "DSS Optimization" calls the Dijkstra's algorithm in BGL. As we were dealing with large-scale problems, we kept a record of the run time for each OD pair, especially the BGL run time. In this way, we could track the performance as well as the results from the BGL algorithm.

2.5.5 Freight Flow Assignment Heuristics Implementation - Output Analysis

A total of 6 output files are generated by the DSS Optimization project. These are AllLinkFinalFlow_TimeCost.csv; General Times.csv; Graph_with_Adj_List.csv; LinkODPath.csv; NodeODPath.csv; and TimeForAllTheODPairs.txt.
In this remainder of this subsection sample screenshots are provided to give the reader an idea of the final output that is generated.

AllLinkFinalFlow_TimeCost.csv

The "AllLinkFinalFlow_TimeCost.csv" output file mainly records the final truck flow and transit time of each arc in the highway network. Table 7 shows this output for a sample of 15 links.

Table 7: Sample Records in AllLinkFinalFlow_TimeCost.csv

Start	End	TotalFlow	FinalTransitTime
1988	1989	276488	0.017310001
1988	1992	293460	0.072530004
1989	1988	276488	0.017310001
1989	69017	205678	0.41352001
1990	1991	257905.8	0.036120019
1990	69153	744064.9	0.047270173
1991	1990	249854.9	0.036120016
1991	1995	125378	0.358870001
1991	2431	257539.8	0.084180045
1992	1988	293460	0.072530004
1992	1996	219912	0.023750001
1993	1994	78840	0.428110002
1993	2031	125195	0.594470001
1993	2616	105120	0.152230002

Graph_with_Adj_List.csv

"Graph_with_Adj_List.csv" output file shows the adjacent node list for each node in the directed network. Table 8 shows a sample of 12 nodes of this output file. The first column is the start node and the following columns are nodes that are adjacent to it. The adjacent node list is a very efficient graph descriptor used by the BGL.

Table 8: Sample Records in Graph_with_Adj_List.csv

Start	End		
1988	1989	1992	
1989	1988	69017	
1990	1991	69153	
1991	1990	1995	2431
1992	1988	1996	
1993	1994	2031	2616
1994	1993	69019	
1995	1991	2027	2430
1996	1992	2359	
1997	1998	2015	
1998	1997	2001	2359
1999	2000	2007	

NodeODPath.csv

The output file "NodeODPath.csv" contains the details of the shortest path chosen by the heuristic for each O-D pair. In Table 9 , "OD_ID" indicates the OD pair number; "ODPathTMiles" indicates the total distance between the corresponding origin and destination locations in miles; "ODPathTtimecost" indicates the total transit time cost for the corresponding O-D pair in hours; and the last column shows all the nodes on the shortest path for this O-D pair in the proper sequence. Only a partial node sequence is shown for each path in Table 9.

Table 9: Sample Records in NodeODPath.csv

OD_ID	ODPathTMiles	ODPathTtimecost	AllODPairs shortest paths: Nodes on shortest path in sequences of O to D						
1	306.098	4.94326	139527	139526	122085	125758	120120	120643	122361
2	80.9242	1.43327	139735	139734	56248	56249	60915	58903	58919
3	230.313	3.92156	139569	139568	22559	20687	20688	22662	26228
4	359.55	5.55392	139648	139647	101297	101296	101303	101309	101323
5	102.004	1.86284	139648	139647	101297	100257	100258	100277	103698
6	359.55	5.54762	139642	139641	101953	101945	101946	101989	101987
7	80.9242	1.42937	139733	139732	63913	63872	63873	65342	65344
8	105.047	1.71901	139654	139653	109307	109308	108493	108599	108322
9	248.581	4.11333	139604	139603	111713	112568	112567	112731	112184
10	313.652	5.37907	139569	139568	22559	20687	20688	22662	22663
11	104.151	1.74458	139539	139538	9408	8829	9407	10161	10163
12	49.5382	0.85179	139620	139619	93706	94406	94410	94408	94409
13	228.791	3.77669	139527	139526	122085	125758	120120	120643	122361
14	132.757	1.94896	139604	139603	111713	111714	111716	111711	111712
15	254.922	4.39716	139541	139540	119920	125062	127969	127971	127972
16	313.652	5.37027	139577	139576	17698	25695	18480	17697	17696
17	30.0244	0.577888	139711	139710	86171	86592	86597	86595	86594
18	82.479	1.38559	139652	139651	27167	28552	27001	26996	26995
19	157.607	2.46244	139696	139695	52130	52131	50386	50385	50384
20	391.324	6.2157	139616	139615	67379	67380	67505	67513	67510
21	37.8994	0.674515	139822	139821	42432	42431	42433	42503	42507

LinkODPath.csv

In the "LinkODPath.csv" output file, the data contained is similar to that in "NodeODPath.csv". The difference is that "NodeODPath.csv" shows the node-based path and "LinkODPath.csv" shows the path using links. As before, "ODPairID" refers to the O-D pair number; "start" refers to the source of a link on the corresponding path; "end" refers the sink of the same link;

“finalflow” and “finaltimecost” refer to final truck flow and final transit time on that link respectively. For rows with same “ODPairID”, they are sequentially arranged, containing information of arcs sequentially connecting the origin node to the destination node for the O-D pair. Table 10 shows sample records in the LinkODPath.csv output file. It shows data for the first few links that belong to the shortest path for O-D pair with ODPairID 1.

Table 10 : Sample Records in LinkODPath.csv

ODPairID	start	end	finalflow	finaltimecost
1	139527	139526	5237746	0.00525
1	139526	122085	5470798	0.047232
1	122085	125758	5491786	0.045503
1	125758	120120	5844011	0.265915
1	120120	120643	5920331	0.139431
1	120643	122361	6190066	0.020398
1	122361	130143	6397810	0.075009
1	130143	122362	6608963	0.002095
1	122362	122360	6608963	0.003474
1	122360	122359	7937015	0.02945
1	122359	125761	7937015	0.018866
1	125761	121719	9196265	0.032555
1	121719	122358	11211065	0.022941

General Times.csv

The output file “General Times.csv” records the following time measurements (all units are CPU seconds):

- Total time to read the graph data
- Total time to construct the graph (adjacent node list)
- Total time spend in heuristics step 1, initialization
- Total time to print each O-D pair solution time; namely file “TimeForAllTheODPairs.csv”
- Total time to print “AllLinkFinalFlow_TimeCost.csv ”
- Total time to print “LinkODPath.csv”
- Total time to print “NodeODPath.csv”

This output file generally records all the time measurements except for time spent solving for the shortest congested time for each O-D pair. Table 11 shows all data recorded in the output file "General Times.csv"

Table 11: Records in General Times.csv

TreadingGraph	TMakingGraph	Tinitialization	TPrintAdjacentLis	TPringAllODSOlving	TPrintAllLinkFinalFLow	TPrintLinkODPath	TPrintNodeODPath
48.017	29.656	15.069	2.527	1.591	13.619	1653.58	58.282

TimeForAllTheODPairs.csv

The output file "TimeForAllTheODPairs.csv" records the following time measurements for each O-D pair:

- Time for heuristic step 1
- Time for mapping the calculated time (cost) to the graph
- Time for solving the shortest path problem with Dijkstra's with mapped time (cost)
- Time to record the shortest O-D path
- Time for heuristic step 3

The average time for running each OD pair was 14 seconds.

Table 12: Sample Records in TimeForAllTheODPairs.csv

OD_ID	Time_H_Step1	Time_Mapping Cost	Time_Solving Dijkstra	Time_Recognizing Path	Time_HStep3
1	3.464	6.645	4.368	0	0
2	3.495	6.63	4.399	0	0
3	3.572	6.63	4.368	0	0
4	3.479	6.692	4.384	0.015	0
5	3.495	6.567	4.43	0	0
6	3.479	6.49	4.43	0	0
7	3.479	6.599	4.29	0	0
8	3.51	6.646	4.461	0	0
9	3.479	6.599	4.43	0	0
10	3.478	6.615	4.477	0	0
11	3.448	6.661	4.446	0	0
12	3.463	6.802	4.446	0	0.015
13	3.495	6.583	4.431	0	0
14	3.588	6.723	4.383	0	0
15	3.51	6.568	4.4	0	0
16	3.541	6.615	4.337	0.015	0
17	3.588	6.724	4.493	0	0

AllLinkFinalFlow_TimeCost.csv

The end goal of the assignment heuristic is to assign freight flows to links in the US Highway network. The output file "AllLinkFinalFlow_TimeCost.csv" records the freight flow for each link in the simple directed network that was constructed for the flow assignment heuristic. We need to further map these freight flows back to the original FAF2.2 highway network. This completes the freight flow assignment step of the FMM methodology.

3 Supply Chain Network Design

The DSS also implements a novel approach for the design of supply chain networks. This implementation brought together research conducted at OSU on supply chain design and the results of the FMM effort. The congested travel times on the highway segments provided by the FMM model were used to obtain more realistic transportation costs and times and served as an input to the supply chain optimizer module. In addition, the shortest-time paths from the FMM model were used to define a simplified logistical network for the supply chain optimizer. In this section, we show the connections between the Supply Chain Network Design (SCND) module and the other modules within the DSS environment by showing the execution sequence and then providing the implementation details of the various steps involved. The section ends with an overview of the supply chain optimization model implemented in the SCND module.

3.1 Supply Chain Network Design (SCND) Module and its Interactions

The SCND module implements the supply chain optimization model, but has interactions with other parts of the DSS as shown in Figure 6. The interactions are facilitated through a database developed using MS Access. The complete execution sequence is shown in Figure 6 and is explained in detail below.

3.1.1 Execution Sequence

1. A user downloads an input template hosted on the DSS website under the "Supply Chain Network Design" option. The template is a spreadsheet file, and its structure and format details will be explained later in the "Inputs and Outputs" sub-section. Once the user completes the input template, he/she submits the file to the DSS website.
2. The data in the input template is linked to tables in the Microsoft Access database. The database executes the embedded VBA code to manipulate the user-given input data to implicitly build the supply chain network of the user. By "implicitly build the supply chain network", we mean the code reads the user supply chain input data, and specifies the locations of facilities, the legitimate supply-demand links between facilities, customer demand, cost structure, etc. thereby forming the supply chain network of the user.
3. The database then calls the embedded VBA code to create a text file consisting of every legitimate O-D pair in DIMACS format where the head and tail ID numbers are the

TRANSCAD ID numbers. This O-D pair text file is then sent to the FMM directory where the executable file of FMM code resides.

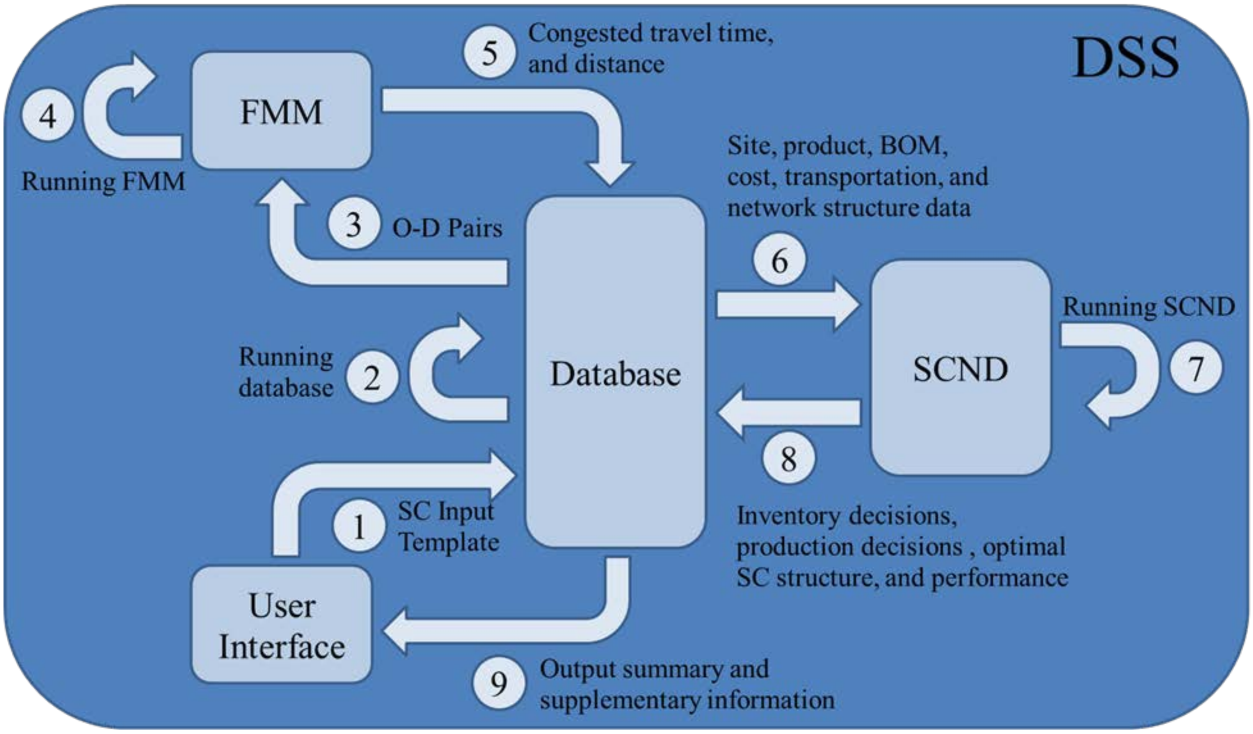


Figure 6: Interaction Diagram Showing the Implementation of the SCND Module

4. The database consequently runs the VBA code to run the FMM model with the O-D pair text file generated in Step 3. This step automatically starts upon the completion of the O-D pair file creation, and waits for the run to finish before processing the next line of code. This execution of the FMM flow assignment model uses the highway network preloaded with passenger and freight flows to compute the shortest congested travel-time path for every O-D pair in the supply chain network.
5. After the FMM execution is completed it determines the congested travel time and distance between origin and destination locations for every O-D pair that is specified in the O-D pair text file. The solutions are stored in a .csv file, which is automatically linked to the linked table in the Access database.
6. The database processes the FMM solutions in the linked table, changing time unit from hour to day, and creating the table for supply chain transportation information, i.e., transit times and distances of all valid O-D pairs in the supply chain of the user. The database then runs the VBA code to generate all the input files of the SCND module, which are

text files containing the data regarding facilities, products, bill of materials (BOM), costs, transportation, and network structure. All the files are located in the directory where the executable file of the SCND code resides in.

7. The database executes the VBA code to run the SCND in FICO Xpress-MP (optimization software) to determine the optimal location of the facilities and other related production and distribution decisions. The outputs of the model include the inventory and production decisions, optimal supply chain configuration, and optimal costs. The corresponding text files for outputs are created.
8. The database runs SQL statements to import the output from the text files into the designated tables in the database. These outputs can be seen by the modeler or shown to the user from the output buttons in the execution window.
9. The supply chain outputs and the supplementary information are put together in a spreadsheet. This spreadsheet will then be uploaded onto the DSS webpage or sent directly to the user. We will describe this spreadsheet in detail in the sub-section on "Inputs and Outputs".

3.2 Online and Offline Tasks

An online task is a task that is initiated and completed by the user via the real-time interaction with the DSS web page. Whereas an offline task is a task that is completed at a different time by a modeler/researcher using the information provided by the user to do analysis or to test the performance at the backend and then to provide the results to the user when they are available. The online and offline tasks with respect to the sequential operation of SCND module can be categorized as shown below.

Online tasks

Tasks described in steps #1 and #9 are online tasks in which the user interacts with the DSS web page by downloading the supply chain input template, uploading the completed template, and again retrieving the output summary and supplementary information.

Offline tasks

Tasks described in steps #2 through #8 are offline tasks. These steps do not require interaction between the user (professional/decision-maker) and the DSS web page. However, they will most likely require a modeler/researcher to interact with parts of the DSS web page that are not accessible to the user. These tasks are implemented in an automated fashion requiring the click of the execution button in the execution window. This button executes embedded VBA code and SQL statements.

3.3 Inputs and Outputs

3.3.1 SCND Input Template

The input template of the supply chain network design model is a spreadsheet with six worksheets in it. Each of the worksheets contains a specific kind of information, which when combined defines the supply chain network of the user and provides the necessary inputs for the supply chain optimization model.

The first worksheet, called CUSTOMERSITES, contains information about the facilities. This information includes the zip code, location type, fixed cost, maximum capacity and minimum capacity of every facility in the supply chain. A sample of the CUSTOMERSITES worksheet is shown in Table 13.

Table 13: Sample records in CUSTOMERSITES Worksheet

MAIN_ID	ZIPCODE	LOCATION_TYPE	FIXED_COST	MAX_CAPACITY	MIN_CAPACITY
6	14201	M	300000	999999999	0
3	19019	D	250000	999999999	0
7	21201	S	300000	999999999	0
2	27601	C	0	0	0
9	35201	S	400000	999999999	0
4	46201	D	200000	999999999	0

The second worksheet called PRODUCTINFO contains product-specific information. This information includes the days-of-inventory, inventory carrying rate, product weight, and product value of every product in the supply chain. The information in this worksheet need not only be product-specific, but can also be site-specific. Table 14 shows a sample of the PRODUCTINFO worksheet.

Table 14: Sample records in PRODUCTINFO Worksheet

PRODUCT	DESCRIPTION	SITE	DAYS	ICCRATE	PRODUCTWEIGHT	PRODUCTVALUE
1	PRODUCT1	1	0	0.12	200	600
1	PRODUCT1	10	0	0.12	200	600
1	PRODUCT1	2	0	0.12	200	600
1	PRODUCT1	3	21	0.12	200	600
1	PRODUCT1	4	21	0.12	200	600
1	PRODUCT1	5	21	0.12	200	600
1	PRODUCT1	6	21	0.12	200	600
1	PRODUCT1	7	0	0.12	200	600
1	PRODUCT1	8	0	0.12	200	600
1	PRODUCT1	9	0	0.12	200	600
2	PRODUCT2	1	0	0.12	220	800
2	PRODUCT2	10	0	0.12	220	800

The third worksheet called BOMINFO contains the bill of materials (BOM) information. This information shows the relationship between the parent and child products, which specifically tells how many units of the child product is needed to produce one unit of a parent product. This BOM information can be site-specific as well. Table 15 shows a sample of the BOMINFO worksheet and shows partial BOM information.

Table 15: Sample Records in BOMINFO Worksheet

SITE	PARENT	CHILD	BOM
5	1	6	3
6	1	6	3
5	1	5	2
5	2	3	2
5	2	5	2
6	1	5	2

The fourth worksheet called ROUTES contains information about links between facilities. It shows legitimate links between two facilities with a specific product for every pair of facilities and products defined in the supply chain network of the user. Specifically, if the link with a product is provided in this worksheet then the link with the product is established in the supply chain. Table 16 is a sample of the ROUTES worksheet and shows a few links in an example supply chain.

Table 16: Sample records in ROUTES Worksheet

FROM	TO	PRODUCT
3	1	1
3	1	2
3	2	1
3	2	2
4	1	1
4	1	2

The fifth worksheet called VARCOSTS contains the variable cost information. Variable cost is defined as unit cost incurred for a specific product that is assembled or handled at a specific site. Table 17 shows a sample of the VARCOSTS worksheet and shows the unit costs for a few products at various sites.

Table 17: Sample records in VARCOSTS Worksheet

SITE	PRODUCT	VARCOST
3	1	600
4	2	600
4	1	500
3	2	400
5	3	300
2	1	200

The last worksheet called PRODDEMAND contains the demand information. This information basically shows the customer demand for the final products at the various customer sites. Table 18 shows a sample of the PRODDEMAND worksheet.

Table 18: Sample records in PRODDEMAND Worksheet

SITE	PRODUCT	DEMAND
1	1	25000
1	2	20000
2	1	25000
2	2	20000

3.3.2 SCND Output Summary and Supplementary Information

The output summary and supplementary information file is a spreadsheet, which will be available to the user at the end of the supply chain network design process. The spreadsheet consists of five worksheets, which contain the solutions to the supply chain network design problem as well as additional information such as transportation information obtained by FMM execution.

The first worksheet called COSTS shows the costs incurred in the optimal supply chain network configuration. These costs include the optimal total cost and other supply chain and logistics related costs that are considered in the model, namely fixed cost, variable cost, transportation cost, in-transit inventory cost and inventory carrying cost. Table 19 shows a sample of the COSTS worksheet and shows sample values of the above-mentioned cost elements.

Table 19: Sample records in COSTS Worksheet

Field 1
Costs:
Overall Total Cost = $4.2904e + 007
Total Fixed Cost = $750000
Total Variable Cost = $4.1e + 007
Total Transporation Cost = $710970
Total In-Transit Inventory Cost = $14937
Total Inventory Carrying Cost = $428055

The second worksheet called OPENSITES indicates the locations and types of sites, except customer sites, that are selected by the optimizer to be open for the optimal configuration.

Table 20 shows a sample of the OPENSITES worksheet that contains sample site information.

Table 20: Sample records in OPENSITES Worksheet

SiteLocation	Type
PHILADELPHIA, PA	DISTRIBUTION_CENTER
INDIANAPOLIS, IN	DISTRIBUTION_CENTER
BUFFALO, NY	MANUFACTURER

The third worksheet called CUSMETDEMAND presents the production amount or the amount of the final product demand met at the customer sites, and the open sites serving that customer demand. Table 21 shows a sample of the CUSMETDEMAND worksheet that displays data for two customer locations.

Table 21: Sample records in CUSMETDEMAND Worksheet

ProductionSite	CustomerLocation	Product	Production
INDIANAPOLIS, IN	RALEIGH, NC	2	20000
INDIANAPOLIS, IN	SPRINGDALE, AR	2	20000
PHILADELPHIA, PA	RALEIGH, NC	1	25000
PHILADELPHIA, PA	SPRINGDALE, AR	1	25000

The fourth worksheet called MFGPRODUCTION summarizes the production quantity of the products at open manufacturing sites, and the destinations that each open site supplies products to. Table 22 shows a sample of the MFGPRODUCTION worksheet that displays sample data for one manufacturing site and its 2 destination sites.

Table 22: Sample records in MFGPRODUCTION Worksheet

Site	Customer	Product	Production
BUFFALO, NY	INDIANAPOLIS, IN	2	40000
BUFFALO, NY	PHILADELPHIA, PA	1	50000

The last worksheet called TRANSINFO contains the transportation data, which is the output of the FMM execution step. This data consists of transit times (in days) and distances for all O-D pairs specified in the supply chain of the user. This transportation information, which is an input to the SCND optimization model, takes into account not only the travel distance, but also the transit time that captures the congestion effect of the flows on the route chosen by FMM for each O-D pair. Table 23 shows a sample of the TRANSINFO worksheet and shows the transit time and distance for several sample O-D pairs.

Table 23: Sample records in TRANSINFO Worksheet

OriginID	DestID	OriginLoc	DestLoc	TransitTime	Distance
10	5	BALTIMORE, MD	HOUSTON, TX	0.897554	1425.16
10	6	BALTIMORE, MD	BUFFALO, NY	0.250179	365.394
3	1	INDIANAPOLIS, IN	SPRINGDALE, AR	0.361289	566.582
3	2	INDIANAPOLIS, IN	RALEIGH, NC	0.414563	620.017
4	1	PHILADELPHIA, PA	SPRINGDALE, AR	0.769662	1207.48
4	2	PHILADELPHIA, PA	RALEIGH, NC	0.281114	401.816
5	1	HOUSTON, TX	SPRINGDALE, AR	0.367269	519.355
5	2	HOUSTON, TX	RALEIGH, NC	0.758316	1173.17
5	3	HOUSTON, TX	INDIANAPOLIS, IN	0.651654	1011.34
5	4	HOUSTON, TX	PHILADELPHIA, PA	0.972675	1526.76
6	1	BUFFALO, NY	SPRINGDALE, AR	0.68057	1064.45
6	2	BUFFALO, NY	RALEIGH, NC	0.417075	594.868
6	3	BUFFALO, NY	INDIANAPOLIS, IN	0.319282	497.87
6	4	BUFFALO, NY	PHILADELPHIA, PA	0.240002	350.327
7	5	LOS ANGELES, CA	HOUSTON, TX	0.974608	1549.6
7	6	LOS ANGELES, CA	BUFFALO, NY	1.580687	2543.93
8	5	RIVERDALE, IL	HOUSTON, TX	0.691058	1070.8
8	6	RIVERDALE, IL	BUFFALO, NY	0.343665	535.011
9	5	BIRMINGHAM, AL	HOUSTON, TX	0.411376	652.959
9	6	BIRMINGHAM, AL	BUFFALO, NY	0.577179	900.595

3.4 Overview of the Supply Chain Optimization Model

3.4.1 Problem Statement

The supply chain optimization problem considered in the DSS is the problem of determining the supply chain network structure that would minimize the total cost of operating the supply chain while ensuring that customer demand for final products is satisfied. In this model, the supply chain operations are considered at an aggregate level and hence only one time period is considered. The model considers production, distribution and demand of products on an annual basis. Examples of the decisions that need to made are

- Whether a manufacturing/distribution site should be open or closed?
- Which transportation mode to use, if a choice exists?
- Which manufacturing site(s) should produce a product and which distribution/customer sites should be supplied?

- Which supplier should supply the raw materials?
- How much inventory should to be stored at a facility?

Supply chain optimization involves multiple sites, which can be grouped broadly into four types, namely, suppliers, manufacturers, distribution centers and customers. A product *p* is manufactured at manufacturing site *i*. The product *p* is either stored at distribution center *d* or directly delivered to the customer site *c*. The annual demand for final product *p* at customer site *c* is known. Each product will have a corresponding unit value *v* and weight *w*. The distribution center *d* for final product *p* can be supplied by more than one manufacturing site *i*. The supplier site *s* provides raw material *r* to the manufacturing site *i* to produce the product *p* according to the bill of materials.

For each of the "supply" links involving the supplier site, manufacturing site, distribution center site, or customer, the existence of a viable transportation option is specified by the user. If a link exists, there could be multiple transportation modes for that link with mode-specific transit time and cost. For the DSS implementation, we assumed that the transportation uses the Full-Truck-Load (FTL) transportation mode, and the basis for transportation cost is the travel distance. Therefore, the input parameters for calculating transportation cost will be $/truck-mile and weight (pounds)/truck.

The manufacturing sites can have inventory for raw materials, but cannot have inventory for the final product. The inventory level in days at manufacturing sites for raw material is specified, and the manufacturing site incurs the inventory holding cost for storing raw material. Similarly, the inventory level in days is specified for the final product stored at a distribution center. The manufacturing sites and distribution centers have two types of inventory cost: site inventory holding cost and in-transit inventory holding cost. Specifically, a site inventory unit is derived from a corresponding inventory in days; an in-transit inventory unit is derived from a corresponding transportation time. There is no inventory decision to be made for the supplier sites, but they can influence other decisions in the model.

Other than a customer site, every site can be open or closed. If it is open, the site incurs fixed cost, and depending on the volume produced, the corresponding variable cost is also incurred. For each non-customer site, the total production volume considering all products are constrained by production capacity, i.e., the production capacity is specified at the aggregate level; a unit of every product equivalently consumes a unit of capacity. The production volume is also constrained by minimum capacity (i.e., the minimum production volume) for each of the sites excluding the customer site.

3.4.2 Linkage between Supply Chain Optimization Model and Freight Movement Model

Origin-Destination (O-D) pairs defined by the user serve as inputs to the FMM freight assignment model as shown in Figure 6. A US Highway network structure with passenger and truck flows assigned to the highway links is readily available as a result of the FMM model execution. For each O-D pair specified by the user, Dijkstra's algorithm is used to determine the shortest congested travel time path on the US Highway network. The transit time and distance obtained for each O-D pair from the FMM model are used as inputs to the supply chain model to establish transit times and distances between facilities. Transit times and distances are defined between suppliers and manufacturers, manufacturers and distribution centers or end customers, between distribution centers and end customers, and between any other pertinent locations.

The freight assignment output includes shortest congested travel time routes for each origin and destination pair. Each shortest path consists of nodes and links that are part of the highway network. Links are specific highway network arcs along an O-D path and nodes are the link endpoints. Each link has two nodes (i.e. a start node and an end node). A link is a portion of a highway used to transport goods. For example, a link could be a 5-mile portion on a highway from one on-ramp to the next on-ramp or could be a 0.5-mile highway section between two cross streets. There are potentially many links between each origin and destination location along a path. The FMM freight assignment output is in the form of a flat text file, which is imported and stored in a Microsoft Access application that houses the supply chain model.

4 Design of a Switchgrass Supply Chain

The DSS project also included a case study on the design of a biomass supply chain for switchgrass in western Oklahoma and southwestern Kansas. The basic supply chain model was extended to include the effect of weather patterns on the allocation and use of land and mechanical resources for a biomass supply chain by employing a scenario optimization approach. The material contained in this section was an integral part of a doctoral dissertation that was completed at OSU [7].

4.1 Biomass Supply Chain

Increasing demand and dependence in the U.S. on foreign oil has focused the attention of researchers in exploring new alternative energy sources [8]. Advanced biofuels from herbaceous energy crops (switchgrass, miscanthus etc.), agricultural residue (corn stover, wheat straw etc.), and waste material (vegetative, animal, food, yard waste etc.) are recognized as the future renewable energy sources [9]. The lignocellulosic biomass has significant potential for the growing ethanol industry by supplying large quantities of less expensive and high yield raw material [10]. The Energy Independence and Security Act (EISA) of 2007 amended and increased the Renewable Fuel Standard (RFS), to achieve the goal of 36 billion gallons per year of renewable fuel by 2022. The conventional biofuels will contribute about 15 billion gallons of ethanol per year and the remaining 21 billion gallons will be derived from advanced biofuels [11]. The major barrier preventing the commercialization of lignocelluloses bio refineries is the complex conversion process of biomass to biofuel and the lignocellulosic biomass supply chain.

The biomass supply chain consists of several distinct operations categorized as production processes (harvesting, baling, and pre-processing) and logistical processes (storage, transportation, and transshipment) as illustrated in Figure 7. The doctoral dissertation [7] study developed a scenario optimization model for a biomass supply chain with an objective of minimizing supply chain cost subject to local and regional conditions. A case study based on the Abengoa Bioenergy Biomass of Kansas (ABBK) at Hugoton, Kansas was developed.

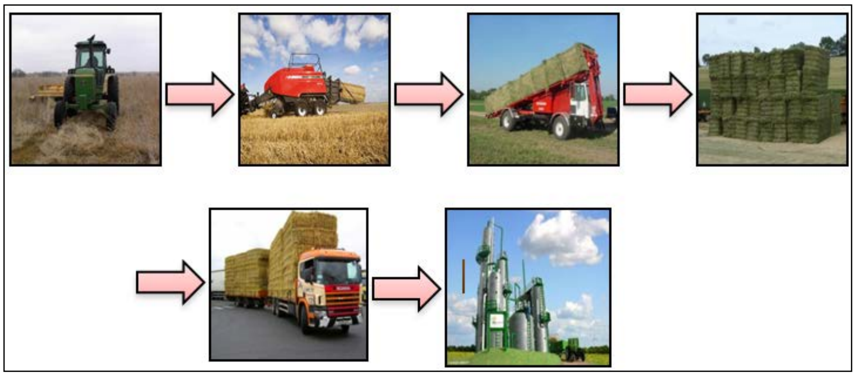


Figure 7: Biomass Supply Chain: Production and Logistical Processes

One of the major issues preventing the commercialization of lignocellulosic bio refineries is the lack of infrastructure required for on-time, cost-effective and continuous delivery of large volumes of dense biomass to the bio refinery. It is estimated that biomass supply accounts for 20-35% of the ethanol production cost and 90% of the biomass supply cost is the associated with logistics processes [7]. Weather uncertainty is also one of the major factors affecting the constant supply of biomass to bio refinery. The growing biofuels industry also poses a new challenge to the existing road infrastructure. To meet the bioenergy targets, the production of biomass and cellulosic ethanol is expected to increase drastically. This will result in net addition to the traffic of low-energy density biomass on the highway network. For example, the operation of ABBK bio refinery will increase the traffic congestion with approximately 200 trucks moving per day to meet the daily demand. This increase in congestion could result in an increase in the transportation cost and create community resistance, which in turn might affect crucial bio refinery decisions. In the past, the biomass supply chain models developed by researchers have not considered the roadway congestion. Therefore, it is important to design and develop a biomass supply chain, which can effectively manage and coordinate all processes resulting in a reliable and cost effective system beneficial to the farmer as well as the bio refinery while minimizing any negative impact on the environment and the local population.

4.2 A Scenario Optimization Model

The study developed a comprehensive mathematical model, which incorporates material flow decisions, number of harvest units, and number of transportation units along with traffic congestion impact of the biomass supply chain [7]. Scenario optimization technique is a natural, convenient way to deal with uncertainties [7]. A deterministic model with different weather scenarios that take into consideration before and after frost harvesting was developed. The bio refinery can use different lignocellulosic biomass feedstock such as wood, agricultural residues and herbaceous crops for ethanol production. Different biomass feedstocks have different physical characteristics; harvesting, handling and storage techniques; and different costs associated with each operation. Considering a specific biomass feedstock will not only limit the number of assumptions but also provide realistic estimates on cost. The case study took into consideration different harvest, collection and storage options for lignocellulosic biomass feedstock, switchgrass. Switchgrass is a bioenergy crop, which can be harvested for eight months from July to February of the following year. Thus switchgrass can satisfy the yearly demand of bio refinery with some storage. The model was tested for Abengoa Bioenergy Biomass of Kansas (ABBK), located at Hugoton, Kansas, which intends to run at 100% switchgrass in the future. The scenario optimization model developed maximizes profit subject to local and regional conditions. The model included 7 biomass supply counties and 4 inventory sites. Switchgrass supply counties were adjacent counties within a 50-mile radius. The constraints in the model were land, biomass availability, capacity of harvesting and transportation units, balance constraint at bio refinery, biomass supply counties and bio refinery capacity constraints, etc. The objective was to deliver biomass to the bio refinery in a way that maximized the profit considering harvest, transportation, and storage costs. The model decisions included the following:

- Biomass harvesting schedule and amount harvested at each biomass source site
- Number of harvest units allocated and required
- Number of transportation units
- Number of in-field transportation units
- Amount stored at each inventory site
- Amount of biomass transported from source site to bio refinery site

- Amount of biomass transported from source site to inventory site
- Amount of biomass transported from inventory site to bio refinery site
- Storage treatment selected for biomass

Figure 8 illustrates the structure of the scenario optimization model in a graphical format. It shows concepts such as switchgrass source sites, before and after frost scenarios, and transportation to intermediate and storage sites.

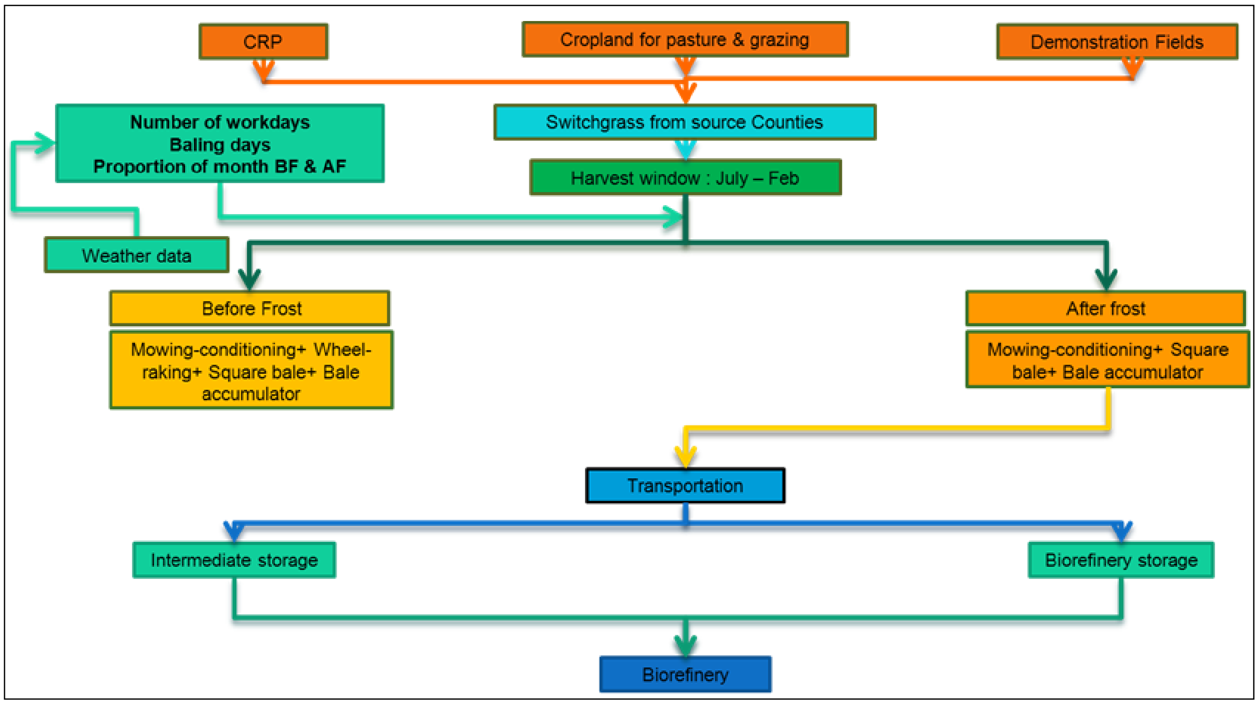


Figure 8: Schematic Showing Scenario Optimization Model Structure and Inputs

4.2.1 Model Constraints

Supply Constraints

These constraints considered the tons of biomass available, biomass harvested, and transported for each weather scenario and time period. The total acres of biomass harvested must not exceed the total acres contracted for biomass cultivation in each source site, weather scenario and time period. The total tonnage procured by the bio refinery is equal to the acres of biomass harvested multiplied by the yield and yield adjustment factor. The yield adjustment factor varies between 0 and 1, and adjusts the change in yield of biomass with harvest time periods.

The storage of biomass at the harvesting sites or biomass source sites was not considered as it was assumed that farmers will not be willing to allocate their land for storing biomass. Since the biomass source sites were not considered for storing biomass, the total biomass harvested at the source site was equal to the biomass transported to the inventory sites and biomass transported to the bio refinery site in each time period and weather scenario. The quantity of biomass supplied to the bio refinery site from inventory site was equal to the biomass stored at the inventory site less any storage losses at each time period and weather scenario.

Demand constraints

The quantity of biomass transported from all source sites and inventory sites to the bio refinery site in each time period must satisfy the demand of the bio refinery. Considering unmet demand for weather scenarios was permitted.

Capacity constraints

The total quantity of biomass harvested at the source site was constrained by the harvest work hours available and the capacity of the harvest units. The total number of harvest units after frost was equal to the number of harvest units used during the before frost period along with additional units required to handle the heavier demands of added acreage for after frost harvesting.

4.2.2 FMM and Biomass Supply Chain Model Linkage

As explained in Section 3, congested transit times and distances for each O-D pair and shortest path routes between each origin and destination based on congested transit times are outputs of the FMM model. These were used as input in the biomass supply chain model and provide transit times and distances between facilities. Transit times and distances are defined between bio refinery site and inventory site, harvest site and inventory site, and harvest site and bio refinery site.

The scenario optimization approach allows us to solve the supply chain design problem under probabilistic conditions such as weather. The model developed assisted in deciding the assets that needed to be purchased and deployed to cope with a highly seasonal production situation. The model also took into account congested travel time on links, which provided a better estimate of the transportation cost.

The scenario optimization model was tested for Abengoa Bioenergy Biomass of Kansas, LLC (ABBK), at Hugoton, Kansas (see Figure 9). The model provided a better understanding of the real world situation and can be applied to other bio refinery and lignocellulosic biomass types with modification to the local and regional constraints.

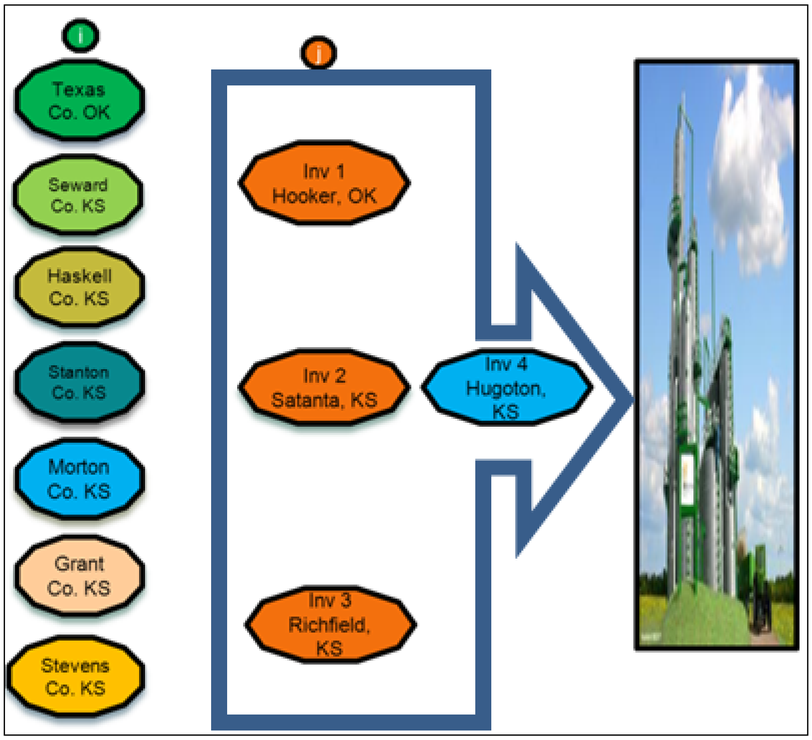


Figure 9: Switchgrass Supply Chain for Abengoa Bioenergy Biomass of Kansas (ABBK) Bio Refinery at Hugoton, Kansas

5 TISCSoft – A Web-based Decision Support System (DSS)

A decision support system (DSS) was built around the FMM and supply chain design models in order to facilitate critical decisions related to transportation infrastructure planning in the public sector and supply chain system planning in the private sector. The original version of the DSS was developed for a workstation environment. The research team then switched to a web-based DSS called "TISCSoft" to make the results of several years of research available to users in a convenient on-demand format, while providing the researchers a mechanism to keep the models and results current. The functionalities of the DSS have been incorporated into the web-based interface of TISCSoft using Microsoft Visual Studio 2005 as the implementation platform. This section provides an overview of TISCSoft and briefly describes its main functionalities and interfaces.

5.1 TISCSoft Home Page

The TISCSoft home page shown in Figure 10 is the main interface that leads to all functionalities of the DSS and has been designed to give the main page the look and feel of a typical web-based software interface. The page introduces the DSS software and has links to other parts of the DSS and external web sites through menus on the left and right panes.

The top part of the left pane of the home page contains a standard group of links, namely, *Home*, *About TISCSoft*, *Resources*, and *Contact Us*. The middle part of the left pane contains a group of three links that provide secure access to the various functionalities and features of the DSS to different user groups; these are *Research Team Login*, *Planner/Designer Login* and *Student Login*. The bottom part of the left pane contains links to web sites of agencies that provided primary funding for the research conducted in this project; they are *Oklahoma Transportation Center* and *Research and Innovative Technology Administration*.

The top part of the right pane lists links to key web sites that were sources for technical knowledge as well as data for the research conducted in this project; they are *National Transportation Atlas Database*, *Commodity Flow Survey*, and *Freight Analysis Framework*. The bottom part of the right pane lists links to centers/agencies that provided matching or supplemental funding for the research conducted in this project; they are *Oklahoma BioEnergy Center*, *CELDi*, and the *National Science Foundation*.

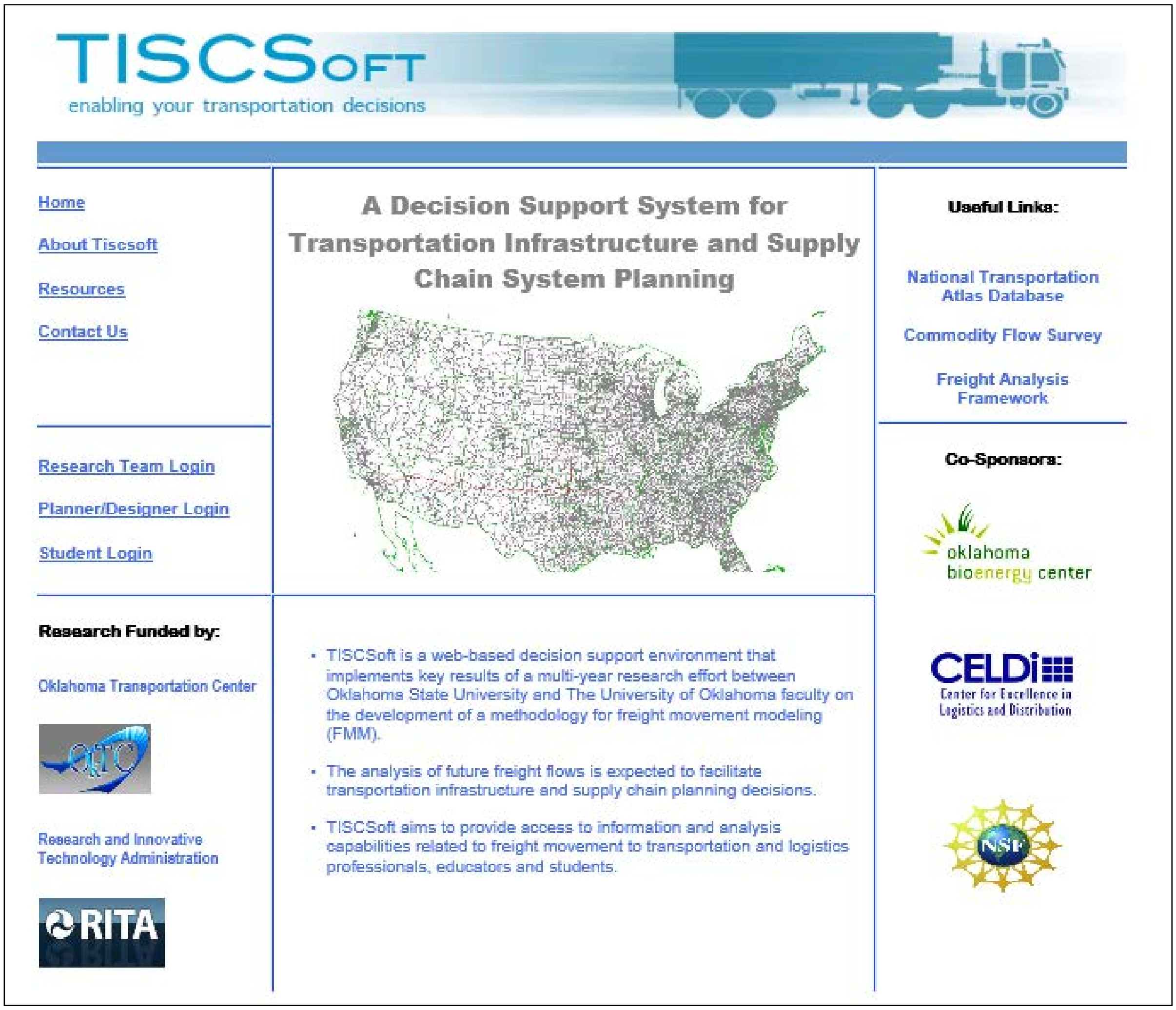


Figure 10: Screenshot of TISCSoft Home Page

The following subsections provide additional details for the DSS related (internal) links mentioned above.

5.1.1 About TISCSoft

This link leads to another web page, which includes a brief introduction to the DSS project and links to additional pages that provide details about *Research Faculty*, *Research Assistants* and *Research Sponsors.* The *Research Faculty* link leads to a page that displays the names, photographs and contact information of faculty researchers and also provides links to their official web pages. In a similar manner the *Research Assistants* and *Research Sponsors* links lead to pages that list names of research assistants that have worked on this project and the agencies that have provided funding to support the research conducted.

5.1.2 Resources

Clicking the *Resources* link in the home page leads to the resources page that provides links or access to some of the main resources, namely *User Manual*, *Project Background,* and *Link to FAF Database.* The *Project Background* link leads to a pdf version of the FMM project report and the *FAF Database* link opens the official web page containing the FAF database.

5.1.3 Contact Us

On clicking the *Contact Us* link in the home page, the contact information for the main research faculty will be displayed.

5.2 TISCSoft User Access Levels

Three main groups of users are expected to access and use the various DSS functions and features. The home page has three links, Research Team Login, Planner/Designer Login and Student Login that provide secure access to the various functionalities and features of the DSS to these different user groups. Each of these links first leads to a login window where the login id and password have to be entered to access the corresponding page. The links displayed on this page define the access that a user belonging to that group has to the DSS functions.

5.2.1 Research Team Page

The Research Team group consists of faculty and research assistants and has the highest level of access. All features and functions of the DSS are available to a user belonging to this group. Figure 11 shows a screenshot of the Research Team page, which has 7 categories of links namely *Freight Movement Model*; *Supply Chain Network Design*; *User-defined Extreme Event Analysis*; *Education*; *Training*; *Freight Flow Analysis* and *Case Studies*. The *Freight Movement Model* has 4 sub links namely *Freight generation: regression models*; *Freight distribution: gravity model*; *Mode split* and *Freight assignment.* The *Case Studies* link has 2 sub links namely *Bio-fuel supply chain design* and *Extreme event analysis*. Additional details of these seven categories of links will be provided later in this section.

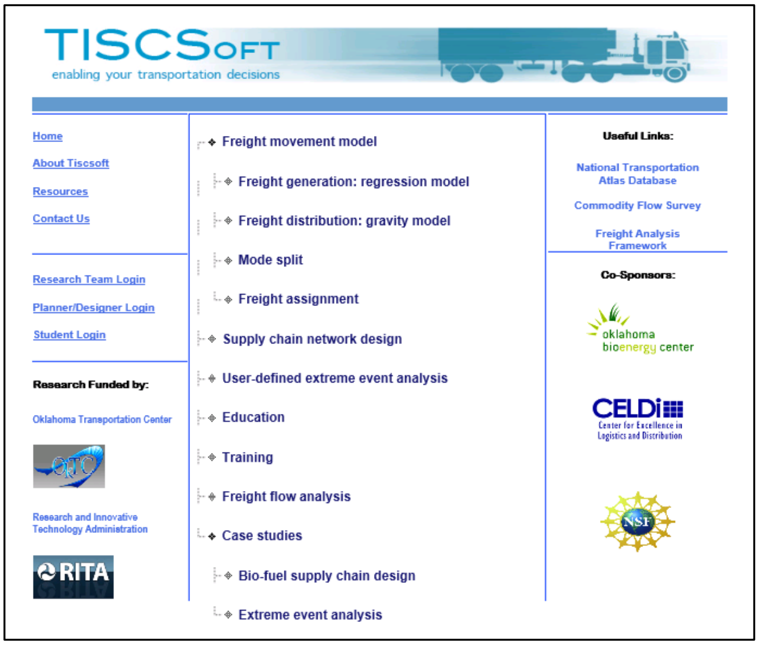


Figure 11: Screenshot of Research Team Page

5.2.2 Planner/Designer Page

The Planner/Designer group is the main target audience for this DSS. This user group includes transportation and logistics/supply chain professionals. A user in this group has access to all functionality except the Freight Movement Model modules. Figure 12 shows a screenshot of the Planner/Designer page.

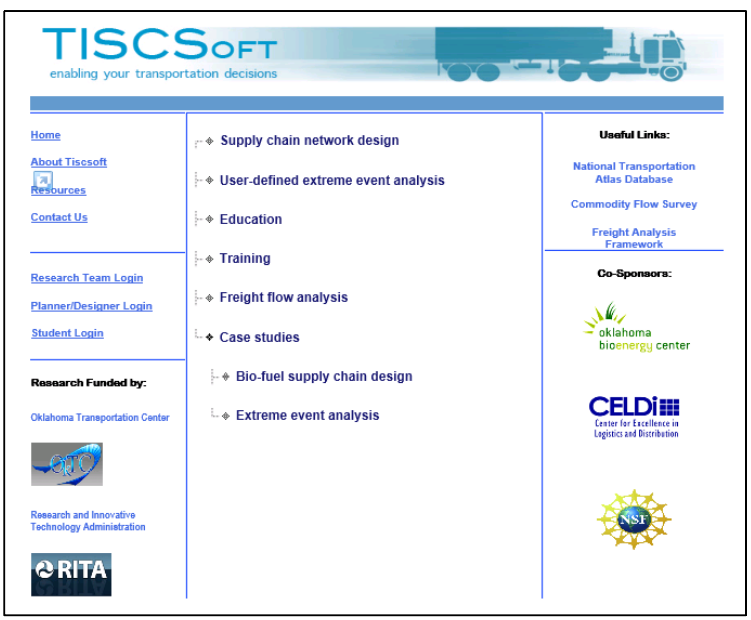


Figure 12: Screenshot of Planner/Designer Page

5.2.3 Student Page

The Student user group includes both undergraduate and graduate students pursuing coursework in transportation or logistics. We assume that their main purpose is to understand the concept and purpose of the FMM effort. Figure 13 shows a screenshot of the Student page. In addition to the *Education* and *Training* modules, the *Freight Flow Analysis* and *Case Studies* modules are the main modules that are available to the student user.

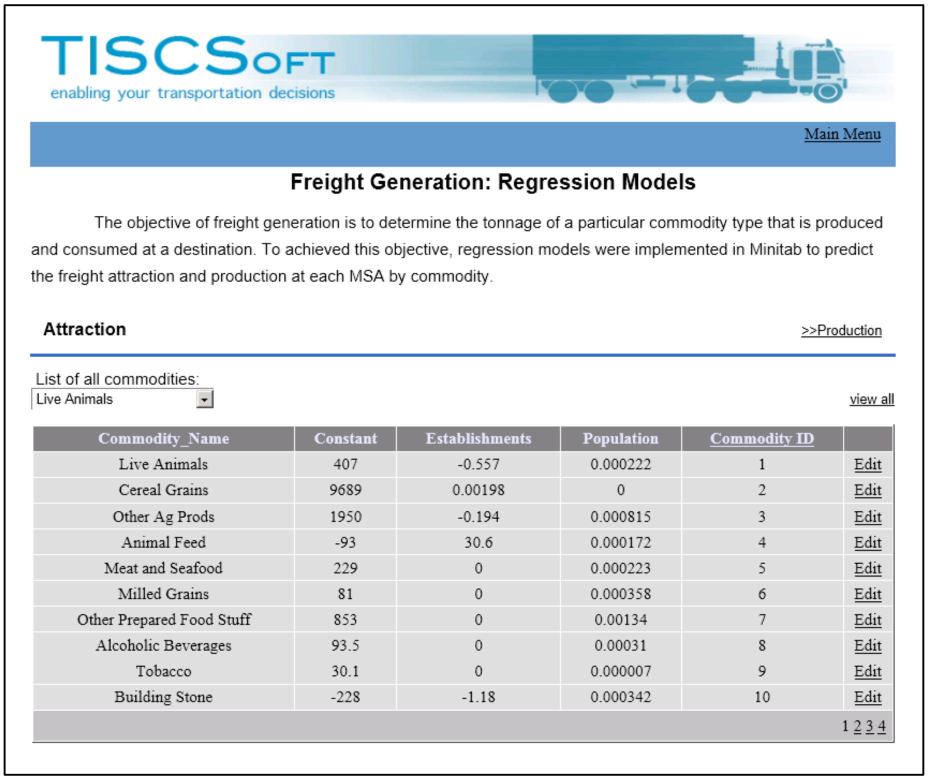
Figure 13: Screenshot of Student Page

5.3 Freight Movement Model

The FMM methodology and the implementation of the various models within the methodology were explained in Section 2. Executing the "FMM Model" has to interpreted appropriately. As explained in Section 2, some of the steps require extensive data collection (from public web sites and data sources) and data cleansing/preparation. Hence, these steps must be executed offline. FMM related functionality within TISCSoft provides a convenient way for members of the research team to access input and output data and execute some of the steps in the models.

5.3.1 Freight Generation

Freight generation essentially involves the use of a pair of regression models, one for freight production and the other for freight attraction for each of the 43 commodity groups. These regression models were developed using the Minitab® software and will need to be updated whenever nee FAF data sets become available. As explained in Section 2, the development of the regression models require extensive data collection and preparation and an iterative procedure to fine tune the regression model. TISCSoft provides a convenient way for the researcher to access the current coefficients of any of the freight production and attraction regression model and to update their values when new data is available. On clicking the *Freight Generation: regression model* link in the Main Menu of the Research Team page, the page shown in Figure 14 will be displayed. It shows the attraction regression model coefficients for each commodity in a tabular format. Normally data for 10 commodities will be displayed in the table. One can view all the regression models for commodities by clicking on the *View All* option. To view the regression models for freight production, the user need to click the *Production* option the page shown in Figure 15 will be displayed. It shows the production regression model coefficients for each commodity in a tabular format. Normally data for 10 commodities will be displayed in the table. Again, we can view all the regression models for commodities by clicking on the *View All* option.



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Main Menu

Freight Generation: Regression Models

The objective of freight generation is to determine the tonnage of a particular commodity type that is produced and consumed at a destination. To achieved this objective, regression models were implemented in Minitab to predict the freight attraction and production at each MSA by commodity.

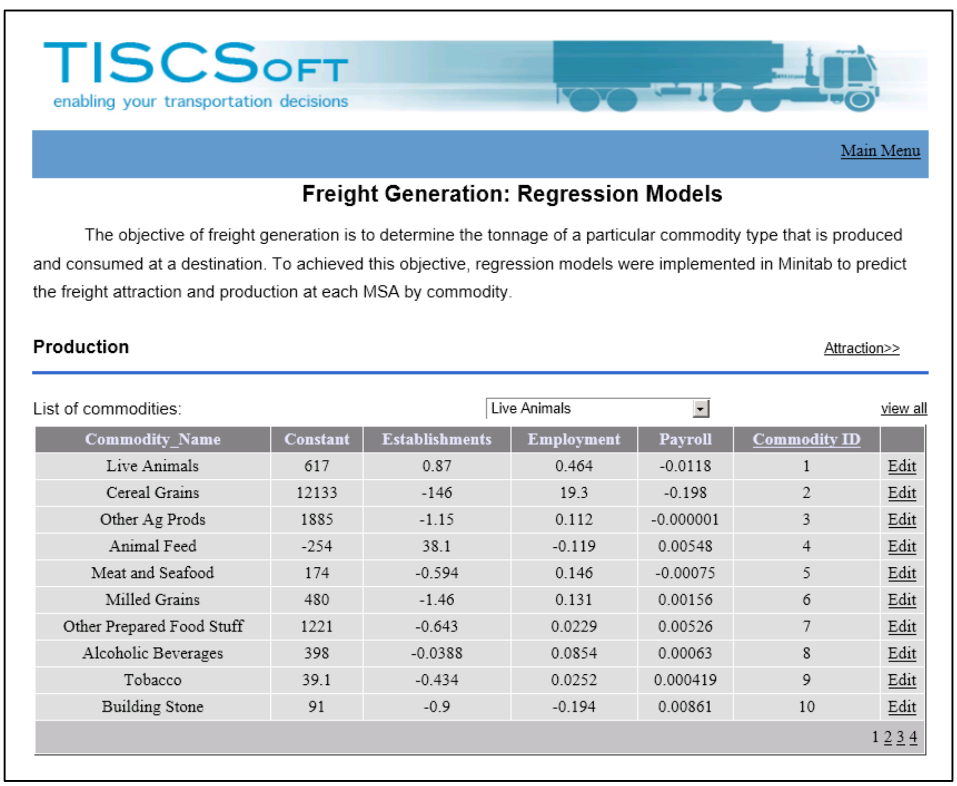
Attraction >>Production

List of all commodities: Live Animals view all

Commodity_Name	Constant	Establishments	Population	Commodity ID	
Live Animals	407	-0.557	0.000222	1	Edit
Cereal Grains	9689	0.00198	0	2	Edit
Other Ag Prods	1950	-0.194	0.000815	3	Edit
Animal Feed	-93	30.6	0.000172	4	Edit
Meat and Seafood	229	0	0.000223	5	Edit
Milled Grains	81	0	0.000358	6	Edit
Other Prepared Food Stuff	853	0	0.00134	7	Edit
Alcoholic Beverages	93.5	0	0.00031	8	Edit
Tobacco	30.1	0	0.000007	9	Edit
Building Stone	-228	-1.18	0.000342	10	Edit

1 2 3 4

Figure 14: Screenshot of Regression Models - Attraction



TISCSoft
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Main Menu

Freight Generation: Regression Models

The objective of freight generation is to determine the tonnage of a particular commodity type that is produced and consumed at a destination. To achieved this objective, regression models were implemented in Minitab to predict the freight attraction and production at each MSA by commodity.

Production Attraction>>

List of commodities: Live Animals view all

Commodity_Name	Constant	Establishments	Employment	Payroll	Commodity ID	
Live Animals	617	0.87	0.464	-0.0118	1	Edit
Cereal Grains	12133	-146	19.3	-0.198	2	Edit
Other Ag Prods	1885	-1.15	0.112	-0.000001	3	Edit
Animal Feed	-254	38.1	-0.119	0.00548	4	Edit
Meat and Seafood	174	-0.594	0.146	-0.00075	5	Edit
Milled Grains	480	-1.46	0.131	0.00156	6	Edit
Other Prepared Food Stuff	1221	-0.643	0.0229	0.00526	7	Edit
Alcoholic Beverages	398	-0.0388	0.0854	0.00063	8	Edit
Tobacco	39.1	-0.434	0.0252	0.000419	9	Edit
Building Stone	91	-0.9	-0.194	0.00861	10	Edit

1 2 3 4

Figure 15: Screenshot of Regression Models – Production

5.3.2 Freight Distribution

The freight distribution step involves distributing freight production and attraction at an MSA to all other MSAs. Freight production and attraction data resulting from the freight generation step are inputs to the distribution model along with a MSA level distance-based friction factor matrix. A doubly constrained gravity model was used for freight distribution between production and attraction locations. Details of the gravity model and its implementation were presented in Section 2. TISCSoft provides a simple mechanism for the researcher to provide MSA-level friction factor data by uploading a file. On clicking the *Freight Distribution: gravity model* link in the Main Menu of the Research Team page, the page shown in Figure 16 will be displayed. This page contains a brief description of the freight distribution step. The user can select the commodity for the distribution step from a drop down list. The user should also upload a MSA-level friction factor matrix by choosing the file path using the *Browse* button and then clicking on the upload image to upload the file into the *TISCSoft* database.

Figure 16: Screenshot of Freight Distribution Page

5.3.3 Mode Split

As explained in Section 2, mode split involves the distribution of freight flows between MSAs by the different transportation modes (i.e. highway, rail, and water). The mode-split percentages for each SCTG commodity were determined for year 2002, and for the DSS implementation it was assumed that the transportation mode sharing among the different modes would be roughly the same for future years. On clicking the *Mode Split* link in the Main Menu of the Research Team page, the mode split page is displayed. In the current version of TISCSoft, the main purpose of this page to explain the mode split step in the FMM model execution.

5.3.4 Freight Assignment

For the DSS implementation, we focused on assigning the freight flow on the US Highway network. Section 2 provided a detailed explanation of the new freight flow assignment heuristic and its implementation. Almost all of the program execution for this step must be done in an off-line mode. On clicking the *Freight Assignment* link in the Main Menu of the Research Team page, the Freight Flow Assignment Page is opened. In the current version of TISCSoft, the main purpose of this page is to explain the freight assignment step within the FMM methodology. As explained in Section 2, all the steps from input data preparation, heuristics implementation and output generation have been coded and readily available for off-line execution.

5.4 Supply Chain Network Design

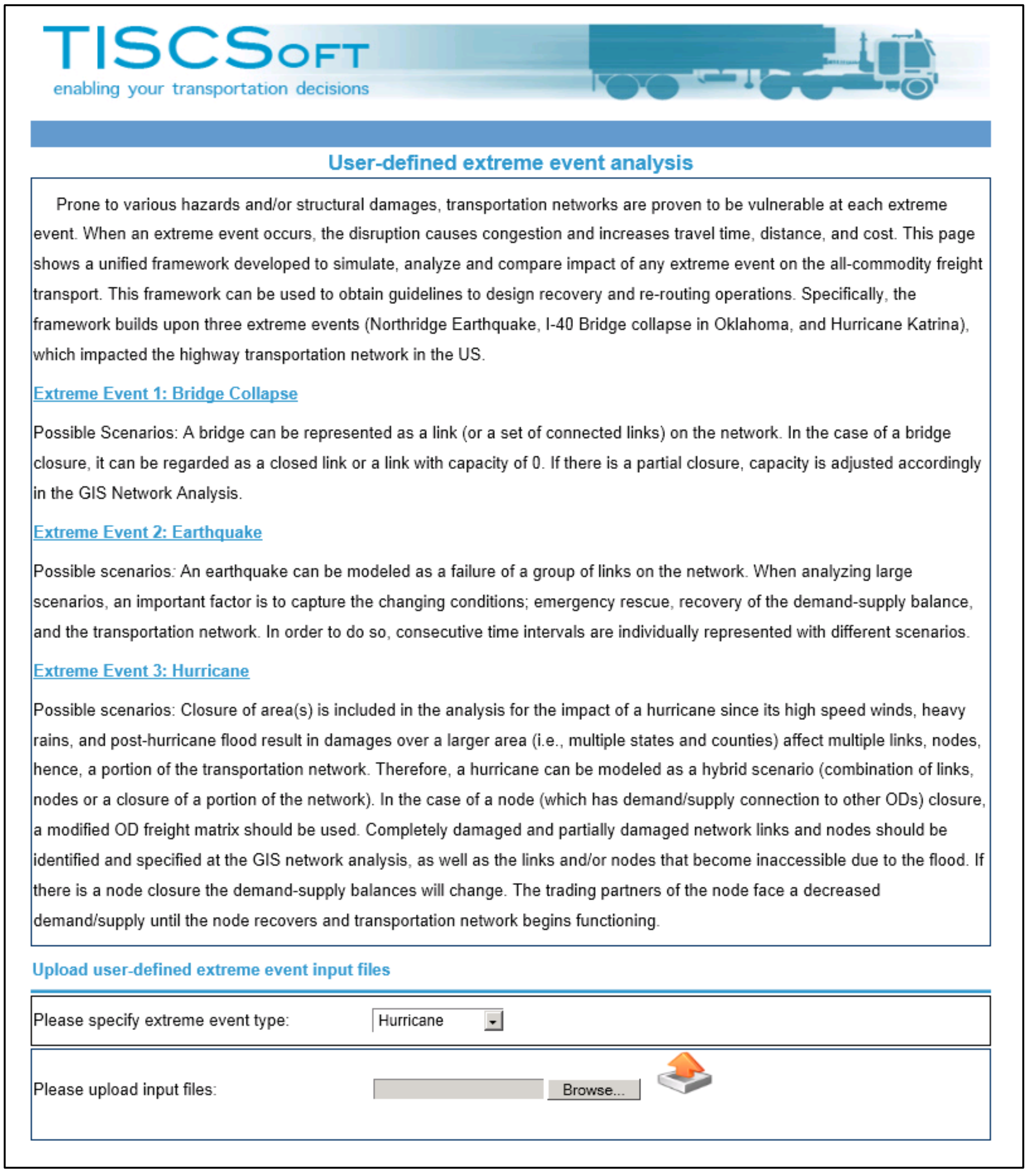
TISCSoft implements a novel approach for the design of supply chain networks. As explained in Section 3, the congested travel times on the highway segments provided by the FMM model were used to obtain more realistic transportation costs and times and served as an input to the supply chain optimizer module. In Section 3, we also explained in detail the connections between the Supply Chain Network Design (SCND) module and the other modules within TISCSoft by showing the execution sequence and then providing the implementation details of the various steps involved. Most of these steps have to be executed off-line by a research team member. The main step where the user needs to interact with the DSS is the first step where the user has to provide the input data for their supply chain network (see Section 3.3).

In TISCSoft when the user clicks the *Supply Chain Network Design* link in the Main Menu of the Research Team or Planner/Designer page, the supply chain network design page is displayed. This page has the following content: (i) a brief explanation of the supply chain network design approach that incorporates congested travel time information obtained from the FMM model, (ii) a link to obtain the prescribed SCND input template, and (iii) an *Upload user-defined case* link to upload a completed SCND input spreadsheet. The user-defined case can be uploaded by using the *Browse* button and then by clicking the upload image.

5.5 User Defined Extreme Event Analysis

TISCSoft supports scenario analysis involving either changes in demographic/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 currently supports scenario analysis in an asynchronous mode through a combination of on-line scenario definition and off-line execution of freight flow models. A framework was developed for extreme-event analysis [12] and the implementation within TISCSoft follows the framework published in [12]. On clicking the *User-Defined extreme event analysis* link in the main menu of the Research Team or the Planner/Designer page, the page shown in Figure 17 will be displayed.

This page explains how catastrophic events like bridge collapse, earthquakes and hurricanes affect the transportation network and infrastructure. A user can upload a user-defined scenario, which will then be studied by the Research Team offline to provide detailed analysis for the user-defined situation. The user can pick an event-type from the drop down list and then upload input files that describe the scenario to be analyzed. Currently, there is no prescribed format for the input files and we envision considerable interaction between members of the Research Team and the user during the analysis phase. Based on the extreme-event situation, the exact nature and scope of the data needed has to be determined and requested from the user if appropriate.



TISCSoft
enabling your transportation decisions

User-defined extreme event analysis

Prone to various hazards and/or structural damages, transportation networks are proven to be vulnerable at each extreme event. When an extreme event occurs, the disruption causes congestion and increases travel time, distance, and cost. This page shows a unified framework developed to simulate, analyze and compare impact of any extreme event on the all-commodity freight transport. This framework can be used to obtain guidelines to design recovery and re-routing operations. Specifically, the framework builds upon three extreme events (Northridge Earthquake, I-40 Bridge collapse in Oklahoma, and Hurricane Katrina), which impacted the highway transportation network in the US.

Extreme Event 1: Bridge Collapse

Possible Scenarios: A bridge can be represented as a link (or a set of connected links) on the network. In the case of a bridge closure, it can be regarded as a closed link or a link with capacity of 0. If there is a partial closure, capacity is adjusted accordingly in the GIS Network Analysis.

Extreme Event 2: Earthquake

Possible scenarios: An earthquake can be modeled as a failure of a group of links on the network. When analyzing large scenarios, an important factor is to capture the changing conditions; emergency rescue, recovery of the demand-supply balance, and the transportation network. In order to do so, consecutive time intervals are individually represented with different scenarios.

Extreme Event 3: Hurricane

Possible scenarios: Closure of area(s) is included in the analysis for the impact of a hurricane since its high speed winds, heavy rains, and post-hurricane flood result in damages over a larger area (i.e., multiple states and counties) affect multiple links, nodes, hence, a portion of the transportation network. Therefore, a hurricane can be modeled as a hybrid scenario (combination of links, nodes or a closure of a portion of the network). In the case of a node (which has demand/supply connection to other ODs) closure, a modified OD freight matrix should be used. Completely damaged and partially damaged network links and nodes should be identified and specified at the GIS network analysis, as well as the links and/or nodes that become inaccessible due to the flood. If there is a node closure the demand-supply balances will change. The trading partners of the node face a decreased demand/supply until the node recovers and transportation network begins functioning.

Upload user-defined extreme event input files

Please specify extreme event type: Hurricane

Please upload input files: Browse...

Figure 17: User Defined Extreme Event Analysis

5.6 Education and Training

The purpose of the Education module of TISCSoft is to assist users (primarily students) in learning the basics of FMM and decision-making related to transportation and supply chain planning issues. On clicking the *Education* link from any page, the TISCSoft Education page shown in Figure 18 will be displayed. The material is organized in the form of short learning modules as shown in the Table of Contents part of the page. The various learning modules can be accessed through the links labeled *Background of the Four Step Model*, *Introduction*, *Freight Generation*, *Freight Distribution*, *Freight Modal Split*, *Freight Assignment*, and *Supply Chain*. Each of the links mentioned above leads to content about various concepts that bear the same name as that of the link. The user can assess their level of understanding of the various concepts by taking short quizzes.

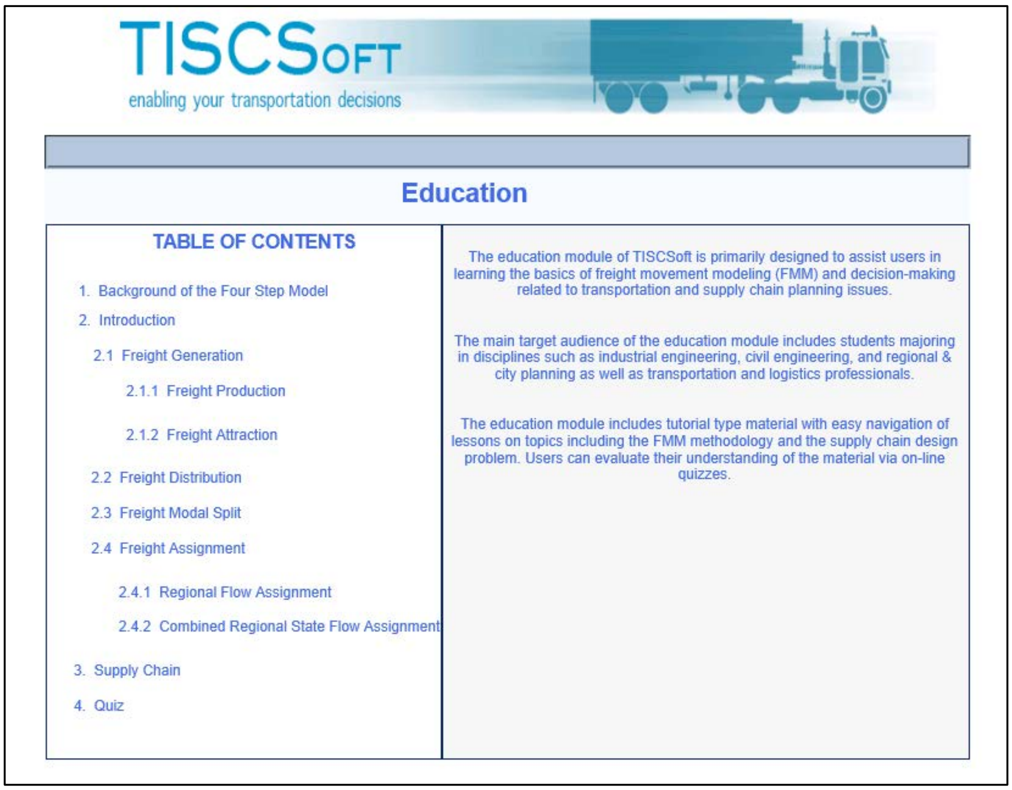


Figure 18: Screenshot of TISCSoft Education Page

On clicking the *Training* link from any page, the training main page will be displayed. The training module contains content to assist the user in learn the functionalities and features of TISCSoft, especially the *Freight Flow Analysis* module.

5.7 Freight Flow Analysis

The Freight Flow Analysis module of TISCSoft is where the user can analyze the FMM results in a GIS format. This module was developed using the ArcGIS server for the Microsoft .Net framework 9.3. Currently there are three maps, a map for the whole United States, a map for Oklahoma, and a map for South Carolina. While the need for the first two maps is obvious, the map for South Carolina was the result of a demonstration of some of the freight flow analysis capability to researchers from Clemson University. The maps enable the user to visually see the results from the freight assignment model from many different perspectives. Clicking on the *Freight Flow Analysis* link from the main menu in any of the pages establishes a link to the GIS application developed in ArcGIS and displays the page shown in Figure 19.

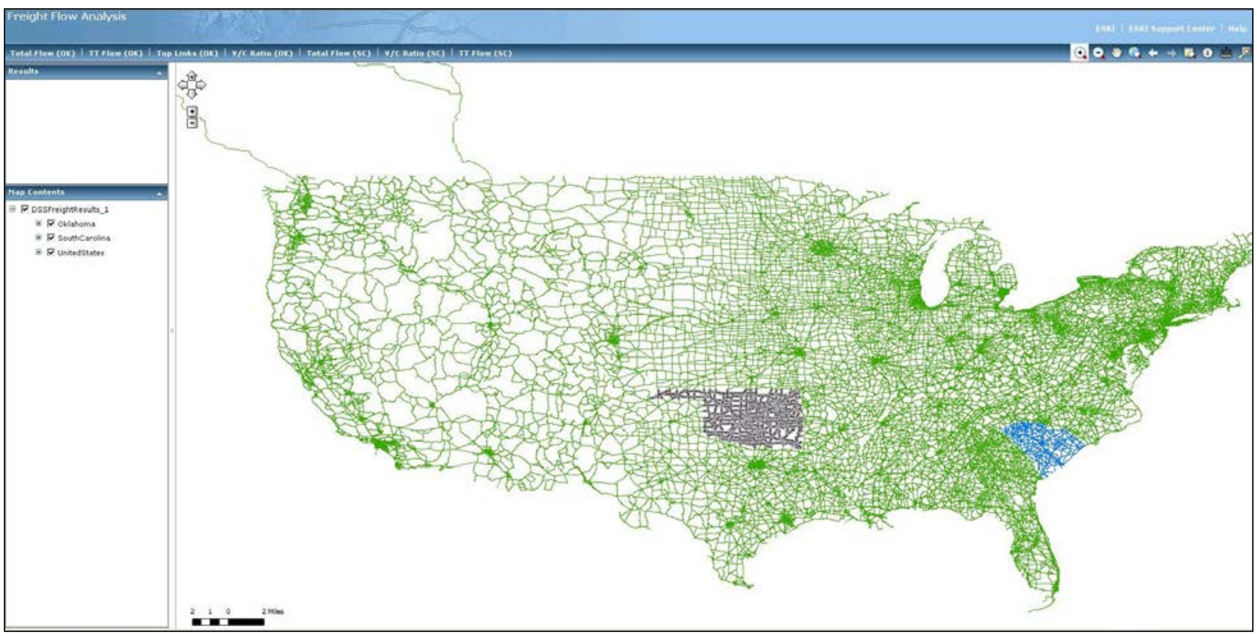


Figure 19: Screenshot of Freight Flow Analysis Page

The toolbar on the right corner Figure 19 of provides basic navigation tools such as zoom in, zoom out, magnifier, and measure. The detailed information stored in the GIS database for any arc or link can be obtained by first clicking on the information icon in the tool bar and then clicking on the arc to be investigated. A result of this operation is shown in Figure 20 for an example link in the state of Oklahoma.

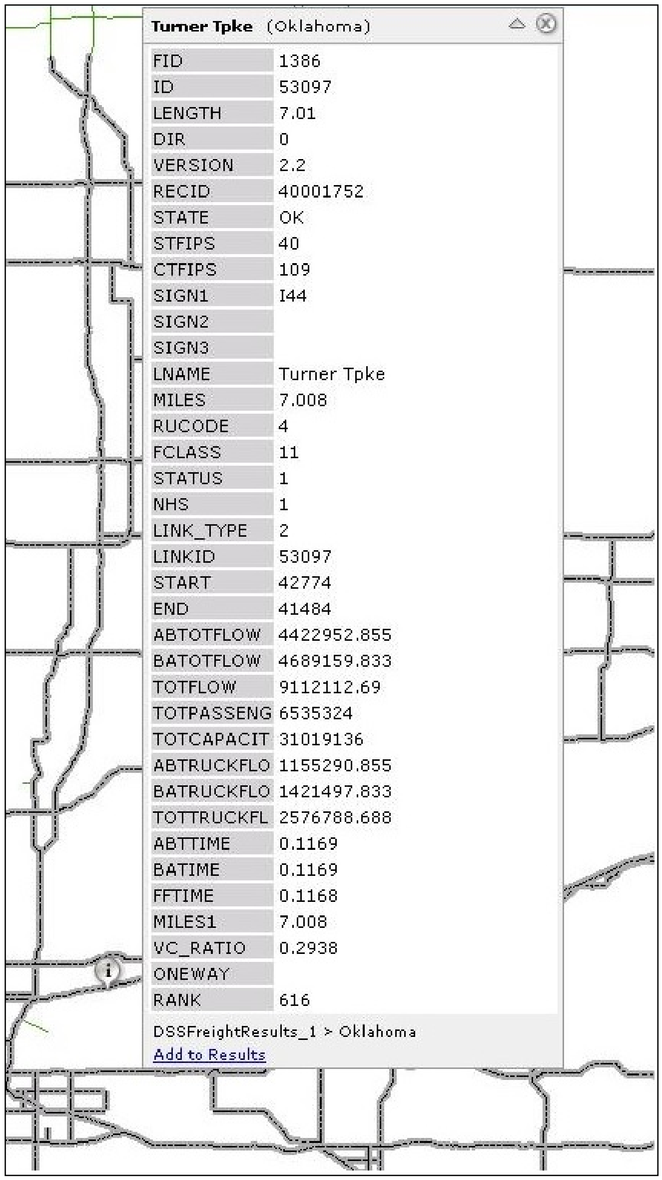


Figure 20: Screenshot Showing the Information Stored for an Arc

To facilitate the freight flow analysis, several queries have been defined and are available to the user as shown in Figure 19 at the top. These queries highlight transportation links based on total flow, total truck flow, top links by total flow and V/C ratio. The corresponding window is activated once the item is clicked.

- **Total Flow (OK)** query retrieves arcs or links in Oklahoma with total flow greater than or equal to a user-specified value. Figure 21 shows all the arcs (highlighted in yellow) in Oklahoma with total flow greater than or equal to 5,000,000 truck equivalents.

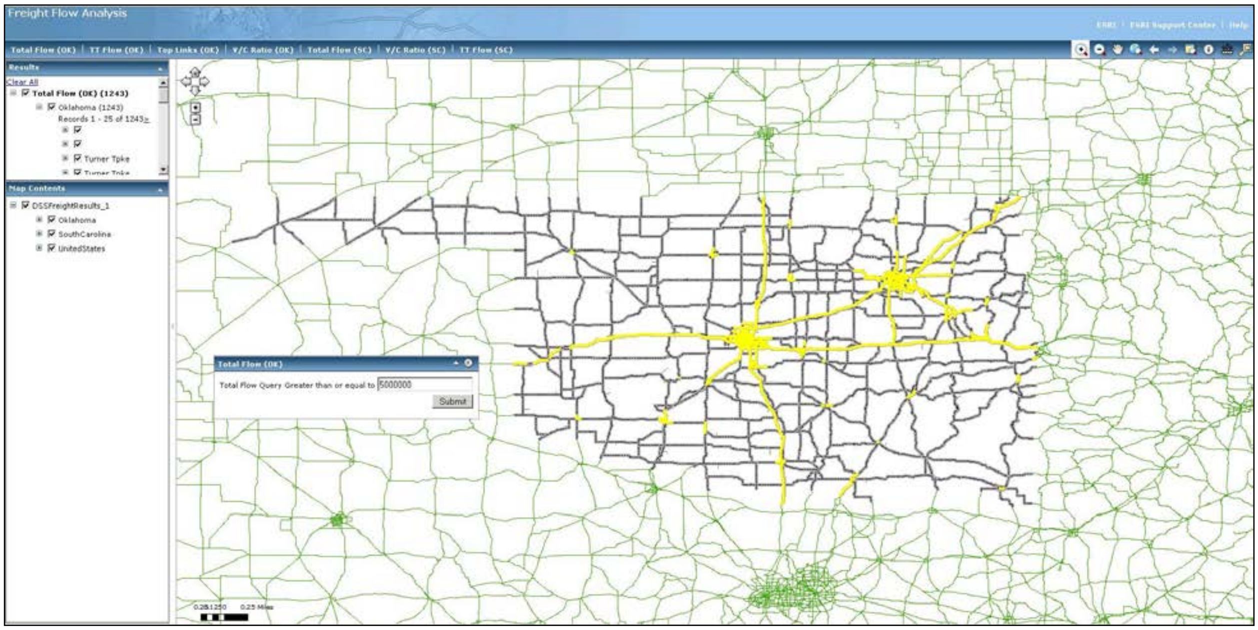


Figure 21: Oklahoma Links with Total Flow Greater than or Equal to 5,000,000 Truck Equivalents

- **TT Flow (OK)** query retrieves arcs or links in Oklahoma with total truck flow greater than or equal to a user-specified value. Figure 22 shows all the arcs (highlighted in yellow) in Oklahoma with total truck flow greater than or equal to 1,000,000 trucks.

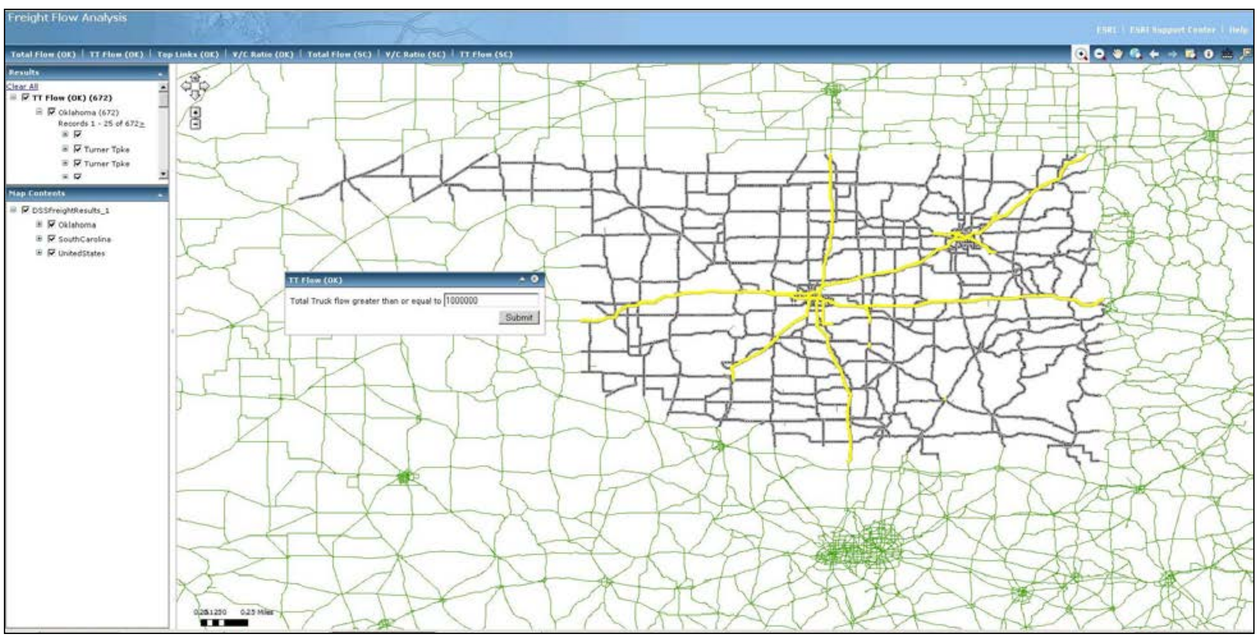


Figure 22: Oklahoma Links with Total Truck Flow Greater than or Equal to 1,000,000 Trucks

- **Top Links (OK)** query retrieves top (user-specified number) arcs in Oklahoma based on total flow. Figure 23 shows top 500 arcs (highlighted in yellow) in Oklahoma.

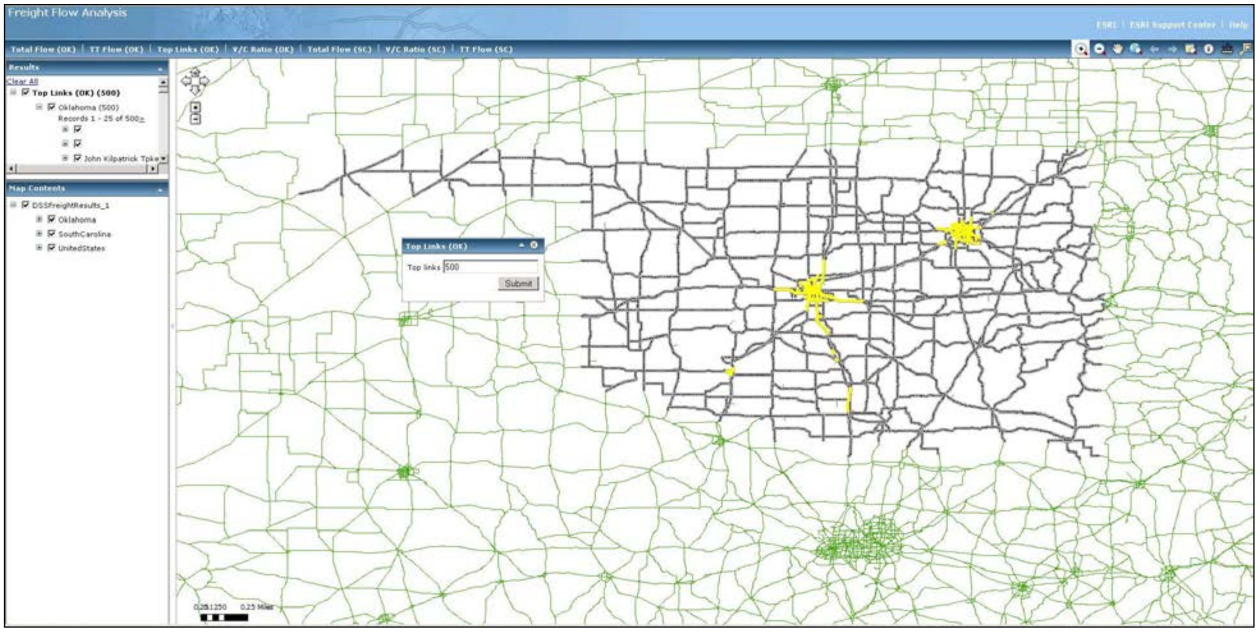


Figure 23: Top 500 Oklahoma Links by Total Flow

- **V/C Ratio (OK)** query retrieves arcs in Oklahoma with volume/capacity (V/C) ratio greater than or equal to a user-specified value. Figure 24 shows all the arcs (highlighted in yellow) in Oklahoma with V/C ratio greater or equal to 0.4.

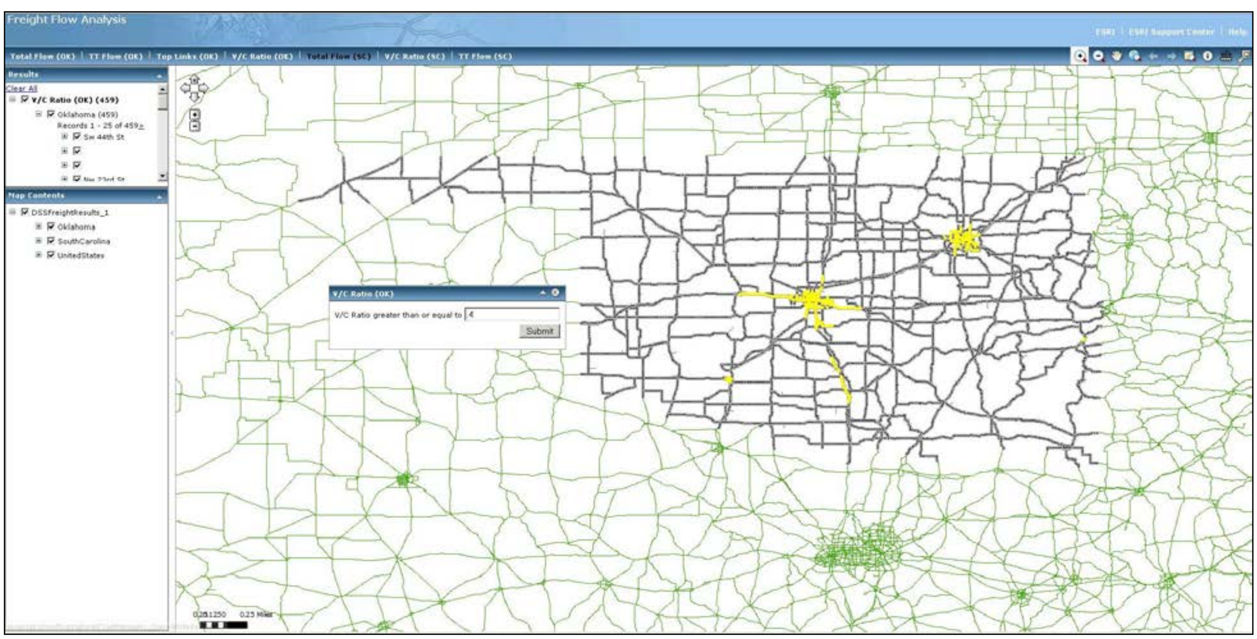


Figure 24: Oklahoma Links with V/C Ratio Greater than or Equal to 0.4

As illustrated above the first four queries highlight transportation links based on total flow, total truck flow, top links by total flow and V/C ratio for Oklahoma. The last three queries were designed to show similar results for the South Carolina. The three queries, namely, total flow, total truck flow, and V/C ratio were developed for a demonstration of some of the freight flow analysis capability to researchers from Clemson University.

5.8 Case Studies

The *Case Studies* module of TISCSoft has links to a *Bio-fuel Supply Chain Design* case and *Extreme Event Analysis* cases.

5.8.1 Bio-Fuel Supply Chain Design

As explained in Section 4, the DSS project also included a case study on the design of a biomass supply chain for switchgrass in western Oklahoma and southwestern Kansas.   This case study was an integral part of a doctoral dissertation that was completed at OSU [7]. On clicking the *Bio-fuel Supply Chain Design* link from the main menu, the page shown in Figure 25 will be displayed. The content on this and related pages summarizes the development of a scenario optimization model for designing a biomass supply chain (see Section 4).

Figure 25: Screenshot of Bio Fuel Supply Chain Design Case Page

5.8.2 Extreme Event Analysis

In addition to developing a framework for extreme-event analysis, this DSS project also developed three cases based on retro-analysis of three extreme events [12]. On clicking the *Extreme Event Analysis* link in the main menu, the page shown in Figure 26 will be displayed. This page has links to the following three cases - *Hurricane Katrina*, *I40 Bridge Collapse* and *NorthRidge Earthquake*.

Figure 26: Screenshot of Extreme Event Analysis Case Studies Page

Hurricane Katrina Case Study. This case study describes the scenario based analysis that was carried out to quantify the effect that the Hurricane Katrina had on traffic and freight flow. The main page of the Hurricane Katrina Case Study presents an overview of the case, which includes the scenario description and a brief summary of the damage caused by the hurricane. There are 5 tabs namely, *Scenario Construction*, *Data*, *How To*, *Results*, and *References*. A brief description of the content under each of these tabs is given below.

- *Scenario Construction* – A scenario is constructed based on the data collected. 23 links were considered and 7 time point scenarios were constructed – pre-disaster (1 point) and post-disaster (6 points).
- *Data* – Contains data about damaged bridges and roadways due to the calamity.

- *How To* – More information is provided on the 7 time point scenarios
- *Results* – The results of the analysis are summarized.
- *References* – Contains a list of references that aided the analysis.

I40 Bridge Collapse Case Study. The I40 bridge in Oklahoma collapsed after a barge hit it in 2002. This case describes a study that aimed to quantify the impact of this man-made disaster. The main page of this section gives us a brief description of the scenario. There are 2 tabs namely, *Scope* and *Result*.

- *Scope* – This section defines the scope of the analysis, which is a single line failure in the network system. Two time points of prior and post failure were investigated.
- *Results* – Quantitative results, which convey the impact on traffic and freight flow due to the bridge collapse are presented in this section.

Northridge Earthquake Case Study. This case describes the impact an earthquake that struck the Los Angeles area in 1997 had on the transportation network. The main page of this case study describes the scenario that occurred during the earthquake. There is another tab named Scenario Setting, which quantifies the scenario with respect to time before and after the disaster.

6 References

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