USDOT Region V Regional University Transportation Center Final Report

NEXTRANS Project No. 053PY03

Estimating the Economic Impacts of Disruptions to Intermodal Freight Systems Traffic

By

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DISCLAIMER

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TECHNICAL SUMMARY

NEXTRANS Project No. 053PY03 Final Report, Date

Estimating the Economic Impacts of Disruptions to Intermodal Freight Systems Traffic

Introduction

The identification and quantification of the economic and social impacts of disruptions is fundamental for sound transportation policy decisions. The impacts due to disruptions on goods movement are significant. Disruptions in their various forms cause direct short/long term impacts that include fatalities, infrastructure destruction and economic loss. Immediate economic impacts result from the inability of travelers and businesses to adapt to changed circumstances after a disruption. Quantifying the economic impact of different facilities on the transportation network has the potential to dramatically strengthen transportation systems and develop sound policies for network recovery and mitigation. To quantify the economic impacts, one has to clearly capture the consequences of a disruption which is usually a challenging task (Rose, 2009). More recently, these issues have surfaced to the forefront with the increasing realization about the interdependence of the national and global transportation supply chains, where one transportation network is an integral part of a “flat” global transportation network. Various completed and ongoing studies explored this topic from different perspectives (e.g. Series of reports NCHRP 525); however these studies fail to arrive at comprehensive modeling approaches that quantify the complex relationship between goods movement and economic activity. While few models have quantified the “direct” impacts such as infrastructure damage and loss of travel time (Ukkusuri and Yushimito, 2008) there is relatively little understanding of “indirect” impacts which cause the multiplier effect due to reduction in jobs, property values etc in the long term. The ability to estimate the short/long term economic impacts using quantitative methodologies and simulation tools requires the integration of engineering, economic and policy frameworks. Since transportation disruptions have medium and long-run impacts on local, regional and national economies, there is a significant need that warrants their quantification using state of the art tools.

The development of methodologies to quantify the impact of disruptions in goods movement is further crucial because of the significant economic value of the cargo. Globally, the United States imported $1.95 trillion and exported $1.16 trillion of goods in 2007. Of the $3.1 trillion in total U.S. trade, 45 percent moved by vessel, 25 percent by air, and 30 percent by surface and other modes (BTS, 2008). According to preliminary estimates (Commodity Flow Survey in 2007), American businesses produced shipments valuing $11.8 trillion, totaling 13.0 billion tons, and contributing 3.5 trillion ton-miles on the nation's transportation infrastructure. Trucking continues to dominate as the modal choice for freight shipments, accounting for 71 percent of the value and 76 percent of the tons of all commodity shipments. It is easy to imagine the significant impact that a disruption of even a small fraction of the shipments can have on the economy.

The disruption to the goods whether it is due to increased security screening post 9/11 of goods via air, sea and land or due to disruption of critical links in disasters (e.g. earthquake, hurricane etc.) leads to direct and indirect economic impacts. The losses vary from macro level (relocation of jobs, changes in imports and exports, land use changes etc) to micro level (changes in production, sales and prices) impacts on the economy. Depending on the duration of disruption, availability of alternatives, and resilience of the system, the extent of economic impacts can be measured. The challenge lies in developing appropriate performance metrics and modeling tools that arrive at holistic measures of economic impacts. Previous studies fail to address two important characterizations of disruptions: (1) the resilience of the system and (2) the extended linkages of disruptions (Rose, 2009). The resilience depends on the property of systems to overcome the potential disruption by either adjusting to the situation or by rescheduling the delivery of goods when possible. The extended linkages are related to the behavioral response of whole system to failure which may lead to extended periods to rebuild and bring the system back to functionality. In addition, most of the previous studies on measuring economic impacts for goods movement do not consider the intermodal nature of the transportation system. Short term strategies to overcome the deleterious effects of the disruptions typically include the use of alternative transportation modes and detours to efficiently ship the goods. Typically these strategies maximize the cost-benefit ratio of the shipping/trucking firm.

The goal of this work is to develop and apply a methodology to identify and estimate the economic impacts due to disruption of goods movement. The developed model is based on state of the art economic concepts that will allow the quantification of system wide impacts at the regional level. This advanced research contributes to the NEXTRANS theme of vehicle-infrastructure interactions (Pillar 2) and in integration of various modes and methods. The developed research is beneficial to government agencies such as departments of transportation (DOTs) and metropolitan transportation organizations (MPOs).

Findings

- There are limited secondary data sources appropriate for freight transportation modeling and analysis.
- The best available data source for freight transportation modeling and analysis, the Freight Analysis Framework version 3, can be used for regional freight modeling under a set of assumptions developed in this project in order to overcome limitations associated to data aggregation.
- The framework presented in this paper can be used as a good approximation for the analysis of economic impacts due to freight disruptions.

Recommendations

- Public agencies must improve the way in which secondary data for freight modeling and analysis is presented to the researchers and general public.
- Availability of more data will improve the calibration of the model and, hence, its accuracy.
- Regional planning agencies require to develop freight plans that integrate appropriate data sources and models.

USDOT Region V Regional University Transportation Center Final Report

TECHNICAL SUMMARY

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TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

CHAPTER 1. INTRODUCTION

The identification and quantification of the economic and social impacts of disruptions is fundamental for sound transportation policy decisions. The impacts due to disruptions on goods movement are significant. Disruptions in their various forms cause direct short/long term impacts that include fatalities, infrastructure destruction and economic loss. Immediate economic impacts result from the inability of travelers and businesses to adapt to changed circumstances after a disruption. Quantifying the economic impact of different facilities on the transportation network has the potential to dramatically strengthen transportation systems and develop sound policies for network recovery and mitigation. To quantify the economic impacts, one has to clearly capture the consequences of a disruption which is usually a challenging task (Rose, 2009). More recently, these issues have surfaced to the forefront with the increasing realization about the interdependence of the national and global transportation supply chains, where one transportation network is an integral part of a “flat” global transportation network. Various completed and ongoing studies explored this topic from different perspectives (e.g. Series of reports NCHRP 525); however these studies fail to arrive at comprehensive modeling approaches that quantify the complex relationship between goods movement and economic activity. While few models have quantified the “direct” impacts such as infrastructure damage and loss of travel time (Ukkusuri and Yushimito, 2008) there is relatively little understanding of “indirect” impacts which cause the multiplier effect due to reduction in jobs, property values etc in the long term. The ability to estimate the short/long term economic impacts using quantitative methodologies and simulation tools requires the integration of engineering, economic and policy frameworks. Since transportation disruptions have medium and long-run impacts on local, regional and national economies, there is a significant need that warrants their quantification using state of the art tools.

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CHAPTER 2. LITERATURE REVIEW

A recent study (Arnold et al., 2006) by Congressional Budget Office (CBO) analyzed the national economic costs of disruptions in container traffic at ports. Two specific disruptions scenarios were considered : (i) unexpected one-week halt to all container traffic in the ports of Los Angeles and Long Beach, California, and (ii) unexpected three-year halt to all container traffic through those two ports as well as an initial precautionary one-week stoppage of container shipments at all U.S. ports. The simulations results were shown in terms of changes in gross domestic product (GDP). The net values were shown in terms of the loss in productivity at these ports to be between $65 million and $150 million per day from one week shutdown and between $45 billion to $70 billion, per year for a three-year shutdown (equivalent reduction of real GDP by 0.35 percent and 0.55 percent). The macro level impacts were studied as decrease in GDP and the micro level impacts in terms of loss in production.

The importance of transportation at the microeconomic level for specific regions is linked to producer, consumer and production costs. The micro level impacts of disruptions are related to changes in sales, operating costs, competitiveness, production cost and increased travel cost. In the literature, transportation accounts on average between 10 to 15 percent of household expenditures while it accounts for around 4 percent of the costs of each unit of output in manufacturing (this figure varies widely depending on the industry).

The microeconomic impacts involve the calculation of the economic value of the disruptions to the production and consumer sectors, i.e., the decrease in productivity in the local economy produced by the disruptions and inaccessibility to specific destinations. Although this concept appears straightforward, previous literature has shown that modeling these impacts is an extremely difficult task because of the difficulty in estimating externalities (Mohring (1976), Carnemark et al. (1976)). The best way to compute the economic value of the disruption is to derive the value of travel time and convert the increased delay using appropriate tools. Such approach is the used in almost all of the economic analyses conducted worldwide and understood as the net externalities imposed by the transportation system. Finally, the microeconomic impact analysis will depend on the accurate appraisal of cost of disruptions which is related to how closely prices for transportation approximate the marginal costs to the consumer. To perform this analysis, different performance measures should be identified and appropriate data necessary for capturing these performance measures should be procured.

The measures of direct economic impacts are related to accessibility and mobility change where an efficient transportation system is a harbinger for better market economies -- larger markets for efficient goods movement and enables to save travel time and cost. The improved accessibility and mobility will lead to improved trade and economy whereas the disruptions and inaccessibility may lead to significant economic slowdown. The direct economic measure of the disruptions results in increase in travel cost and loss of reliability which is computed as a loss of social welfare. The indirect economic measures are related to the economic multiplier effect where the price of commodities, goods or services drop and/or their variety increases. The multipliers are valuable to measure the broad impacts of economic development activity. For instance, how does the shutdown in a port (or manufacturing company) change the employment in a region and ultimately the prices of commodities and supplies? A multiplier shows the additional (or indirect) change to the economy resulting from each change in a selected industry. Since these effect are associated with long term effects, they are not considered in this report.

CHAPTER 3. HOLISTIC METHODOLOGY

This chapter presents a holistic conceptual framework to estimate the short-term economic impacts due to disruptions in the freight transportation system. A detailed framework that takes advantages of available state-of-the-art data sources and procedures is presented in the following chapter.

Figure 1 presents a holistic conceptual framework to determine short term economic impacts due to disruptions in a freight transportation system. The following inputs are required:

- Impacted region.
- Zoning system.
- Demand of vehicles between zones.
- Space-time disruptions.
- Network Topology.
- Traffic flows.
- Traffic variables (Links capacity and free flow travel time).
- Vehicle operational costs.
- Value of travel time.

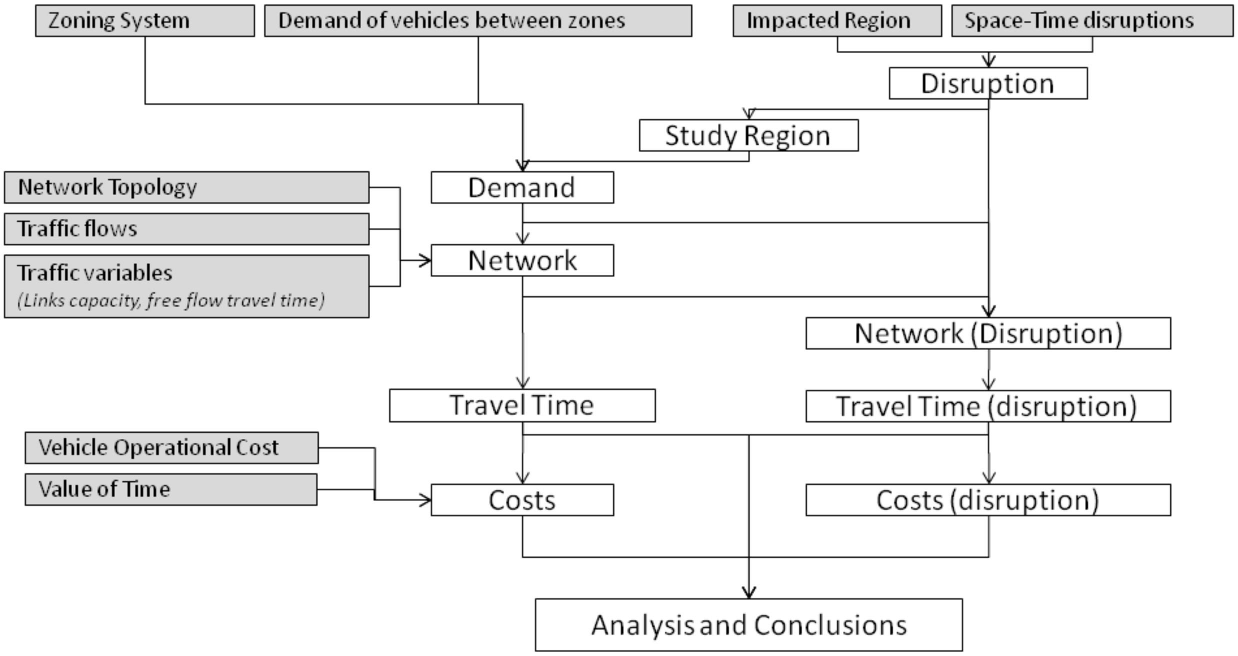

Figure 1. Holistic Conceptual Framework to Determine Short Term Economic Impacts Due to Disruptions in the Freight Transportation System.

A *disruption* in the transportation system is directly related to an *impacted region* and a *space-time disruption. Space-time disruptions* are defined by the modeler based on previous or possible disruptions. These events are related to specific locations and times where they take place, e.g., truck-related accident in a highway between 3:00 p.m. and 6:00 p.m., closure of a dock for one weekend, reconstruction of a bridge after a terrorist attack for 6 months, etc. *Space-time disruptions* also influence the extent of the *impacted region*, which is defined following modeler's criteria and the requirements of the study. Thus, a clear definition of the *disruption* scenario is required to determine the *study region*.

Once the *study region* is identified, the modeler has to complement it with a *zoning system*. The *zoning system* differentiates the *study region* by internal zones and the surrounding environment by external zones. Although the *zoning system* can be created from scratch by the modeler, it is highly recommended to use an existing or a modified version of an existing *zoning systems*, e.g., Transportation Analysis Zones (TAZs) defined by the planning agency on the region, Census Tracts, Counties, ZIP codes, etc. Additionally, the level of disaggregation of these zones depends on other elements in the model, i.e., the hierarchy and scope of the transportation network, demand aggregation, and other criteria defined by the modeler. The *zoning system* is represented with a geographic information system (GIS) file.

Likewise, the *demand of vehicles between zones* is required to determine a base scenario of *demand*. This *demand* is represented by origin-destination (OD) matrixes. The level of disaggregation in which these matrixes are available is essential to define the structure of the model. In an ideal situation, the *demand* is given between each zone in the *zoning system* and disaggregated by vehicle type, e.g., truck configurations, and cars. Likewise, the demand of commercial vehicles is ideally disaggregated by commodity type. However, this is not the average case since public agencies usually do not have OD matrixes at this level of disaggregation. An approach to address this limitation is presented in the detailed framework below (Figure 2).

The *demand* is assigned to a *network* in order to compute the base case *travel time* and *costs*. The network is constructed from GIS files that provide *network topology*, *traffic counts*, and *traffic variables*, e.g. link capacity and free flow travel time. Likewise, the transportation related *costs* are computed based on the estimated of *travel times*, *vehicle operational costs*, and *value of time*.

After getting the *costs* associated with the base case, the modeler has to modify the transportation network to incorporate all the space-time elements associated with the *disruption*. Thus, new *travel times* and *costs* associated with the disruption are computed.

Finally, the travel time and costs associated with the base case and the disruption case are contrasted to present *analysis and conclusions* of the study.

In addition to these short-term economic impacts, a regional economic impact methodology to estimate the economic impacts due to disruption of freight movements can be implemented to observe economic loses in the region, e.g., impacts on employment, labor income, taxes, and vale-added.

In the following subsection a more detailed framework is developed base on these conceptual elements.

CHAPTER 4. DETAILED FRAMEWORK

In this chapter the conceptual holistic elements described above are presented in a detailed framework suitable for implementation of the majority of researchers and agencies facing the quantification of short term economic impact due to disruptions in freight transportation systems in the U.S.

Figure 2 presents a chart that depicts this framework. In this figure, grey boxes represent the basic inputs required for the methodology, boxes in italics represents procedures, and the other boxes are inputs/outputs according to their position with respect to the procedures. The main inputs/outputs guiding the development of the framework are highlighted by bold letters.

In a nutshell, the framework is based in four data sources: The Freight Analysis Framework version 3 (FAF3), Transportation Analysis Zones (TAZs) from planning agencies in the region, a disruption scenario, vehicle operational costs, and value of time. The cornerstone of the framework is the FAF3 (Southworth, et al, 2010; Southworth, et al, 2011; Batelle 2011), or latest version if available. This is because the FAF3 is the most recent and public available data for freight transportation analysis in the U.S. However, there are some challenges in using FAF3. First, the demand for the 42 groups of commodities is given between highly aggregated zones. Second, the highway network is sufficiently detailed for regional analysis but too detailed to be linked with the level of aggregation of the FAF3 zones. Finally, the flow of trucks at each link in the highway network is not disaggregated by commodity. Therefore, the framework properly integrates methodologies to determine the proportions of trucks in each link of the network per commodity type and the assigns this proportions to the available traffic counts in the study region. This allows the modeler to determine multiclass flows in the study region which are useful to estimate base OD matrixes per commodity with their corresponding performance measures. After determining the base demand, it is possible to apply the disruption scenario in the network, compute the changes in travel behavior and the corresponding performance measures associated with the disruption. Finally, the performance measures for the base- and the disruption-case are analyzed to provide conclusions.

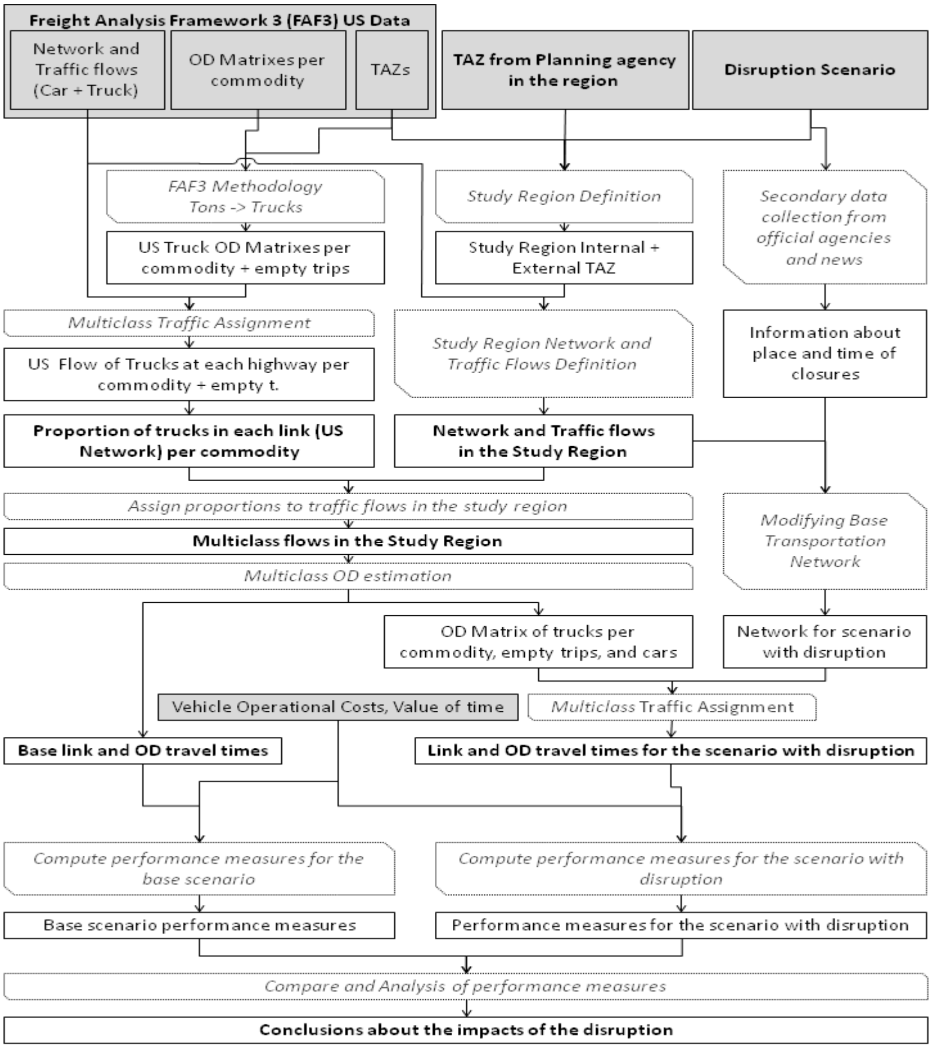

Figure 2. Detailed Framework to Determine Short Term Economic Impacts Due to Disruptions in the Freight Transportation System.

In addition to these short-term economic impacts, a regional economic impact, e.g., impacts on employment, labor income, taxes, and vale-added, can be estimated using the methodology below.

The following subsections expand these ideas providing details about inputs, outputs, and methodologies followed to build the framework.

4.1 Inputs

This subsection presents a description of the main inputs required to implement the framework. These inputs are: the Freight Analysis Framework version 3 (FAF3), Transportation Analysis Zones (TAZs) from planning agencies in the region, a disruption scenario, vehicle operational costs, and value of time.

4.1.1 Freight Analysis Framework version 3 (FAF3)

The cornerstone of the framework is the Freight Analysis Framework version 3 (FAF3) (FMO 2012, Southworth, et al, 2010; Southworth, et al, 2011; Batelle 2011). This is because FAF3 is the most recent and public available data for freight transportation in the U.S. The datasets and TransCAD files with the U.S. zoning system, highway network, OD matrices per commodity, and traffic flows are publicly available in the website of the office of freight management and operations (FMO) (FMO 2012).

The FAF3 uses information from the 2007 Commodity Flow Survey (RITA 2012) and international trade regions to estimate the dollar value and tons of shipments between 123 Transportation Analysis Zones (TAZs) in the U.S., by commodity type, and by mode. Likewise, the FAF3 updates the network database and traffic assignment of the previous version (FAF2). The objectives of the FAF3 are: (i) supporting policy and legislative issues, (ii) developing, maintaining, and updating data for different agencies, such as Federal Highway Administration (FHWA), State Departments of Transportation

(DOT), and Metropolitan Planning Organizations (MPO), and (iii) presenting transparent data to all users outside DOTs.

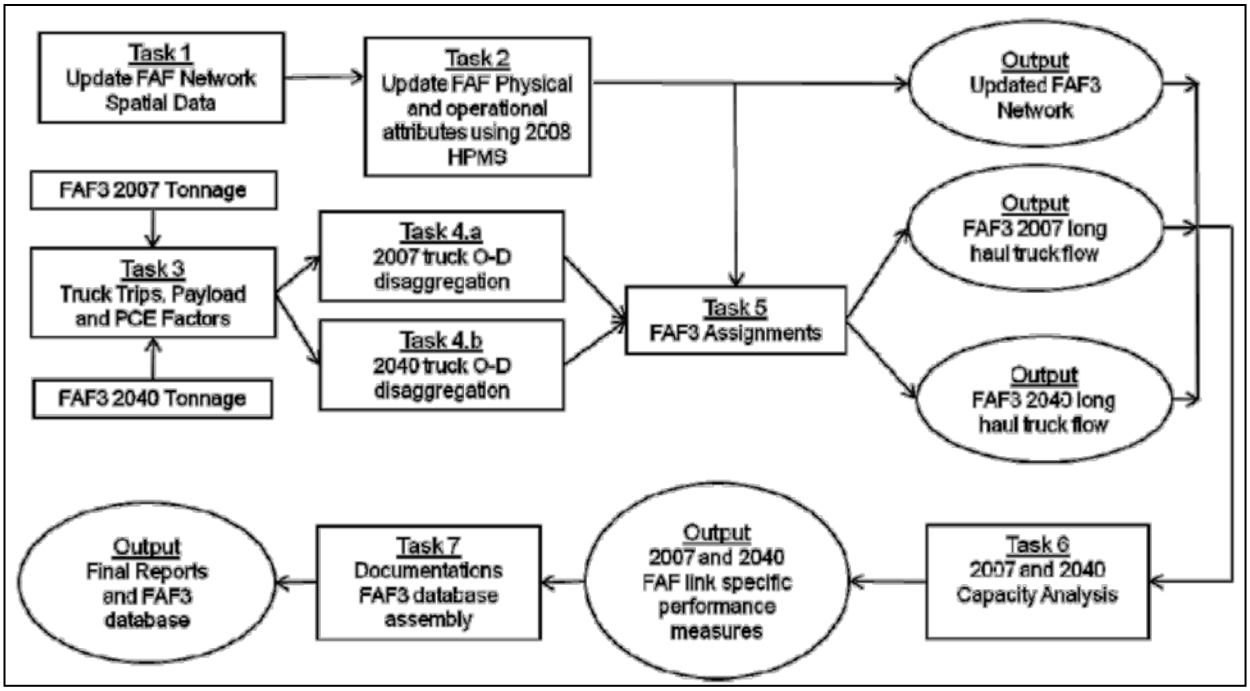

Figure 3. Freight Analysis Framework tasks (Batelle, 2011).

The general framework of the FAF is presented in Figure 3. In this flow chart there are two parallel paths before the 2007 and 2040 Capacity Analysis (Task 6). The first set of tasks updates the FAF3 Network task (Tasks 1 and 2). The second set of tasks, are used to estimate the freight demand and traffic assignment (Tasks 3, 4, and 5 with the updated network), this is, the long haul truck flow. Then, Capacity Analysis (Task 6) is used to estimate link specific performance measures and finally Reports and Databases are released after Task 7.

The FAF3 presents a zoning system for all the U.S. and OD matrixes for 42 groups of commodities in tons and value. Likewise presents a highway network covering these zones and traffic counts for trucks and cars associated with each link in the network. Integrating these inputs in the current framework makes it flexible enough to be implemented by public agencies and researchers in the country. However, there are some challenges in using FAF3. First, the demand for the 42 groups of commodities is given between highly aggregated zones. Second, the highway network is sufficiently detailed for regional analysis but too detailed to be linked with the level of aggregation of the FAF3 zones. Finally, the flow of trucks at each link in the highway network is not disaggregated by commodity.

Figure 4. FAF3 Zoning Systems for a Majority of States in the U.S.

The main challenge with using FAF3 data is that its zoning system (Figure 4) is highly aggregated, i.e., several states are a zone by themselves, e.g., Nebraska, Iowa, Wyoming, etc., and other are (not properly) disaggregate into a small number of zones, e.g., California is disaggregated into 5 zones. By not "properly aggregated" we mean that large zones –that usually represent the remaining part of a state– are not continuous zones, or –if continuous– there is not a clear position where to locate its centroid. An example of the first case is California, which is divided into 5 zones: Sacramento, San Jose, Los Angeles, San Diego, and remaining. As we can see in Figure 4, although the remaining of California (blue area) is one zone it is split into three parts, which is problematic for spatial models. An example of the second case is Indiana, which is divided into three zones: Indianapolis (green), Indiana-Chicago (yellow), and remaining Indiana (blue). Clearly the centroid of the zone "remaining Indiana" is located inside the zone "Indianapolis" which is also problematic for spatial models. Furthermore, locating the centroid in another place inside the zone "remaining Indiana" biases the results of transportation planning models, e.g., traffic assignment. Although dealing with these specific issues is out of the scope of this works, they have to be recognized. However, the framework proposes a series of procedures used to disaggregate the zonal information, i.e., OD matrixes, to a regional level that is appropriate for the assessment of regional disruptions.

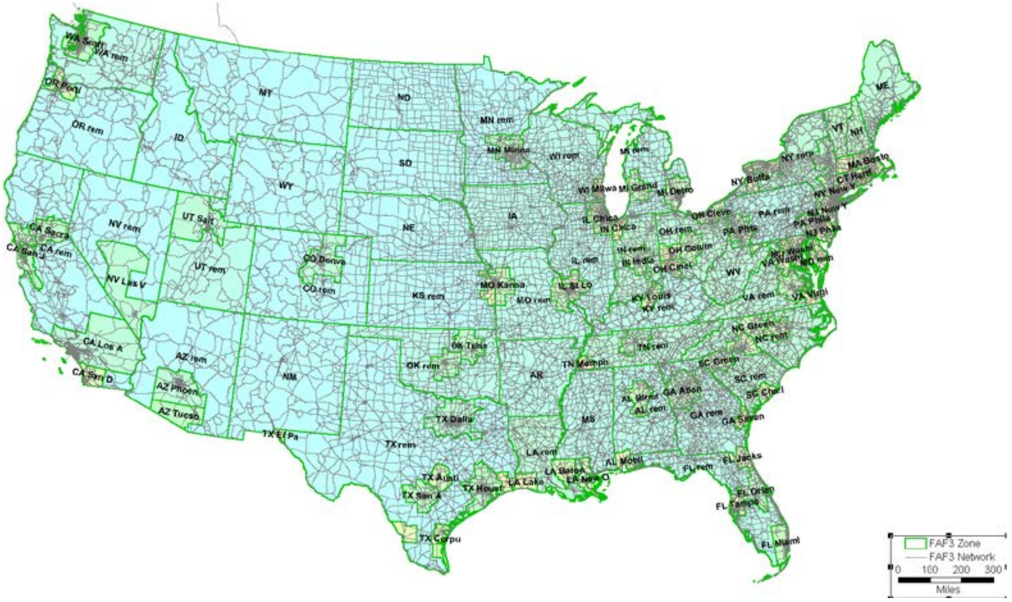

Figure 5. FAF3 Highway Network in the U.S.

On the other hand, the highway network presented in the FAF3 is so detailed that do not properly match with the level of aggregation of the corresponding zones (Figure 5). However, this network has information about the traffic of trucks which can be used to strength the output of the framework. Hence, a sequence of methods is proposed to match the aggregated OD commodity data with the disaggregated traffic flows. Thus, it is possible to estimate the flow of trucks in the highway network by commodity type, which is essential for economic analysis.

4.1.2 Disruption Scenario

Since the objective of this work is estimating the short term economic impacts of disruptions to freight systems, the definition of a disruption scenario is needed. There are different types of disruptions related to abrupt changes in the freight system. These changes are associated to different factors, e.g., natural disasters, accidents in the network, or planned attacks.

A freight system is associated with a transportation network that facilitates the movement of commodities between geographic areas. This network is composed by a set of nodes and links. Nodes represent places where freight is produced/generated or attracted/consumed, point of connectivity in the network, e.g., a junction between a ramp and a highway, and places where there are changes in the attributes of the links, e.g., change from one mode to another. Links represent connections between these nodes. They are associated with several factors, e.g., traversing cost (money, time, length, generalized cost), capacity, mode, speed, flow, etc. Examples of links are highway segments, railroad segments, etc. Even some entities that are seen as nodes, e.g., airports, ports, etc., can be represented as links to increase the level of detail in which the transportation network represents the flow of commodities. There are two main types of flow elements in a freight system: tons of commodities and commercial vehicles. An example of the first one are the OD matrixes per commodity reported in the FAF3. On the other hand, the flow of trucks in the highway network is an example of the second one.

In general, a disruption is related to a reduction in capacity of some elements (nodes or links) in the transportation network, which decreases the amount of flow that can be transferred through these elements. In the worst case, the total capacity of an element is reduced to zero. This means that no flow can use this element when traveling through the transportation network. Furthermore, the reduction in capacity is associated with a period of time. Defining an appropriate time span is needed to properly model the effect of the disruption.

On the other hand, identifying the places where the disruption takes place is important to define the extent of the study region and obtain –or generate– appropiate geographic files associated to this area.

4.1.3 Transportation Analysis Zones (TAZs) from Planning Agencies in the Region.

Once the disruption scenario is defined, the impacted area can be associated with a FAF3 zone. However, as mentioned before, these zones are usually at a high level of aggregation which limits their use for regional analysis. Therefore, they have to be complemented with information from planning agencies in the impacted region.

Ideally, these TAZs correspond to those used by transportation planning agencies in the development of transportation plans and are in GIS file format.

4.1.4 Vehicle Operation Costs and Value of Time.

In order to estimating short term economic impacts due to disruptions in the freight systems, the outputs of the model are presented in monetary units for the corresponding economic analysis. Traffic operation is directly associated with two types of costs: vehicle operation costs and value of time.

The value of time is obtained by vehicle type, e.g., cars, and trucks (different combinations), under different conditions. This value is presented in monetary units per unit of time, e.g., dollars per hour. When detailed information about the traffic flows are available, it is highly recommended to use values of time segregated by user type. However, it is reasonable to work with average values when these details are not available.

The vehicle operational costs are also associated to each vehicle type. In general, they are related to fuel and oil consumption, maintenance and reparations, tires tear, and mileage-dependent depreciation. Additionally, there is a shipping inventory cost associated with the shipment value of each commodity transported by commercial vehicles.

4.2 Network and Traffic Flows in the Study Region.

Before defining the network and traffic flows used for modeling purposes in the study region, it is required to clearly define the extent of this region. Similarly, defining the study region requires a clear formulation of the disruption scenario framed in the zoning system presented in the FAF3 and complemented with TAZs provided by the planning agencies in the region. This subsection presents guidelines to define the study region based on the above mentioned inputs.

There are four criteria that define the coverage of the study region. First, the extent of the impacted region determined by the disruption scenario as presented in the corresponding subsection before. Second, the FAF3 zone(s) closest to the impacted region or containing it. Third, the TAZs provided by planning agencies in the region. Finally, the matching between the FAF3 transportation network and these TAZs.

The first two criteria, i.e., impacted region and related FAF3 zones, define the boundary that separates internal and external zones in the study region. All internal zones are defined within the impacted region and the chosen FAF3 zone(s). These internal zones are based on the TAZs provided by planning agencies in the region, which delineate the smallest size of these zones. However, sometime it is not appropriate to define internal zones identical to these TAZs because there might be a problem if they are so disaggregated that cannot be properly connected to the FAF3 transportation network. Figure 6 presents an example of this mismatching. In this figure there is a considerable number of TAZs surrounded by four highways. Although a few of them can be connected directly to the adjacent highways, this is not the case for many of them. Hence, an additional process that aggregates these TAZs is required before finalizing the definition internal zones in the study region. Some criteria to aggregate these regions are: aggregating TAZs with similar socio economic characteristics, defining continuous internal zones with similar shapes and sizes (ideally convex and not too elongated), connecting these zones directly to the FAF3 highway network, and maintaining natural and political boundaries for these zones.

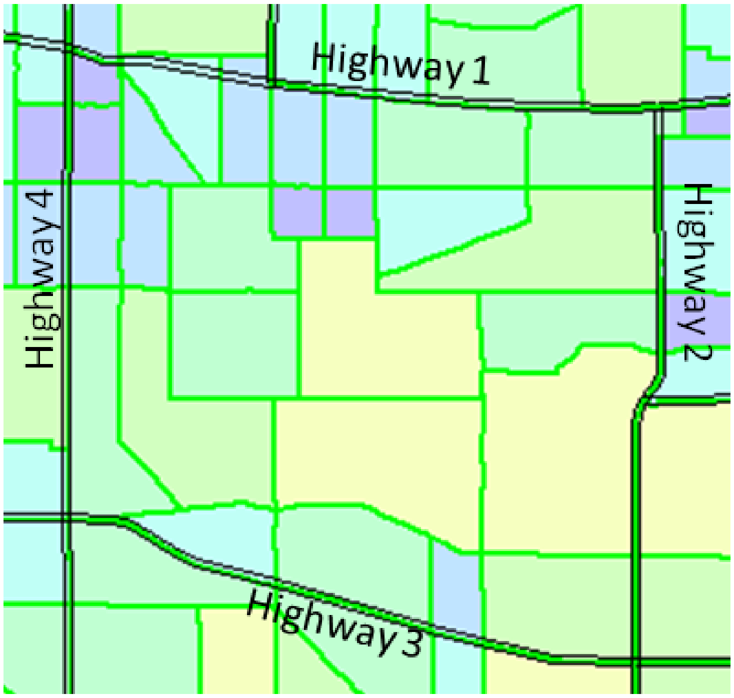

Figure 6. Example of Not Properly Matching Between the Level of Disaggregation of TAZs Provided by Planning Agencies in the Region and the Highway Network in the FAF3.

On the other hand, external zones are defined outside of the study region boundary. These zones are useful to represent the flow of commodities produced from the study region to other FAF3 zones and attracted to the study from other FAF3 zones. Likewise, they are used to represent the flow of commodities that are not produced or attracted in the study region but that could traverse this region while traveling between an OD pair.

Once the internal and external zones in the study region are defined, the FAF3 highway network is used to connect these zones. The FAF3 highway is at an appropriate level of resolution for regional modeling and has traffic characteristics useful for traffic assignment such as: capacity and free flow speed. Likewise, it presents traffic flows for trucks and cars that can be used for traffic estimation and validation.

Therefore, at the end of this stage, the modeler has a study region with internal and external zones and a highway network connected to the centroids of these zones. This network presents features that can be used for the estimation and validation of traffic models.

4.3 Proportion of trucks in each link per commodity.

Having the flow of trucks disaggregated per commodity type in each link of the network is ideal to undertake a multicommodity short-term economic analysis. However, this information is not available in any of the dataset presented in the FAF3 website (FMO 2012). Therefore, a procedure to estimate this multicommodity or multiclass flow is proposed. In essence, it is wanted to find the proportion of trucks associated with each commodity in each link of the network. Then, these proportions are multiplied by the given flow of trucks in each link obtaining a multiclass flow.

Two sequential procedures are required to achieve this goal. The first one is converting the OD flow of tons given in the FAF3 into OD flow of trucks for each commodity, and the second one is performing a multiclass traffic assignment over the U.S. FAF3 highway network.

4.3.1 Conversion of tons into trucks, FAF3 methodology.

This framework follows the methodology presented in the FAF3 (Battelle 2011) to transform OD matrices of tons of commodities into OD matrices of trucks. This methodology is summarized in Figure 7 and explained below.

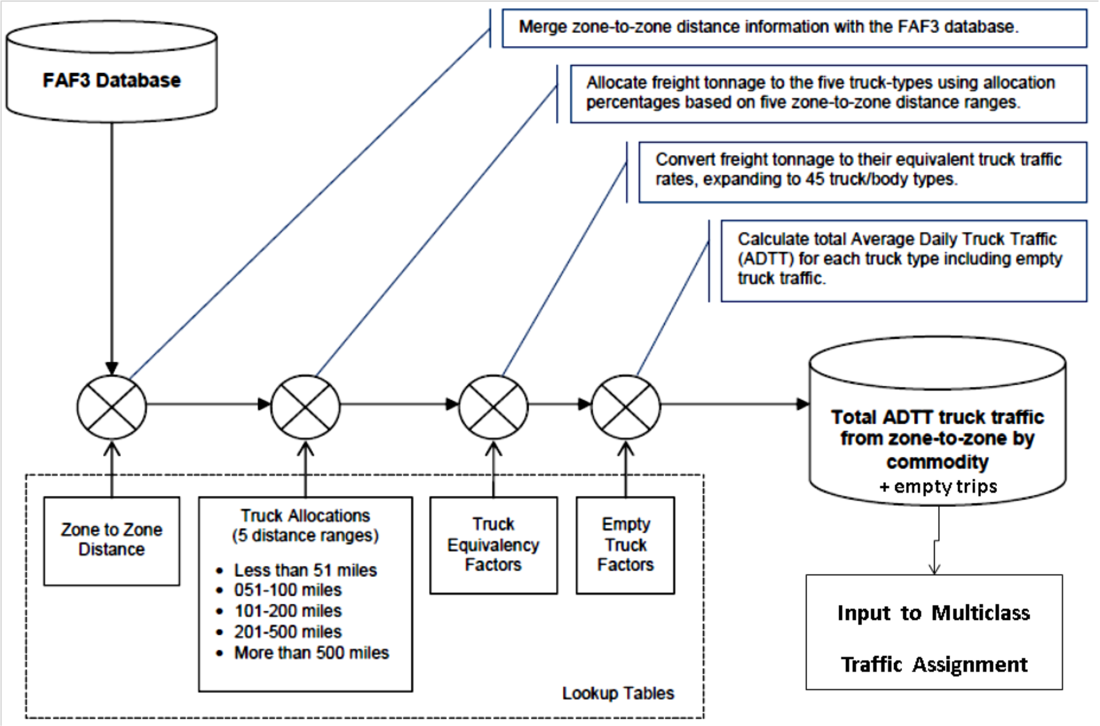

Figure 7. Truck Conversion Flow Diagram (Adapted from Battelle 2011).

The FAF3 database presents the flow of commodities by origin, destination, mode, tons and monetary value. For the purpose of this study, we refer to this database as the OD matrices of tons per commodity.

The first step requires the estimation of a zone-to-zone distance matrix. Recall that the zones correspond to FAF3 zones at this stage. As we mentioned before, the level of aggregation of the FAF3 zones does not match properly with the level of aggregation of the FAF3 network. However, since this is an intermediate step that provides a coarse idea of the fractions of commodities at each link of the network and there is no better data available, we consider that connecting the centroids of the FAF3 zones directly to the FAF3 highway network is reasonable to compute the shortest paths between them in this step. Then, each OD in the FAF3 database is associated with a traveling distance in the FAF3 highway network.

Table 1 Truck Allocation Factors (Battelle 2011).

Min. Range (Miles)	Max. Range (Miles)	Single Unit	Truck Trailer	Combination Semitrailer	Combination Double	Combination Triple
0	50	0.793201	0.070139	0.130465	0.006179	0.000017
51	100	0.577445	0.058172	0.344653	0.019608	0.000000
101	200	0.313468	0.045762	0.565269	0.074434	0.000452
201	500	0.142467	0.027288	0.751628	0.075218	0.002031
501	10000	0.064660	0.014900	0.879727	0.034143	0.004225

After that, each of these distances is categorized by distance range and the corresponding total OD tons are assigned to 5 truck types (single unit, truck trailer, combination semitrailer, combination double, combination triple) multiplying total tons by the corresponding truck allocation factor (Table 1). At the end of this step the total OD tons are split and assigned to 5 truck configurations.

Next, the amount of commodity in each configuration type is multiplied by truck equivalency factors that transform tons of commodities intro number of trucks from 9 body types (Automobile, Livestock, Bulk, Flat bed, Tank, Dry Van, Reefer, Logging, and Other). These factors are presented in the ANNEXES section (Table 29, Table 30, Table 31, Table 32, and Table 33).

Table 2. Empty Truck Factors (Battelle, 2011)

Body Type	Single Unit	Truck Trailer	Combination Semitrailer	Combination Double	Combination Triple
			Domestic and Sea-Port Shipping		
Dry Van	0	0	0.14	0	0
Flat Bed	0	0	0.2	0.16	0
Bulk	0.21	0.14	0.2	0.2	0.06

Body Type	Single Unit	Truck Trailer	Combination Semitrailer	Combination Double	Combination Triple
Reefer	0.14	0.16	0.16	0.2	0.03
Tank	0.17	0.18	0.2	0.2	0
Logging	0.12	0.07	0.1	0.04	0.07
Livestock	0.1	0.08	0.09	0.13	0
Automobile	0.24	0.21	0.2	0.13	0
Other	0.1	0.06	0.25	0	0
Land Border Shipping					
Dry Van	0	0	0.28	0	0
Flat Bed	0	0	0.4	0.32	0
Bulk	0.42	0.28	0.4	0.4	0.12
Reefer	0.28	0.32	0.32	0.4	0.06
Tank	0.34	0.36	0.4	0.4	0
Logging	0.24	0.14	0.2	0.08	0.14
Livestock	0.2	0.16	0.18	0.26	0
Automobile	0.48	0.42	0.4	0.26	0
Other	0.2	0.12	0.5	0	0

After computing the number of loaded trucks by type and body, these values are multiplied by an empty truck factor in order to incorporate such operational behavior. These factors are presented in Table 2. Recall that information about domestic, sea-port, and land border shipping is available in the dataset.

4.3.2 Multiclass Traffic Assignment.

The following step required to find the proportion of trucks in each link of the network per commodity is performing a multiclass traffic assignment between the FAF3 zones over the FAF3 highway network. This procedure requires two inputs: OD matrices of trucks for each commodity type (obtained in the previous step), and a network suitable for traffic assignment as the one available in the FAF3 website (FMO 2012). The outputs are the flow of trucks per commodity type k at each link ij in the FAF3 highway network (x_{ij}^{k}). Multiclass traffic assignment is a procedure available in commercial software like TransCAD.

However, one must be careful when comparing the traffic flows obtained from this assignment with those reported in the FAF3 data. This is because the flows reported in the FAF3 data are obtained from an ad hoc procedure that generates multiple centroids for each zone and iteratively runs traffic assignment up to obtaining a pattern close to the one observed from traffic counts (Battelle 2012). Although the authors contacted the developers of FAF3 looking for more information about this procedure and asking about the possibility of sharing these data, this was not possible.

Therefore, given the public data available in the FAF3 website and the purpose of these step (having a coarse idea of the traffic flows per commodity in the FAF3 highway network) we consider that the results are sufficient to continue with the posterior steps.

4.3.3 Proportion of Trucks in each link per commodity.

The output of the previous step is the flow of trucks per commodity type k at each link ij in the FAF3 highway network (x_{ij}^{k}). Recall that empty trips (previously obtained) are assumed as another commodity type or class ($k = emptyTrip$). Therefore, the proportion α_{ij}^{k} of trucks associated with commodity k (empty trips included) in the link ij is obtained from Equation (1).

$$\alpha_{ij}^{k} = \frac{x_{ij}^{k}}{\sum_{k \in K} x_{ij}^{k}} \quad \forall (i,j) \in A \tag{1}$$

In Equation (1), K is the set containing all the groups of commodities considered in the FAF3 plus the empty trips, and A is the set of all links in the FAF3 network. Other notation is previously defined.

Because of the limitation presented in the previous step, there might be links in the FAF3 network where $\sum_{k\in K} x_{ij}^{k} = 0$ and α_{ij}^{k} cannot be directly computed. For links outside of the study region (internal and external zones) this is not a problem because they are not considered in the analysis. However, for those links within the study region a special manipulation is required and described below.

4.4 *Multiclass OD Estimation in the Study Region*

At this stage we have defined the study region (internal and external zones), and the highway network within this region with traffic flows. Likewise, we estimated the proportions of trucks per commodity (and empty trips) in each link of the FAF3 network. These inputs are used to estimate the OD matrices per commodity type (and empty trips) in the study region. The steps required for this estimation are: assigning the proportion of trucks per commodity (and empty trips) to each link in the network within the study region, adding the flows of cars available in the FAF3 network data, obtaining multicommodity or multiclass flows at each of these links, and performing multiclass traffic assignment in the study region. The output of this stage is a set of vehicle OD matrices for each vehicle type, e.g., cars and trucks, and, for trucks, for each commodity type (and empty trips) where the origins and destinations correspond to internal; and external zones in the study region.

4.4.1 Assign proportions $\boldsymbol{\alpha_{ij}^{k}}$ to the traffic flows in the study region

In a previous step, the proportions α_{ij}^{k} of trucks associated with commodity k (empty trips included) were related to each link ij in the FAF3 Network. Therefore, at this point many of the links in the study region are associated with a proportion α_{ij}^{k}. However, as we mentioned before, when $\sum_{k\in K} x_{ij}^{k} = 0$ it is not possible to compute α_{ij}^{k}. Therefore, the proportions for these links are assigned manually following modeler's criteria and giving continuity to the values of α_{ij}^{k} in the adjacent links.

Then, it is possible to obtain the flow of trucks x_{ij}^{k} for each commodity type k (and empty trips) at each link ij in the network by applying Equation (2),

$$x_{ij}^{k} = \alpha_{ij}^{k} x_{ij} \quad \forall (i,j) \in A, \forall k \in K \tag{2}$$

where x_{ij} is the total flow of trucks in the link ij and A is the set of arcs in the study region (in this case). Other variables are previously defined.

Additionally, the flows of cars x_{ij}^{c} at each link ij in the network can be considered for multiclass OD estimation because the information is available from the FAF3 data. Therefore, the set of classes K used for multiclass OD estimation is $K = \{1, \dots, 43\} \cup \{emptyTrips\} \cup \{c\}$, where $\{1, \dots, 43\}$ are the indexes associated to the flows for each commodity group considered in the FAF3, $emptyTrips$ is the index associated to the flow of empty trips, and c is the index associated to the flow of cars.

4.4.2 Base Link and OD travel times

All inputs required to perform multiclass OD estimation are available at this point: zoning system and transportation network in the study region, multiclass flows at each link of the network x_{ij}^{k}, and other network characteristics such as link capacity and free flow speed. Multiclass OD estimation is available in commercial transportation software like TransCAD. The outputs of this procedure are OD matrices for cars and trucks between internal and external zones in the study region. The matrices for trucks are disaggregated by commodity type and empty trips. Likewise, this step associates each link in the network with a traversing travel time which can be used to compute economic indicators such as total value of travel time and total vehicle operational costs in the base case.

4.5 Link and OD Travel Times for the Scenario with Disruption.

In the previous step multiclass OD matrices are determined between internal and external zones in the study region. Likewise, this demand is associated with a set of traversing times at each link. However, we are interested in finding the new travel patterns that emerge when there is a disruption in the network.

This is achieved by reducing the capacity of the arcs according to the disruption characteristics previously defined. Assuming that in the short term the OD demand remains fixed, we can perform traffic assignment over the disruption network and obtain a new set of link travel times that can be combined with the value of travel time and the vehicle operational costs in order to estimate the economic impact associated with this disruption.

4.6 Conclusions about the Impacts of the Disruption

At this point we are able to estimate the total user cost associated with the base scenario (no disruption) and the total user cost associated with the disruption. Therefore we can quantify the short term economic impacts due to a disruption in the freight system and provide conclusions about the vulnerability and reliability of the system. Likewise, providing a regional analysis for the estimation of regional economic losses.

4.7 Regional Economic Impact Methodology

There are numerous regional economic impact methodologies used to measure the economic impacts in the freight transportation industry, also known as the transportation, distribution, and logistics (TDL) industry. Various regional economic impact models have been used in the past to evaluate economic impacts. These range from the simplest model in regional economies – the economic-base model to more sophisticated input-output models. A critical review of major regional economic impact models is provided here (Crihfield & Campbell, 2001; Leontief, 1986; Lynch, 2000; Miernyk, 1965; Miller & Blair, 1985; Richardson, 1972; Schaffer, 1999; U.S. DOT, FHWA, 1994) by highlighting the advantages and disadvantages of these models. Based on our literature review, an integrated regional economic impact model that exploits the complementary nature of econometric models and input-output models was used. This methodology provides an improved regional analysis methods compared to the use of any one model in isolation.

Economic-base models focus on the demand side of the economy. They ignore the supply side, or the productive nature of investment, and therefore take a short-run approach. These models ignore capacity constraints, assume perfect elasticity of supply for inputs, and do not show the interdependence between different sectors of the economy. The major assumption of these models is that the exports are the sole determinant of economic growth. Therefore, it ignores several other factors that may contribute to economic growth in a region.

The logic behind input-output (I-O) models is similar to that of economic-base models. An I-O model is designed to trace the effects of changes in an economy and basically takes two forms: a) structural change; and b) change in final demand. Changes in structure of the economy can be through several ways, for example, investment in transportation infrastructure. Changes in final demand are changes in household demand and government demand. The main assumptions of an I-O model are linear production technologies; constant returns to scale; homogeneous consumption functions; and price inflexibility.

The standard I-O model in matrix notation is given by:

$$Y = (I - A)X \tag{3}$$

The solution structure of (3) is

$$X = (I - A)^{-1}Y \tag{4}$$

X is a vector of inputs, Y is the vector demand of final demand variables, and $(I - A)^{-1}$is the matrix of interdependence coefficients.

For example, in the case of a regional employment model, the elements in the $(I - A)^{-1}$ matrix measure the direct and indirect employment levels from each sector of the economy to satisfy given levels of final demand. Using equation (4), the levels of employment from all sectors required to support specified levels of final demand in all sectors of the economy can be obtained. In addition, equations (3) and (4) have dynamic representations of

$$\Delta Y = (I - A)\Delta \mathrm{X} \tag{5}$$

and

$$\Delta X = (I - A)^{-1} \Delta Y \tag{6}$$

An illustration of a simple input-output model is presented in Appendix of this section. The I-O models are essentially general equilibrium in nature and assume that markets clear through supply adjustments to demand shocks and prices play no role in the market. On the other hand, regional econometric models use a partial disequilibrium approach and the focus is typically on the dynamic adjustment to exogenous shocks. Unlike I-O models, econometric models do not assume price rigidity.

The key motivation for integrating I-O model and econometric model in our regional economic impact analysis is to improve the regional modeling method by utilizing the strengths of each model and overcoming the weakness of one model by the complementary nature of the other. The integrated model has the advantage of increased sectoral disaggregation and also addresses the assumption of a fixed employment-output technology in the I-O model. In addition, integrated econometric and I-O model can improve forecasting performance, provide more comprehensive impact analysis, and address measurement error concerns.

There is a wide range of commercially available input-output models that can be used to evaluate economic impacts of the TDL industry. They range from relatively inexpensive and fairly simple models to most sophisticated and expensive integrated input-output econometric models. The mostly widely used among these models are RIMS II, REMI, and IMPLAN.

RIMS II is based on an I-O table derived from Bureau of Economic Analysis's (BEA) national input-output table and the regional economic accounts. There are several advantages of using RIMS II. The accessibility of the data sources makes it possible to estimate regional multipliers without conducting relatively expensive surveys. The RIMS II multipliers are available from the BEA and widely used by both the public and private sectors. These multipliers can be compared across regions and are updated to reflect changes in local area personal income and wage data.

The REMI model is the most sophisticated and expensive integrated input-output and econometric model. It has several advantages over RIMS II. It provides a wider range of outputs and a lager set of policy variables. However, confidentiality requirements produce suppressions in many of the data.

The IMPLAN model falls in between RIMS II and REMI models both in terms of sophistication and price. It has all the characteristics of RIMS II and REMI and also allows integrating regional input-output model with econometric model. The IMPLAN model generates two types of multipliers comparable with the other two models. The structural matrices form the basis for the inter-industry flows. There are two types of structural matrices. The Use Matrix shows the use of commodities by each industry while the Make Matrix shows the production of commodities made by each industry.

This study employs the IMPLAN model. It is a 440 sector input-output model. REMI's econometric component is the major structural difference between the models, but in other regards the models are similar. Both the models are typically used for economic impact analysis. Both models use data from a variety of sources, including CEW (Covered Employment and Wages – formerly known as ES202 data), Regional Economic Information System (REIS) data, County Business Patterns, Censuses of Manufactures, Transportation, and Government, and the Survey of Current Business.

IMPLAN uses both REIS and BLS data to estimate jobs. BLS data do not include self-employed or proprietorship employment data. This accounts for roughly 10 percent of the total employment. Therefore, IMPLAN estimates employment data from both CEW/ES202 and REIS. For some non-disclosed data in Northwest Indiana, such as Air, Rail, and Water, IMPLAN uses County Business Patterns data to estimate the number of jobs based on number of establishments, size-category of the establishments, etc[1].

REMI's reliance on regional time-series data offers a dynamic forecasting capacity unavailable in IMPLAN. REMI model has been used widely by regional planners to perform impact and forecasting analysis for state and local economies. However, recently IMPLAN is also becoming popular for economic impact analysis because impact outcomes of IMPLAN are very similar to REMI's outcomes. Recent studies2 showed that in terms of several performance criteria used to compare RIMS II, REMI and IMPLAN, IMPLAN's outcomes, on balance, are somewhat in between and more plausible than those for REMI.

4.7.1 Freight Disruption Scenario

Network disruptions due to natural disasters or attacks for short time periods can be used to estimate the economic impacts for freight movements. The temporal nature of disruption will be examined for potential economic consequences. This is considered as a short-term disruption, that is, one lasting a day or up to a week. It might cause some temporary or short-term economic loss, but overall would have minimal economic impacts. However, if a disruption scenario lasted a much longer time we could expect

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[1] This is definitely an improvement over just relying on one source of data or excluding self-employed and proprietorship employment data. However, underestimation or overestimation of employment data is not unlikely if there is any estimation bias.

[2] Crihfield and Campbell (2001); Lynch (2000).

severe consequences, depending on how industries and supply chains adjust. It should be noted that temporally short disruptions could also have long-term effects. Thus, network resiliency in placing back into service the necessary facilities and services to move freight becomes an important consideration in assessing overall economic impact.

4.7.2 Data from TRANSCAD Multiclass Traffic Assignment

In an earlier section of the report, a multiclass traffic assignment was employed where the value of travel time lost by the trucking industry and the loss in the value of truck shipments of 43 FAF commodities were estimated. The value of travel time lost by the trucking industry were used to estimate the increase in the vehicle operating costs (including fuel and maintenance costs) and the increase in shipping inventory costs. The travel time delay for each commodity in trucks was used to estimate the loss in value of the total truck shipments of these 43 FAF commodities.

4.7.3 IMPLAN Analysis

The study region's input-output model, developed using IMPLAN, was used to estimate the ripple effects of the highway closures as they spread in the internal and external traffic analysis zones of the freight transportation network.

Two key activities were modeled in IMPLAN to analyze the economic impacts. These are: (1) Increase in the Trucking Industry Costs, and (2) Decrease in value of FAF commodities

Since the input-output model requires inputs in terms of sales revenue or employment, the additional trucking costs were converted into revenue changes. These data assumed that additional costs of truck freight transportation were built into the price of service and passed along to consumers. The change in value of 43 FAF commodities were also matched with the IMPLAN industry sectors as shown in Table 3:

Table 3. Matching of Values of FAF 3 Commodities to IMPLAN Sectors

Sector	Industry Sales
335 Transport by truck	$1,371,401.00
43 Flour milling and malt manufacturing	$394,861.00
42 Other animal food manufacturing	$55,272.00
319 Wholesale trade businesses	$11,932,956.00
153 Pottery, ceramics, and plumbing fixture manufacturing	$597,533.00
187 Ornamental and architectural metal products manufacturing	$1,125,492.00
132 Medicinal and botanical manufacturing	$213,052.00
115 Petroleum refineries	($471.00)
224 Mechanical power transmission equipment manufacturing	$748,028.00
390 Waste management and remediation services	$32,854.00

4.7.4 Economic Impact Analysis Findings

Regional economic impacts fall under five main categories. A brief description of each of the five impacts is provided below:

a) Output impact

The output impact is the value of production of the freight dependent sectors for an annual calendar year. Output impact is measured by the total value of purchases by intermediate and final consumers. It can also be measured by the intermediate outlays plus value added by these freight dependent sectors. Another way of interpreting the output impact is the value of sales plus or minus business inventories.

b) Employment impact

Employment impact of the freight dependent sectors includes total wage and salary employees as well as self-employed jobs created in the study region. Both full-time and part-time workers are measured in annual average jobs.

c) Value added impact

The value added impact of the freight dependent sectors in Northwest Indiana consists of the following four major components :

i) Employee compensation: It includes all income to workers paid by employers of the industry in wages, salaries, and benefits (including health and life insurance, retirement payments, and any other non-cash compensation).

ii) Proprietary income: Income received by self-employed individuals, such as, private business owners, doctors, lawyers, private consultants, etc. are included.

iii) Other property type income: It consists of interest income, rental income, dividend income, individual and corporate profits, and royalties.

iv) Indirect business tax: It primarily includes excise and sales taxes paid by individuals to businesses.

d) Labor income impact

The labor income impact of the freight dependent sectors is a part of the value added impact. It includes employee compensation and proprietary income impacts.

e) Tax impact

The tax impact includes the federal, state, and local income taxes, corporate profits taxes, sales taxes, excise taxes, property taxes, payroll taxes, estate and gift taxes, and other personal taxes, such as, motor vehicles taxes, license fees, fines and other fees.

CHAPTER 5. STUDY CASE: 2008 NORTHWESTERN INDIANA FLOODS.

From September 15, 2008 to September 18, 2008, a major flood forced the closure of several highway segments in the Northwestern Indiana region. An important corridor affected by the floods in this region is Borman Expressway (Figure 8). The closure took four days and caused massive traffic jams on U.S. 30 and other main arteries where motorists tried to find alternative routes. Both freight and passenger suffered serious disruption due to this closure.

Figure 8. Borman Corridor Location at Different Scales. Google Maps.

The steps presented in the detailed framework above are applied in this context to estimate the short-term economic impacts due this disruption in the freight highway system.

5.1 Inputs

As mentioned previously, four major inputs are needed to implement the framework: (i) the Freight Analysis Framework version 3 (FAF3), (ii) Transportation Analysis Zones (TAZs) from planning agencies in the region, (iii) a disruption scenario, and (iv) vehicle operational costs, and value of time.

5.1.1 FAF3 Contexts

A description of the FAF3 and the datasets associated with this source is presented in the previous section. This subsection describes different network settings required to use the FAF3 network data in the corresponding traffic models implemented by the framework. The FAF3 highway network contains basic features, e.g., calibrated truck and total traffic average annual daily traffic (AADT) and link capacity, useful to perform OD estimation (as required in some steps of the framework). This features are transformed to hourly values using directional design-hour volumes (DDHV), which are calculated following the procedure presented in the 2000 highway capacity manual (HCM, 2000). Other required feature for the OD estimation procedure is free flow speed. Since this information is not available, state speed limit are used and complemented with correction formulas presented in the FAF3.

5.1.1.1 Computation of Directional Design-Hour Volumes (DDHV)

The directional design-hour volume (DDHV) is computed following the procedure in HCM (2000). Thus, DDHV is computed as presented in Equation (1).

$$DDHV = AADT \times K \times D \tag{7}$$

where

$DDHV$: directional design-hour volume (veh/h).

$AADT$: annual average daily traffic (veh/day).

K: proportion of AADT occurring in the peak hour.

D: proportion of peak-hour traffic in the peak direction.

The K factors are defined according to the values in Table 4 (HCM, 2000).

Table 4. Typical K-Factors (HCM, 2000)

Area Type	K-Factor
Urbanized	0.091
Urban	0.093
Transitioning/Urban	0.093
Rural Developed	0.095
Rural Undeveloped	0.100

Table 5. FCLASS of FAF3 Network

FCLASS (Functional Class)	
01 Rural Interstate	11 Urban Interstate
02 Rural Principal Arterial	12 Urban Freeway or Expressway
06 Rural Minor Arterial	14 Urban Principal Arterial
07 Rural Major Collector	16 Urban Minor Arterial
08 Rural Minor Collector	17 Urban Collector
09 Rural Local	19 Urban Local

The FAF3 network file provides road functional class (FCLASS) and rural/urban code (RUCODE) that can be used to determine the K factors as presented in Table 4. The values of FCLASS available in the FAF3 network are presented in Table 5.

Likewise, the three values of RUCODE in the FAF3 network are: 1 for rural, 2 for small urban (1990 pop 5,000 -49,999), and 3 for large urban (1990 >= 50,000).

The criteria presented in Table 6 is proposed to estimate K according to the available information for FCLASS and RUCODE:

Table 6. K-factor Used in the OD estimation

FCLASS code	RUCODE	Area Type (K-factor)	K-Factor
>9	2	Urbanized	0.091
>9	3	Urban	0.093
1,2,6,7	1	Rural Developed	0.095
8,9	1	Rural Undeveloped	0.1

According to HCM (2000) and information from the FAF3, the D factor used in the project is $D = 0.55$.

5.1.1.2 Free Flow Speed

Since the FAF3 network file does not provide accurate free flow speed (FFS), these values are computed following the set of equations (8) (Battelle, 2011).

$$FFS = (0.88 \times Link\ Speed\ Limit + 14);\ \ for\ speed\ limits > 50$$
$$FFS = (0.79 \times Link\ Speed\ Limit + 12);\ \ for\ speed\ limits \leq 50 \qquad (8)$$

In the FAF3, speed limits are obtained from the 2008 Highway Performance Monitoring System (HPMS). Where this information is missing, the criteria presented in Table 7 are followed.

Table 7. Speed Limits (Mph) for Missing HPMS Speed Data (Battelle, 2011)

Functional Class	Pavement Type	Fully Controlled		Partially Controlled		Uncontrolled	
		With Median	Without Median	With Median	Without Median	With Median	Without Median
Rural	Paved	65	60	65	55	65	55
	Unpaved	25	15	20	15	15	10
Urban	Paved	55	45	45	35	35	25
	Unpaved	15	10	10	10	10	10

Table 8 Speed Limits in the Study Region.

State	Rural Interstates (mph)	Urban Interstates (mph)	Other limited-access roads(mph)	Other Roads (mph)
Indiana	Cars 70, Trucks 65	55	60	55
Illinois	65	55	65	55
Michigan	Cars 70, Trucks 60 Cars < 70, Trucks 55	65	70	55

The HPMS data is not available in this research. Therefore, we used the free flow speed according to the maximum posted speed limits[3]. The speed limits associated with the study region are presented in Table 8.

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[3] http://www.iihs.org/laws/speedlimits.aspx#IN

5.1.2 Transportation Analysis Zones (TAZs) and Centroids

As mentioned before, the FAF3 TAZs and their corresponding commodity OD flows are too aggregated for the level or resolution required in the Northwestern Indiana region analysis. Therefore, the Northwestern Indiana Regional Planning Commission (NIRPC) was contacted in order to find more disaggregated data suitable for this study. This organization provided disaggregated TAZs that can be appropriately used in this study (see Figure 9).

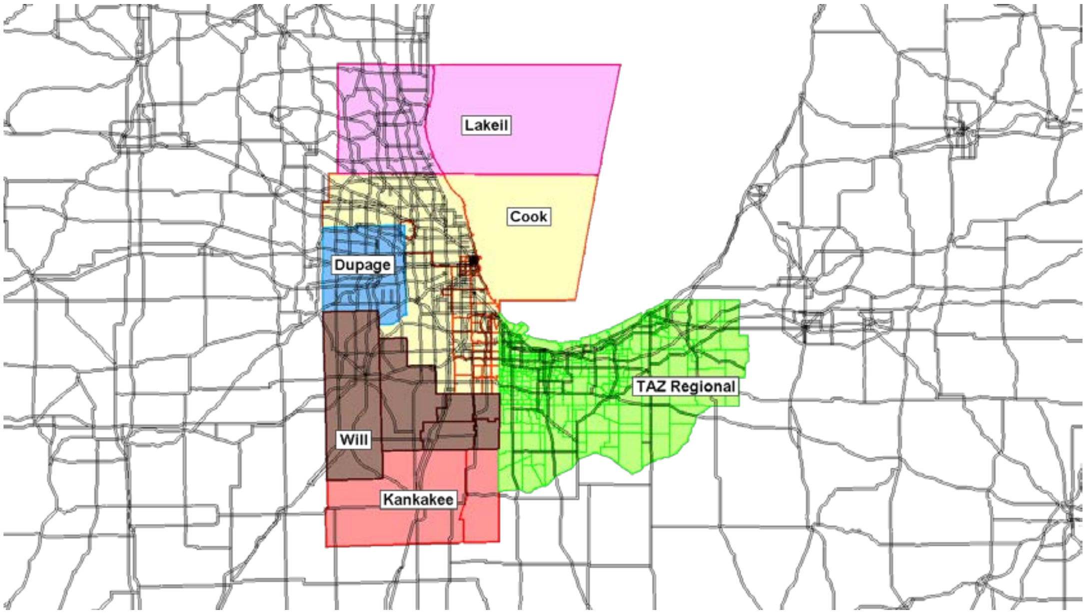


Figure 9 Northwestern Indiana Regional Planning Commission Transportation Analysis Zones.

The study region includes the northeastern part of Illinois, the northern part of Indiana and a small part of the southwestern Michigan. The TAZ system used in this project includes three levels of resolution, which are census tract level and aggregated census tract level and county level. A total of 467 zones are used in this project, as shown in Figure 10.

The area impacted by the 2008 floods includes the following counties: Lake (IN), Porter (IN), Laporte (IN), and part of Cook (IL). The TAZ zones in this region are mainly based on the zoning system provided by Northwestern Indiana Regional Planning Commission (NIRPC), which has a resolution of census tract level, as shown by the yellow zones in Figure 10.

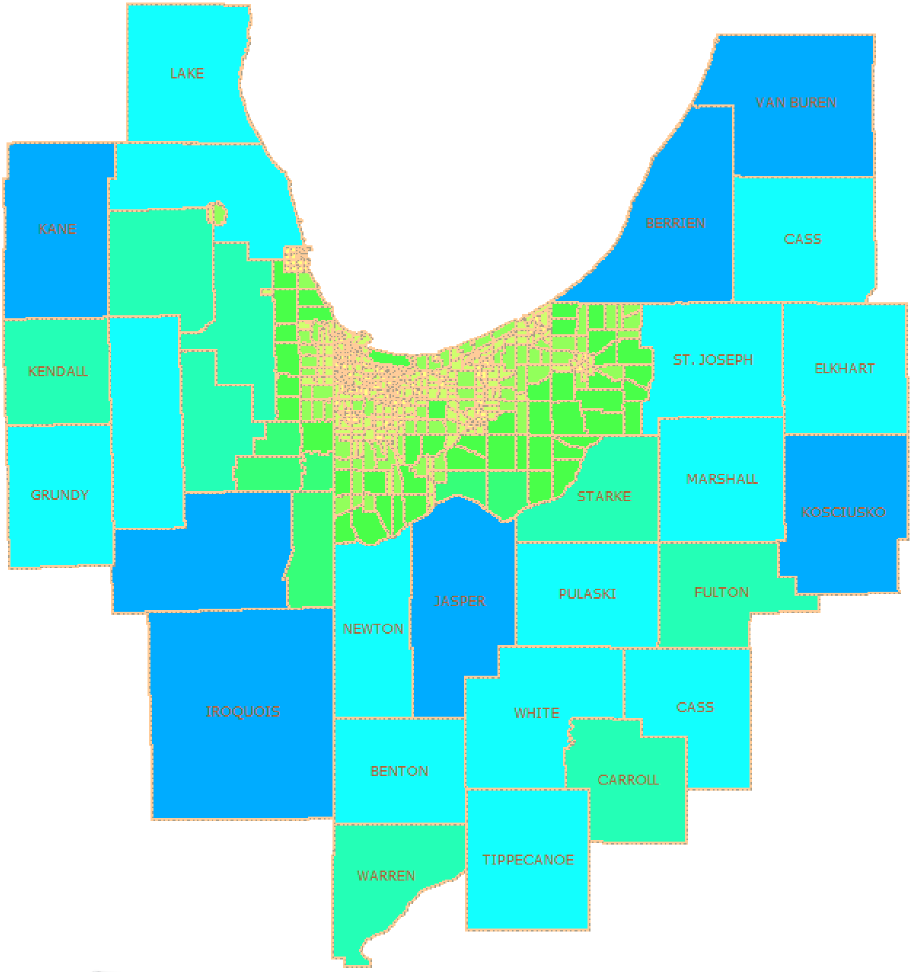


Figure 10 Transportation Analysis Zones in the Study Region.

Considering that the census tract level is too disaggregated for some parts of the region, some small zones are aggregated into larger zones. These zones are mainly distributed in the periphery of the study region (light green zones shown in Figure 10).

The main criteria to aggregate these zones are population density, and accessibility to the highways network. Census tract with similar population density are aggregated together, and some zones that are not connected by major roads are joined with nearby zones to ensure accessibility. These zones constitute the set of internal zones. On the other hand, the external zones are generated using the surrounding counties as TAZs. This counties are located in Illinois, Indiana and Michigan State.

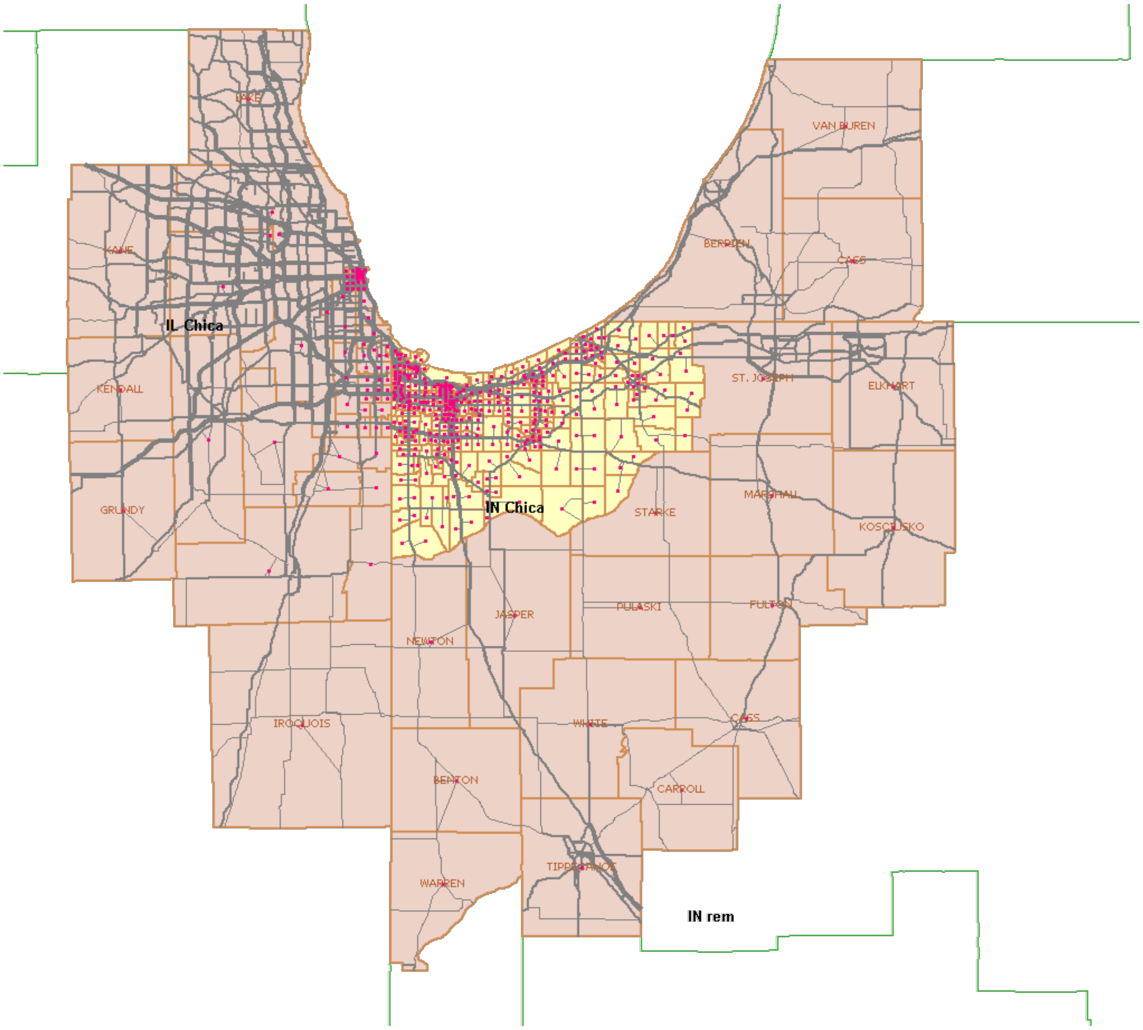


Figure 11 TAZ Centroids and Centroid Connectors

In summary, the whole study area includes the northeastern part of Illinois, the northern part of Indiana and a small part of southwestern part of Michigan State. The TAZ system used in this project include three levels of resolution, which are census tract level and aggregated census tract level and county level. A total of 467 zones are used. Each of these zones is associated with a centroid generated in TransCAD. This centroids represent nodes that connect each TAZ with the transportation network. Therefore, they encapsulate all the information associated with the TAZ. The centroids are connected to the network using centroid connectors. The number of centroid connectors varies according to the size of the underlying TAZ and the density of the network that is adjacent to the centroid. The criteria used to define the number of centroid connectors are presented in Table 9. The centroids and centroid connectors in the study region are presented in Figure 11.

Table 9. Criteria to Define Centroid Connectors

Area	Max. connector distance	Max. number of connections
$\leq 4\ km^2$	$4\ km$	1
$(4\ km^2, 30km^2]$	$7\ km$	1
$> 30km^2$	$25\ km$	3

Although TransCAD can automatically generate centroid connectors, the process requires some adjustments since some centroid connectors can cross zonal and physical boundaries.

5.1.3 Disruption Scenario

The disruption scenario associated to road closures in the 2008 Northwestern Indiana Floods is constructed by collecting and reviewing records from the Indiana Department of Transportation (INDOT) and news from different sources.

The information collected by the research team regarding this disruption scenario is presented below and associated to the corresponding source.

5.1.3.1 INDOT (09/15/08):

Online source:

http://www.in.gov/ActiveCalendar/EventList.aspx?view=EventDetails&eventidn=9068&information_id=18153&type=

Highways/roads closed:

- I-80/94 between U.S. 41 (Calumnet Ave) and SR 912 (Cline Ave) in Lake County
- SR 2 between I-65 and U.S. 231 in Lake County
- SR 51 between U.S. 6 and Fairview in Lake Station, Lake County
- U.S. 6 between Wisconsin St. and SR 51 in Lake County
- U.S. 6 between State Road 149 and Meridian Road in Porter County

5.1.3.2 INDOT (09/16/08):

Online source:

http://www.in.gov/ActiveCalendar/EventList.aspx?fromdate=9/16/2008&todate=9/16/2008&display=Year&type=public&eventidn=9070&view=EventDetails&information_id=18157

Highways/roads closed:

- Northbound I-65 between U.S. 24 in Jasper County and I-80/94 in Lake County

- Eastbound I-80/94 between the Illinois State Line and SR 51 (Ripley St.) in Lake County
- Westbound I-80/94 between SR 49 in Porter County and the Illinois State Line
- SR 2 between I-65 and U.S. 231 in Lake County
- SR 51 between U.S. 6 and Fairview in Lake Station, Lake County

5.1.3.3 ABC Local News (09/17/08):

Online source:

http://abclocal.go.com/wls/story?section=news/local&id=6391816

Highways/roads closed:

- I-80/94 (Borman Expressway) Eastbound between Bishop Ford Freeway and Ripley St (SR 51)
- I-80/94 (Borman Expressway) Westbound between Ripley St (SR 51) and Indianapolis Boulevard.
- Northbound I-65 between SR 24 and I-80/94
- Observation: the issue showed some other closures but they were in IL state and not important to the network in study.

5.1.3.4 NWI Times (09/18/08):

Online source:

http://www.nwitimes.com/news/local/article_df5debf1-38a0-5129-bf69-07a05c5eff97.html

Highways/roads closed:

- I-80/94 westbound between Ripley St. (SR 51) and Indianapolis Boulevard
- I-80/94 eastbound between Illinois State Line and Ripley St. (SR 51)

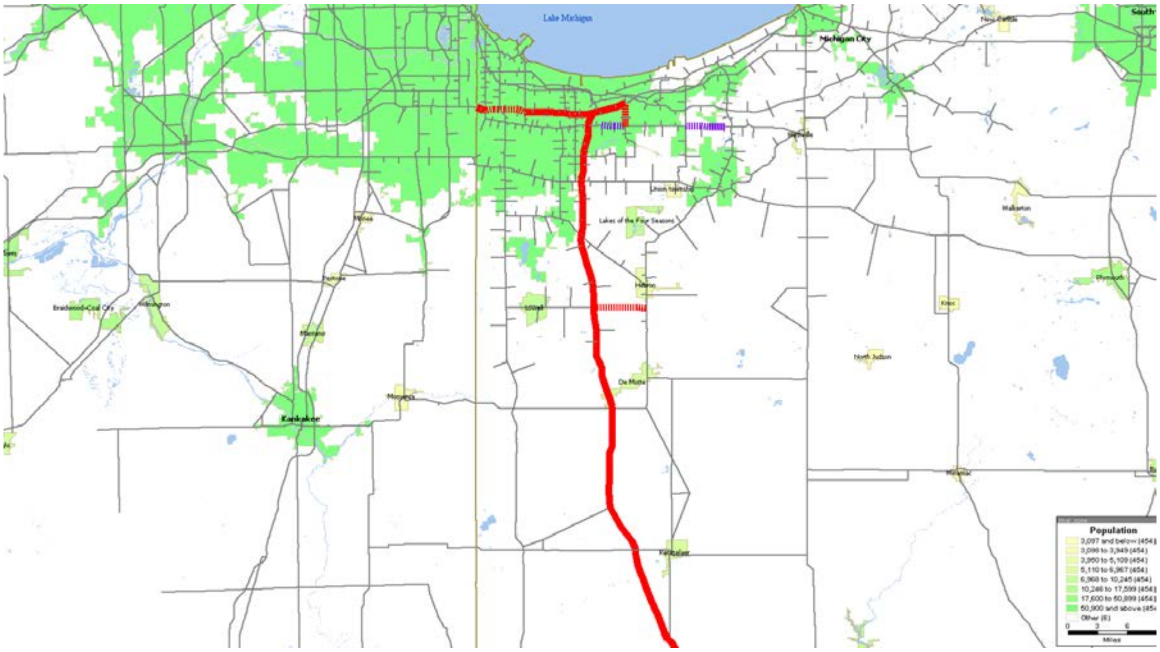
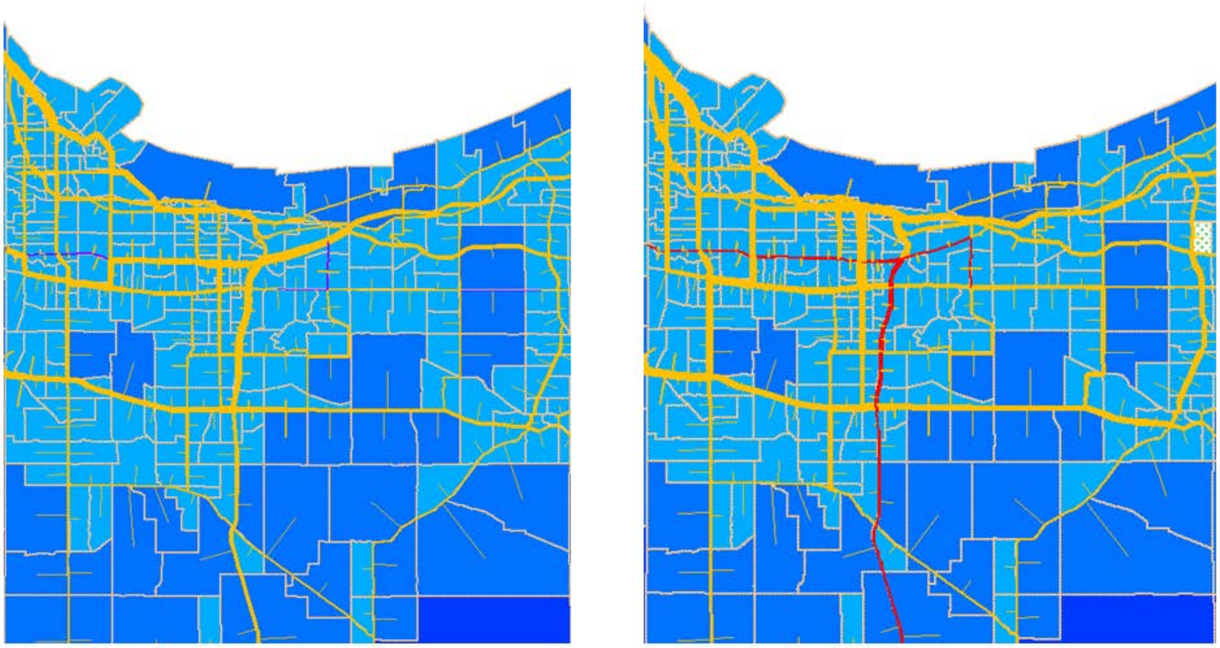


Figure 12 Highway closures in 2008 Northwestern Indiana Floods

After collecting this information we can identify all roads closed by the disruption (Figure 12). Likewise, different sections of roads are closed in different time periods during the four day flood. Therefore, two disruption scenarios with common characteristics are prepared. Figure 13 illustrates these scenarios. In Scenario I (Figure 13 (a)), the closed highways are highlighted with purple. On the other hand, in Scenario II (Figure 13 (b)) the closed highways are highlighted with red.


(a) Scenario I

(b) Scenario II

Figure 13 Disruption scenarios

5.1.4 Value of Travel Time and Vehicle Operation Costs.

The travel time cost and vehicle operating cost (VOC) follows the methodology discussed in Sinha and Labi (2007), chapters 5 and 7.

5.1.4.1 Value of Travel Time

Travel time cost analysis uses the value of travel time to compute the total user cost for passengers cars and trucks. The value of travel time used in the calculation is based on Forkenbrock, D., Weisbrod, G. E. (2001).

Table 10. Distribution of Hourly Travel-Time Value by Vehicle Class (2005 Dollars)

Category	Vehicle Class						
	Small Atutomobile	Medium-sized Automobile	4-Tire Truck	6-Tire Truck	3- or 4-Axle Truck	4-Axle Combination Truck	5-Axle Combination Truck
Labor/fringe	$32.22	$32.22	$22.10	$26.84	$22.35	$26.92	$26.92
Vehicle productivity	$2.11	$2.48	$2.67	$3.77	$10.78	$9.10	$9.78
Inventory	$0.00	$0.00	$0.00	$0.00	$0.00	$2.02	$2.02
On-the-clock	$34.34	$34.70	$24.77	$30.61	$33.13	$38.04	$38.72
Off-the-clock	$17.54	$17.58	$18.50	$30.61	$33.14	$38.04	$38.73

Source: Updated from Forkenbrock and Weisbrod (2001)

The value of travel time for trucks is assumed as the on-the-clock average for 6-Tire, 3- or 4-Axle, 4-Axle combination and 5-Axle trucks (Table 10). This value is $\mathrm{VT}_{\mathrm{truck2005}} = \$35.13/h\ \ (2005\ dollars)$.

For the passenger cars, we assume 15% on-the-clock and 85% off-the-clock vehicles, and compute the weighted average based on the value of travel time for small automobiles, which is $\mathrm{VT}_{\mathrm{car2005}} = \$20.104/h\ \ (2005\ dollars)$.

In order to convert this dollar values from 2005 to 2007 –year that corresponds to the latest information released by the FAF3, the following inflation rate is obtained from the Bureau of Labor Statistics:

$$\mathrm{inflation}_{2007-2005} = \frac{CPI_{2007} - CPI_{2005}}{CPI_{2005}} = 0.061659$$

where CPI_{year} is the yearly CPI value of 2005 and 2007 respectively.

Finally, the 2007's dollar values for the travel time of each user type are $\mathrm{VT}_{\mathrm{truck2007}} = 37.296\$/h\ \ (2005\ dollars)$ and $\mathrm{VT}_{\mathrm{car2007}} = \$21.344/h\ \ (2005\ dollars)$.

5.1.4.2 Vehicle Operating Cost (VOC)

The Vehicle Operating Cost (VOC) encapsulates cost of fuel, shipping inventory (Related to cargo's value, and interest rate), lubricate oil, preservation of vehicle-guideway contact surface, vehicle repair and maintenance, and depreciation. The values used in this study are based on those presented by Sinha and Labi's (2007). For VOC cost other than shipping inventory, we use the average value of the cost presented in Table 11. The average value for truck and small autos are used in the VOC (without shipping inventory) calculation.

Table 11. Average Vehicle Operating Costs (Cents/Vehicle Mile)

	Fuel and Oil	Maintenance and Repair	Tires	Mileage-Dependent Depreciation	Total
Small autos	5.4	3.5	0.5	13.9	20.59
Medium-sized autos	6.44	4.12	1.58	12.5	20.59
Large autos	7.50	4.33	1.90	12.5	22.17
SUVs	8.34	4.33	1.58	12	22.70
Vans	7.50	4.12	1.69	12	21.75
Trucks	21.41	11.09	3.70	10.6	44.64

Source: Costs are updated to 2005 from the following: nontruck fuel, maintenance and repair, and tires, AAA(2005); Truck fuel, maintenance and repair, and tires, Barnes and Langworthy (2003); and, depreciation estimations and projections are on the basis of data from FHWA (2002).

The shipping inventory costs calculation is based on AASHTO 2003's method, only speed is considered to affect the inventory cost. The calculation method is given by:

$$U_{IC} = 100 \times \frac{r}{365 \times 24} \cdot \frac{P}{S} \qquad (9)$$

where U_{IC} is the user inventory cost in cents per vehicle-mile, r is the annual shipper's implicit discount rate, P is the cargo value in dollars, S is the vehicle speed in miles per hour. The discount rate r is determined from the work by Winston and Chad (2004). They provide the propose a daily discount of 0.15 for perishable commodities, e.g., food, 0.05 for bulk commodities, e.g., gravel, and 0.10 for other commodities. A proper daily discount rate is related to each commodity and applied in in Equation (10) to determine the shipping inventory cost. The average cargo value (determined from FAF3) and discount rate for each commodity type are presented in Figure 14 and Table 12.

Table 12. Average commodity cargo value and shippers' implicit daily discount rate

Commodity	Average cargo value per Truck ($)	Shippers' Implicit Daily Discount Rate
Live animals/fish	31047.09	0.15
Cereal grains	3954.65	0.15
Other ag prods.	18236.62	0.15
Animal feed	12413.33	0.1
Meat/seafood	52593.52	0.15
Milled grain prods.	15784.35	0.15
Other foodstuffs	22910.47	0.15
Alcoholic beverages	22340.68	0.15
Tobacco prods.	488409.76	0.1
Building stone	7775.19	0.05
Natural sands	595.22	0.05
Gravel	369.79	0.05
Nonmetallic minerals	2829.61	0.05
Metallic ores	21225.18	0.05
Coal	1465.77	0.05
Crude petroleum	11814.24	0.05
Gasoline	18248.51	0.05

Commodity	Average cargo value per Truck ($)	Shippers’ Implicit Daily Discount Rate
Fuel oils	17634.34	0.05
Coal-n.e.c.	13589.70	0.05
Basic chemicals	17746.23	0.1
Pharmaceuticals	711321.23	0.15
Fertilizers	8083.31	0.1
Chemical prods.	61079.00	0.1
Plastics/rubber	45356.61	0.1
Logs	3256.94	0.05
Wood prods.	14055.90	0.05
Newsprint/paper	20674.98	0.15
Paper articles	18969.80	0.1
Printed prods.	39148.48	0.1
Textiles/leather	145039.19	0.1
Nonmetal min. prods.	10231.46	0.05
Base metals	23436.42	0.05
Articles-base metal	52496.31	0.05
Machinery	183665.96	0.1
Electronics	221176.66	0.1
Motorized vehicles	129333.19	0.1
Transport equip.	274701.61	0.1
Precision instruments	364203.34	0.1
Furniture	78354.00	0.1
Misc. mfg. prods.	81786.09	0.1
Waste/scrap	2618.52	0.05
Mixed freight	54437.84	0.1

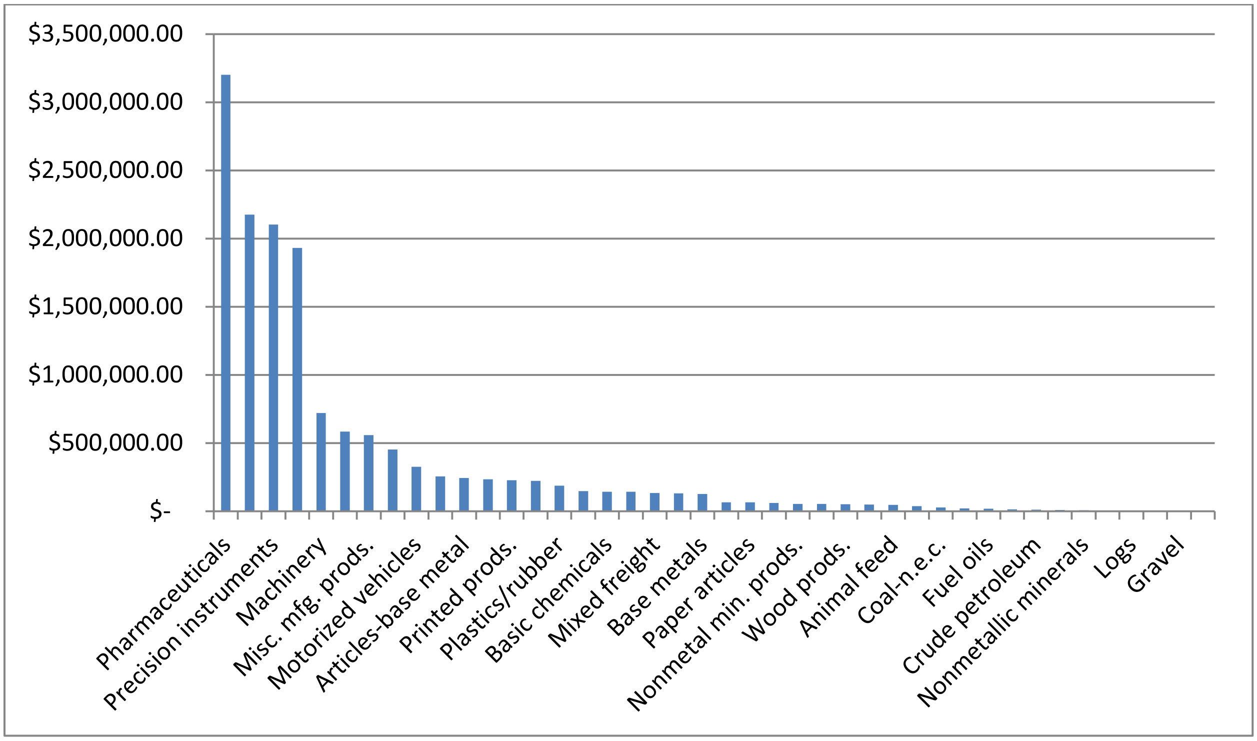


Figure 14 Average values of *P* (Cargo Value)

5.2 *Network and Traffic Flows in the Study Region.*

As discussed in section 4.1.1 and 4.1.2, we use the highway network provided by the FAF3. After defining the internal and external transportation analysis zones (TAZs), the corresponding highway network in the study region is subtracted from the total U.S. Network. This sub-network is used to perform traffic assignment and OD estimation models. An illustration of the highway network in the study region is presented in Figure 9.

5.3 *Proportion of trucks in each link per commodity.*

In order to perform multiclass OD estimation, the bidirectional count of trucks in each link per commodity is required as input. Thus, we are asked to find the proportion of trucks in each link per commodity. As observed in Figure 2, the tonnages of commodities are transformed into truck counts, and then, a multiclass traffic assignment is performed over the U.S. to obtain multiclass truck flows in the links of the FAF3 Network. These flows are used to compute the proportions α_{ij}^{k} that are subsequently used to estimate the truck flow in each link of the study region per commodity type.

5.3.1 Conversion of tons into trucks, FAF3 methodology.

The conversion of tons into trucks is performed following the FAF3 methodology presented in the work by Battelle (2011). This methodology is summarized in subsection 4.3.1. The inputs required are the FAF3 commodity OD matrixes, FAF3 zone-to-zone distances, truck allocation factors, truck equivalency factors and empty trucks factors.

The conversion process is illustrated with the following example from Battelle (2011). Assume that we are asked to find the annual flow of trucks between the origin FAF3 zone 49 and the destination FAF3 zone 41 for agricultural commodities (ID = 03, Table 28). For this example we consider them as border zones, which is important in order to apply the corresponding empty trips factors in a subsequent step. The annual flow of this commodity between these zones is 1519.15 Kilotons. All these inputs are available in the FAF3 commodity OD matrices provided in the FMO website (FMO 2012), which is a single and public database file.

Step1: Merge zone distance information with the raw FAF3 database (Figure 7). This step requires associating each OD pair with a traveling distance. However, this distance is not available in the files presented in the FMO website. Therefore, this information is subtracted from the available data (GIS files) by generating a centroid for each FAF3 zone and connecting it to the FAF3 highway network. Then, a matrix of shortest paths between zones is computed and this distance is used in the current step. For the sake of this example, and following the case presented in Battelle (2011), assume that the distance between zones 49 and 41 is 171.6 Miles.

Step2: Allocate freight tonnage to the five truck-types using allocation percentages based on five zone-to-zone distance ranges (Figure 7). In this step, we multiply the total tons from each OD pair by the corresponding allocation factor (Table 1) according to the distance previously computed. In our example, the distance is 171.3 miles, which corresponds to the share of tonnages presented in Table 13.

Table 13. Tonnage Allocated to the Five Truck Types

Truck Type	Allocation Factors	Value (Kilotons)
Single Unit	0.313468	476.20
Truck Trailer	0.045762	69.52
Combination Semitrailer	0.565269	858.73
Combination Double	0.074434	113.08
Combination Triple	0.000452	0.69

Step3: Convert freight tonnage to their equivalent truck traffic rates, expanding to 45 truck/body types (Figure 7). In this step, we multiply the value of tons associated to each truck type by the corresponding truck equivalency factor related to each truck body configuration. This value is reported either in Table 29, Table 30, Table 31, Table 32, or Table 33. Thus, we obtain the flow of trucks between each OD pair by truck type and body configuration (45 combinations). The results for this example are presented in Table 14. For instance, the tons of agricultural products (ID = 03) associated to single unit truck between this OD pair are 476,200 tons. From Table 29 (single unit truck), the truck equivalency factor for commodity 03 and, lets say, Bulk truck type is 0.01069. By multiply these two values we obtain the number of single unit trucks of body type Bulk related to agricultural products traveling between these two zones per year (5090.62 trucks in Table 14).

Table 14. Annual Truck Traffic, Loaded Trucks

Body Configuration	Single Unit	Truck Trailer	Tractor Semitrailer	Tractor Double	Tractor Triple
Dry Van	0	0	0	0	0
Flat Bed	0	0	429.36	0	0
Bulk	5090.62	1142.21	5461.51	410.46	0
Reefer	9433.60	3765.88	9789.49	3023.65	0
Tank	485.73	29.89	532.41	64.45	0
Logging	4742.99	670.86	3804.16	241.98	0
Livestock	4485.85	0	12185.35	0	0
Automobile	0	0	0	0	0
Other	700.02	387.22	0	0	0

Step 4: Adjust annual truck traffic using empty truck factors. After getting the annual truck traffic for loaded trips, they are multiplied by empty truck factors that incorporate the empty trips associated to these trucks. These factors are differentiated by truck type, body configuration, and two shipping characteristics: (i) domestic and sea-port shipping, and (ii) land border shipping. These characteristics are given in the OD database. In the current example, the values in Table 14 are multiplied by those in the lower part of Table 2. Then, the Annual Truck Traffic is obtained by adding these results to the values in Table 14. The results are presented in Table 15.

Table 15. Annual Truck Traffic, Loaded and Empty Trucks.

Body Configuration	Single Unit	Truck Trailer	Tractor Semitrailer	Tractor Double	Tractor Triple
Dry Van	0	0	0	0	0
Flat Bed	0	0	601.11	0	0
Bulk	7228.68	1462.03	7646.11	574.65	0

Body Configuration	Single Unit	Truck Trailer	Tractor Semitrailer	Tractor Double	Tractor Triple
Reefer	12075.02	4970.97	12922.13	4233.12	0
Tank	650.88	40.66	745.37	90.23	0
Logging	5881.32	764.79	4564.99	261.34	0
Livestock	5383.02	0	14378.71	0	0
Automobile	0	0	0	0	0
Other	840.02	433.69	0	0	0

Step 6: Consolidate the total annual truck traffic for all the body styles together for each truck type. In this step we add the values of loaded and empty trucks for all truck types and body configurations to obtain the annual truck traffic between the OD pair for the analyzed commodity. Likewise, we can estimate the tons per truck dividing the total tons by the number of loaded trucks. Table 16 summarizes this information for the current example.

Table 16. Consolidated Results for Tons-to-Trucks Conversion Example

Total Freight	Total Trucks	Loaded Trucks	Empty Trucks	Tons per Truck
1519150	85748	66877	18872	22.7

These procedure is repeated for each OD pair, commodity type and shipment characteristics.

5.3.2 Multiclass Traffic Assignment.

Since the FAF3 data only report the flow of aggregated trucks at each link of the network, a multiclass traffic assignment is performed to from the the multiclass OD matrix obtained in the previous sub-section. Thus multiclass flows are assigned to the U.S. highway network.

To be consistent with the methodology presented in Batelle (2011), multiclass Stochastic User Equilibrium (SUE) is used instead of deterministic User Equilibrium (UE). SUE is appropriate because this stochastic procedure assigns flow to more links in the network. This is helpful to calculate the proportions of Trucks in each link per commodity in the following step.

5.3.3 Proportion of Trucks in each link per commodity.

Once the multiclass traffic assignment is performed, both the passenger car flow and truck flow (for each commodity) are obtained. The proportion of truck flow in each link per commodity can be easily estimated (see subsection 4.3.3). The actual magnitude of the flow for this assignment (U.S. level) is not relevant because only the proportion of multi-commodity truck flow are required to perform multiclass OD estimation in the study region. The proportion of trucks in each link per commodity is further transformed into proportions parameter α_{ij}^{k}, and obtained for each link in the study region. This process will be discussed in the later section

5.4 Multiclass OD Estimation in the Study Region

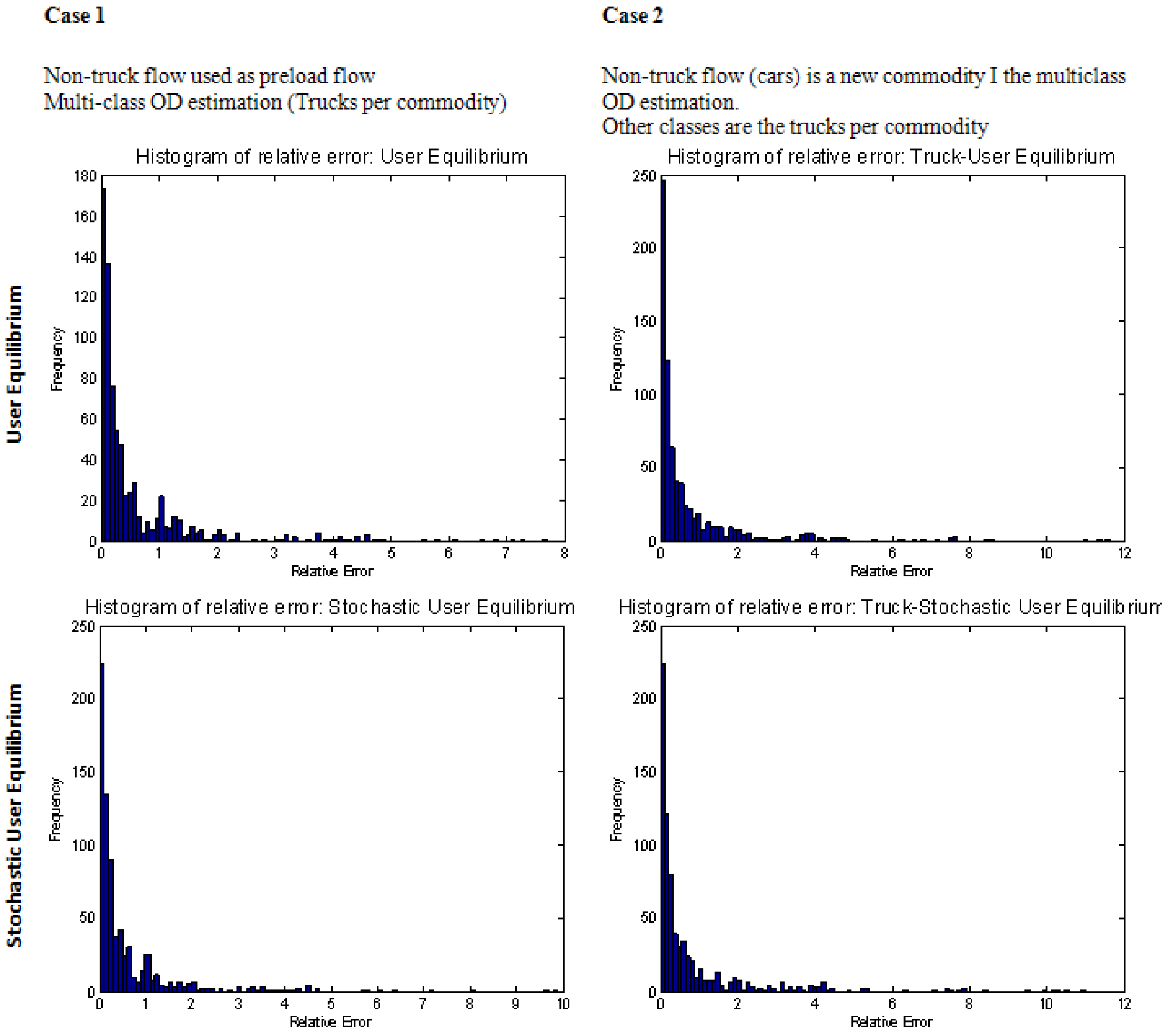
Multiclass OD estimation is used to estimate the truck OD matrices for different commodities and empty trips in the study region. This step is required because such information is not usually available by transportation agencies in many regions in the U.S.

To obtain the multiclass link count information, the single passenger car and truck DDHV value needs to be transformed into multiclass flow information. Using the methodology discussed in section 4.4, with the already obtained proportion of truck flow in each link per commodity information, the proportion parameters α_{ij}^{k} can be easily computed for links in the study region.

The commercial software TransCAD is used to perform multiclass OD matrix estimation. This procedure requires a seed OD matrix and link counts as inputs.

The seed OD matrix does not have any influence in the estimation results because it is merely used as starting point for the multiclass OD estimation algorithm. This matrix is a multi-dimension matrix for each commodity. Multiclass OD matrix estimation in TransCAD also requires multiclass directional link counts (so called AB and BA flow in TransCAD). If count data is provided without any specific direction, TransCAD assumes that the AB and BA flow are equal, and assigns an equivalent value in both directions.

Several tests are performed to compare different approaches used in the multiclass OD estimation in TransCAD. For example, use non-truck flow as preload flow or use non-truck flow as a new commodity in the multiclass OD estimation. The results show that including the non-truck flow as a new commodity achieves a better level of performance because the frequency of links with small relative error is considerably high (Figure 15). Likewise, different traffic assignment schemes, i.e., User Equilibrium (UE) and Stochastic User Equilibrium (SUE), are tested. The results show that SUE can yield a slight better result. Furthermore, the use of SUE is consistent with the U.S. level multiclass traffic assignment used to obtain the multi-commodity flow proportion and proposed in Battelle (2011). Different error term distribution (Normal and Gumbel) and different value error parameter θ have been tested. After several tests, we conclude that the SUE with Gamma distributed error term and $\theta = 2$ fits better to the validation flows from the FAF3 data.



Case 1

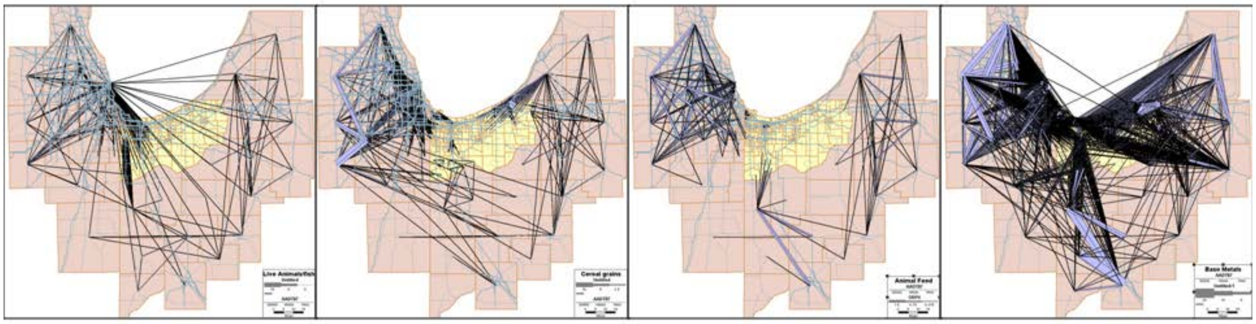
Non-truck flow used as preload flow
Multi-class OD estimation (Trucks per commodity)

Case 2

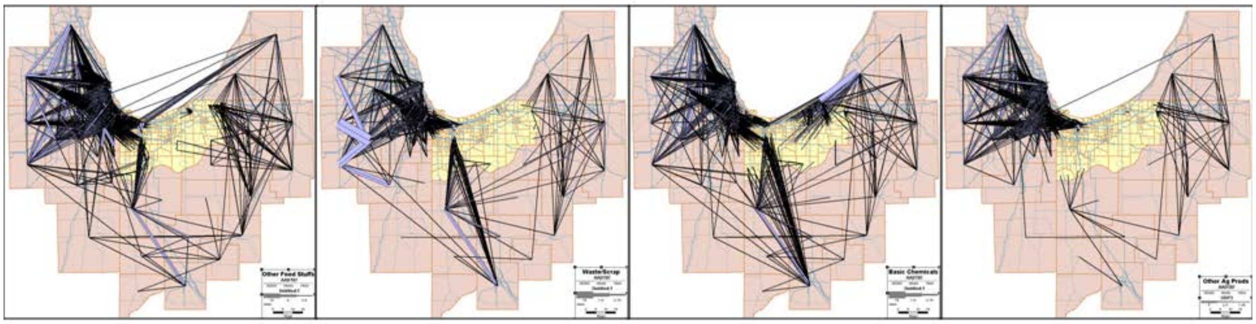
Non-truck flow (cars) is a new commodity I the multiclass OD estimation.
Other classes are the trucks per commodity

Figure 15. Multiclass OD Estimation Validation.

Figure 16 presents the desire lines associated with OD matrixes for a subset of commodities obtained after performing multiclass OD estimation in TransCAD.



Live Animals Cereal Grains Animal Feed Base Metals



Other Food Stuffs Waste/Scrap Basic Chemicals Other Ag Prods

Figure 16. Desire lines for a subset of commodities after the OD matrix estimation procedure.

5.5 Base Link Flow and Link Travel Times

Using the estimated multiclass OD matrix, the multiclass SUE assignment is again used to get the flow pattern for the base condition. The total flow is shown in Figure 17, and the link speed shown in Figure 18. The base link flow and link travel time are used to compare the impacts associated to Scenario I and Scenario II

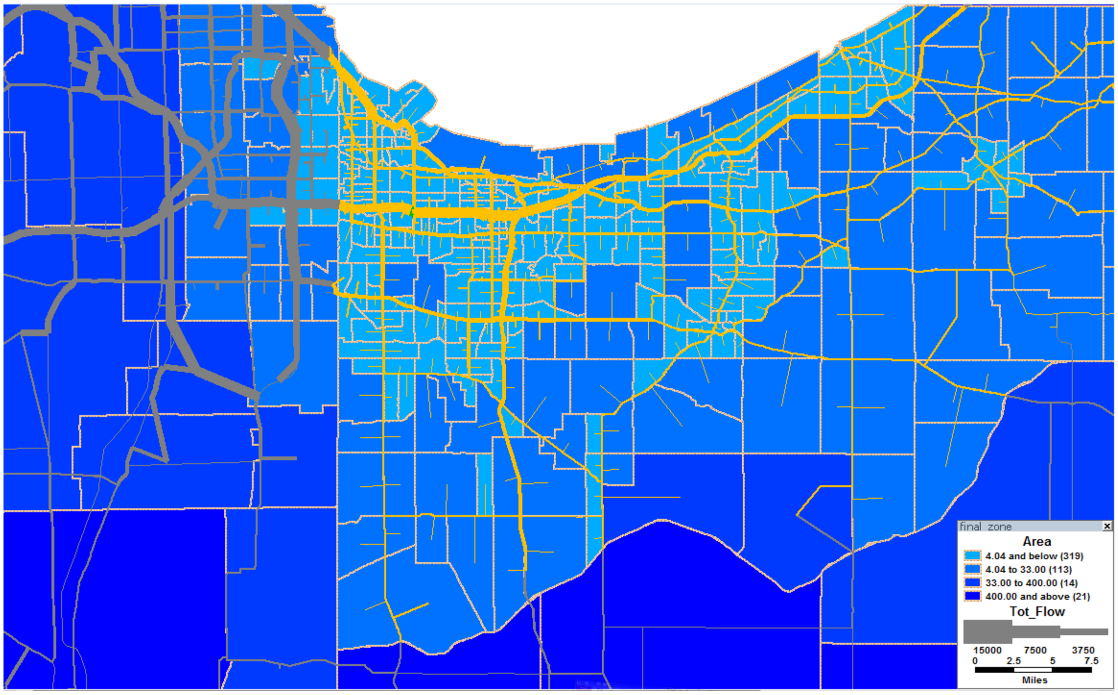


Figure 17 The total traffic flow in the study region for the base case.

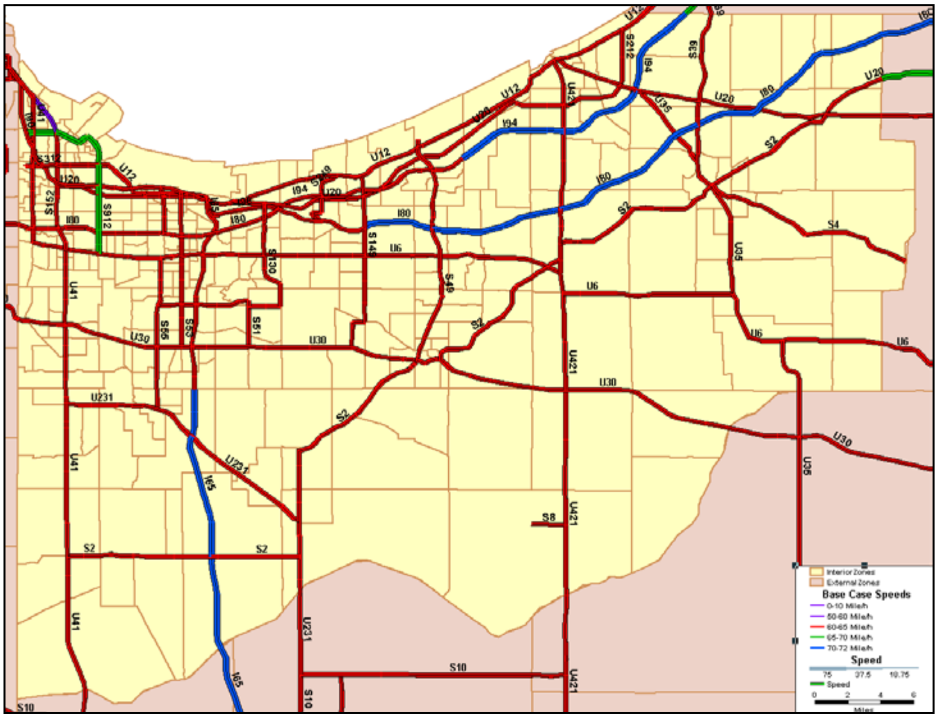


Figure 18 Link speed for base case.

5.6 Link Flow and Link Travel Times for the Scenario with Disruption.

In this section, multiclass traffic assignment is used to obtain the flow pattern for the disruptions in scenarios I and II. The link closures are represented as capacity reductions in the highway network. According to the data collected for the disruption, the capacity of some links is reduced in both directions (totally shutdown) or just in one direction. This information is found in the INDOT report presented in subsection 5.1.3.

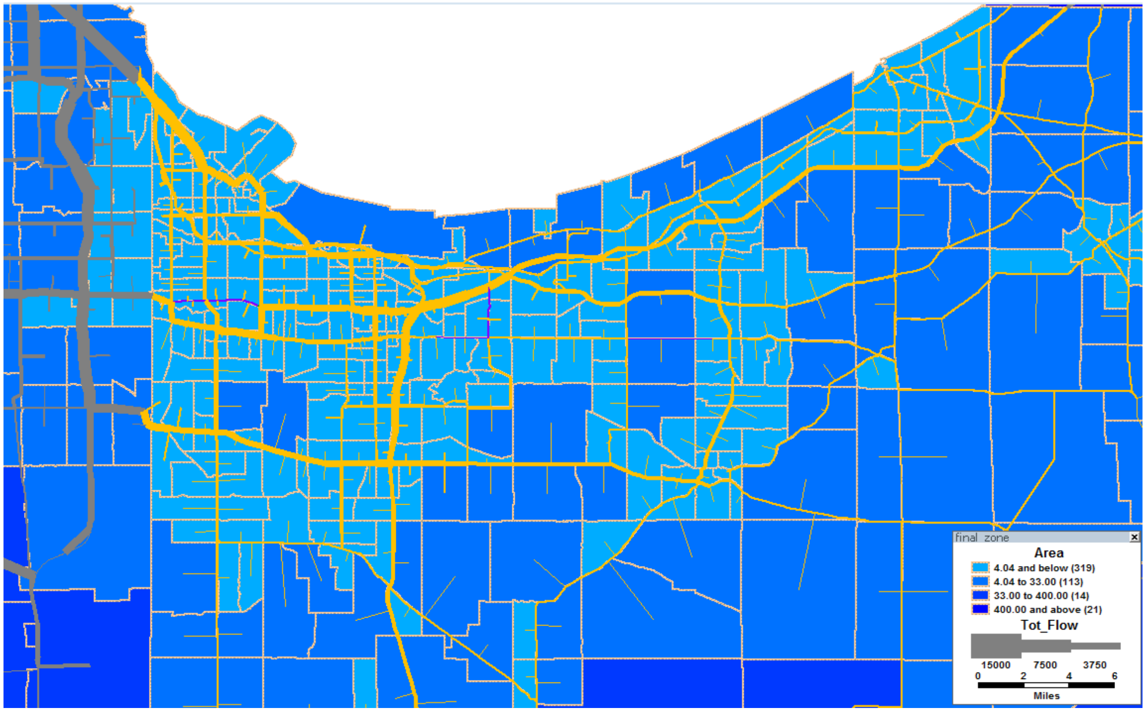


Figure 19 The total traffic flow in the study region for Scenario I.

Figure 19 and Figure 20 present the flow pattern and link speeds associated to disruption Scenario I. In this scenario, few road segments are closed, i.e., part of I-80, U6 and S130. Since there are few closures in this scenario, the pattern of traffic flows slightly varies from those in the base case. However, we can observe how some vehicles change their routes. For example, the flow using I-80 in the base case reroutes to the nearby U6, and merge into the unclosed part of I-80 again. The network wide speed reduction is not significant, mainly in the region near the closed road segments.

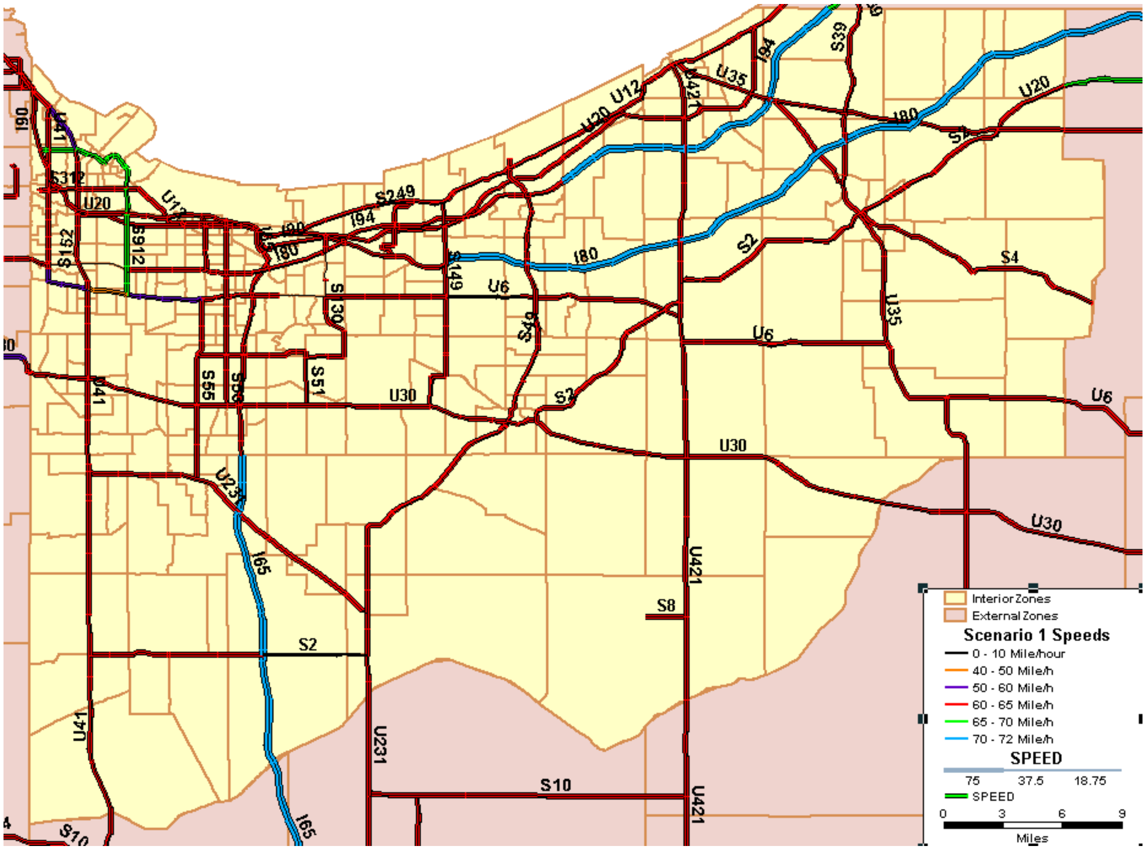


Figure 20 Link speed for Scenario I.

Figure 21 and Figure 22 present the flow pattern of disruption Scenario II. In this scenario, a large number of road segments are closed due to the severe flood. The I-80 segments located at the west side of the Borman Corridor in Indiana are completely closed. Likewise, the segments near Borman Corridor are closed in both directions, and some segments near the Illinois-Indiana border are partially closed. The northbound of I-65 is also closed. Finally, a small part of S130 is also closed.

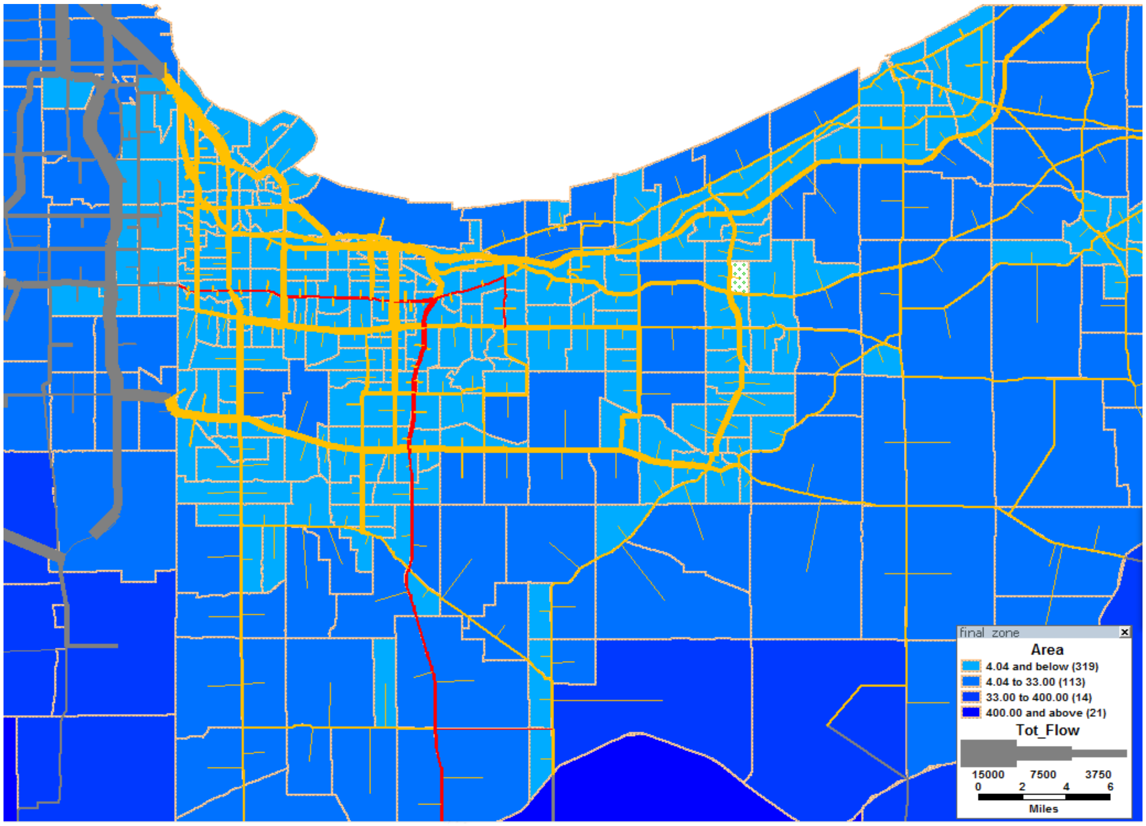


Figure 21 The total traffic flow in the study region for Scenario II.

Since a large amount of links are closed in this scenario, we observe significant changes in the flow pattern and network wide speed. Due to the large closure on I-80, a considerable amount of flow that used this road in the base case reroute to I-90. Additionally, U6 and U30 increase their utilization. Closing the northbound direction of I-65 changes the flow pattern, and several north-south links, e.g., S49, S53, S55, are used to complement the northbnound movements. Likewise, several local roads are used by non-truck flows.

There is a generalized reduction in speed in the surroundings of the impacted region. Several links reduce their speed below 60 Miles/hour.

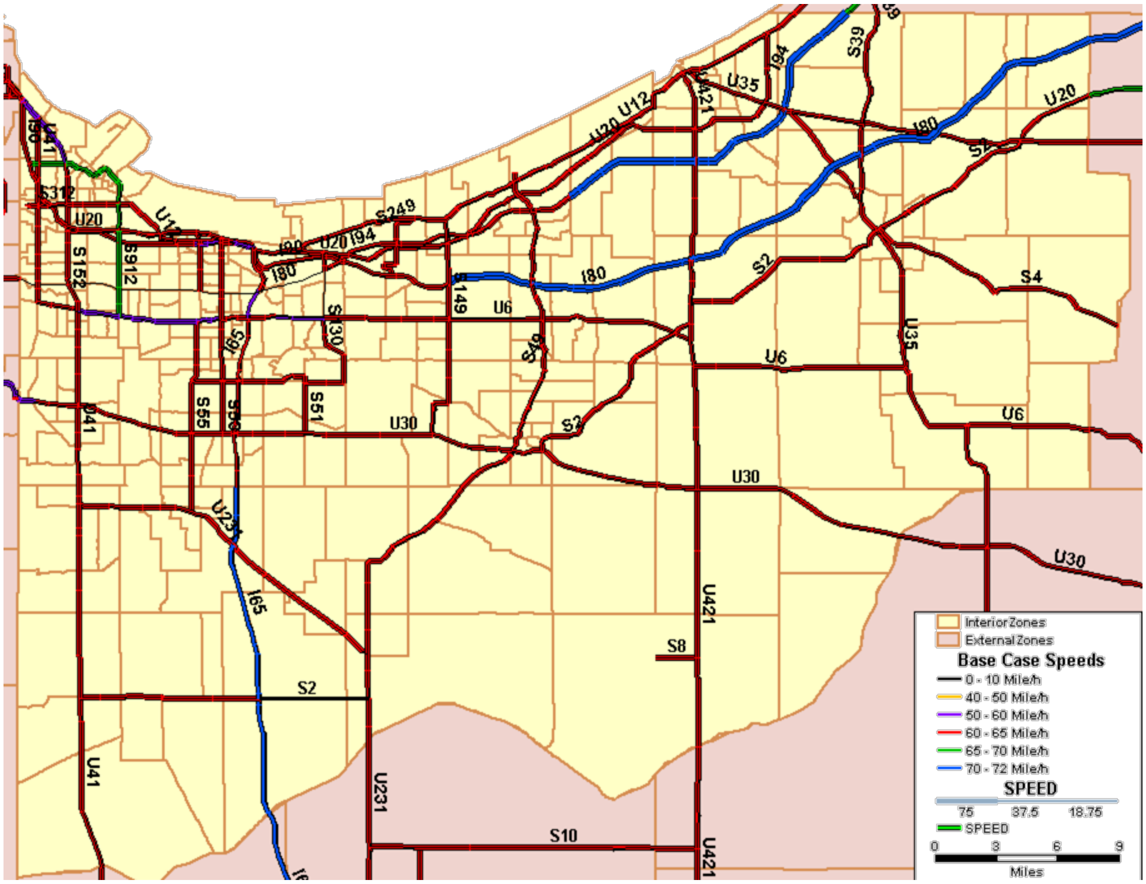


Figure 22 Link speed for Scenario II.

5.7 Conclusions about the Impacts of the Disruption

Using the value of travel time and average vehicle operational cost (VOC) discussed above, the economic impacts are calculated to give a quantitative measure of the impacts of the disruption.

Both the total system costs associated to travel time cost and VOC are computed in a daily basis using 2007 dollar value. These costs are computed only for the flows in the internal TAZs. Figure 23, Figure 24, Figure 25, Figure 26 and Figure 27 show the daily total system costs for the base case and scenarios I and II. As discussed above, Scenario I represents a relatively small increment in the total system costs, i.e., the daily travel time cost increases from $5,760,000 (base case) to $6,640,000, and the total VOC increases from $8,100,000 (base case) to $9,660,000. On the other hand, Scenario II is associated with a large total cost increment, i.e., the daily travel time cost has increased to $8,100,000, and the total VOC increased to $12,300,000. The freight shipping inventory costs contributes to 50% of the total VOC cost.

Figure 27 shows the daily cost composition of passenger car and trucks in the study region. The impacts associated to freight transportation are larger than those for cars. Although the number of car trips is higher than the number of truck trips, the higher costs are associated to larger shipping inventory costs that result from congestion caused by the flood disruption. Likewise, this study ratifies the importance that the Borman corridor (northwestern Indiana region) has for freight transportation.

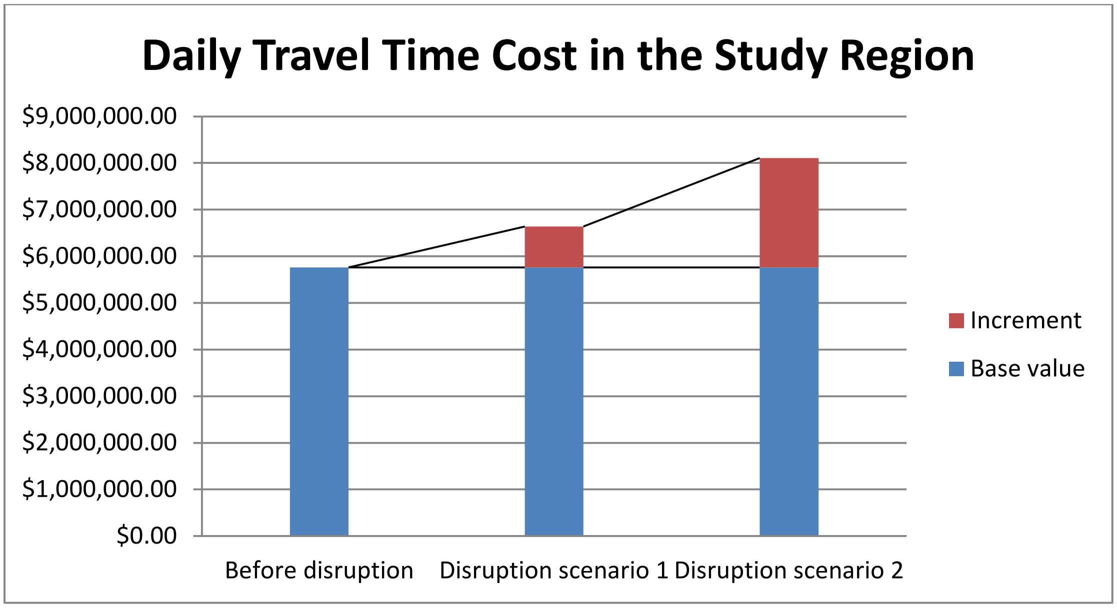


Figure 23 Daily Travel Time Cost in the Study Region

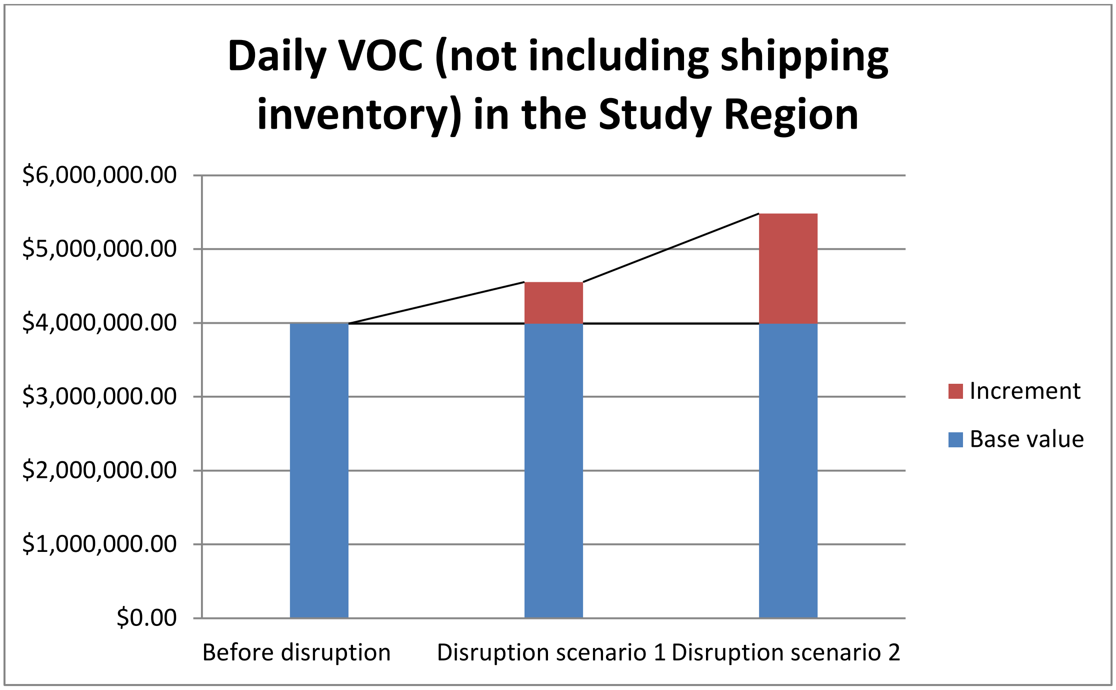


Figure 24 Daily VOC (Not Including Shipping Inventory) in the Study Region.

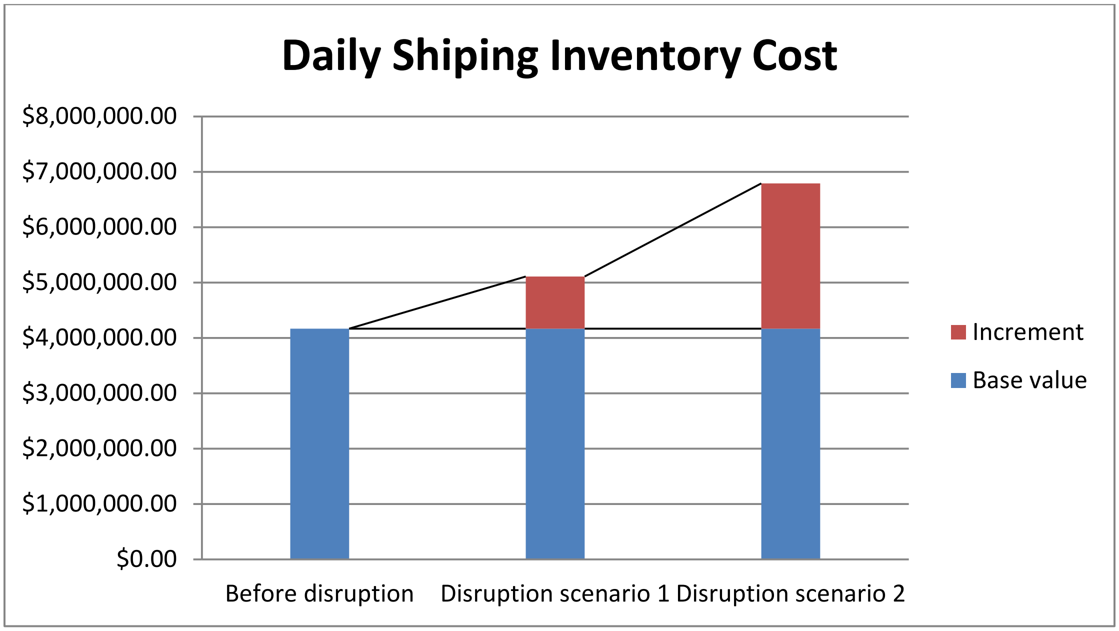


Figure 25 Daily Shipping Inventory Cost in the Study Region

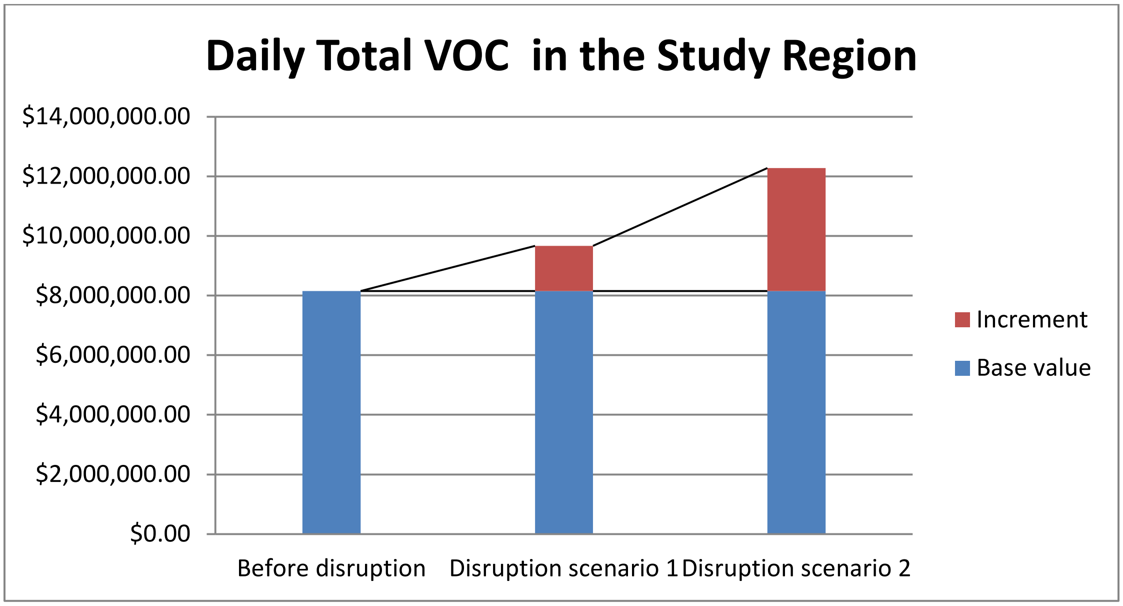


Figure 26 Daily Total VOC Cost in the Study Region (for truck only)

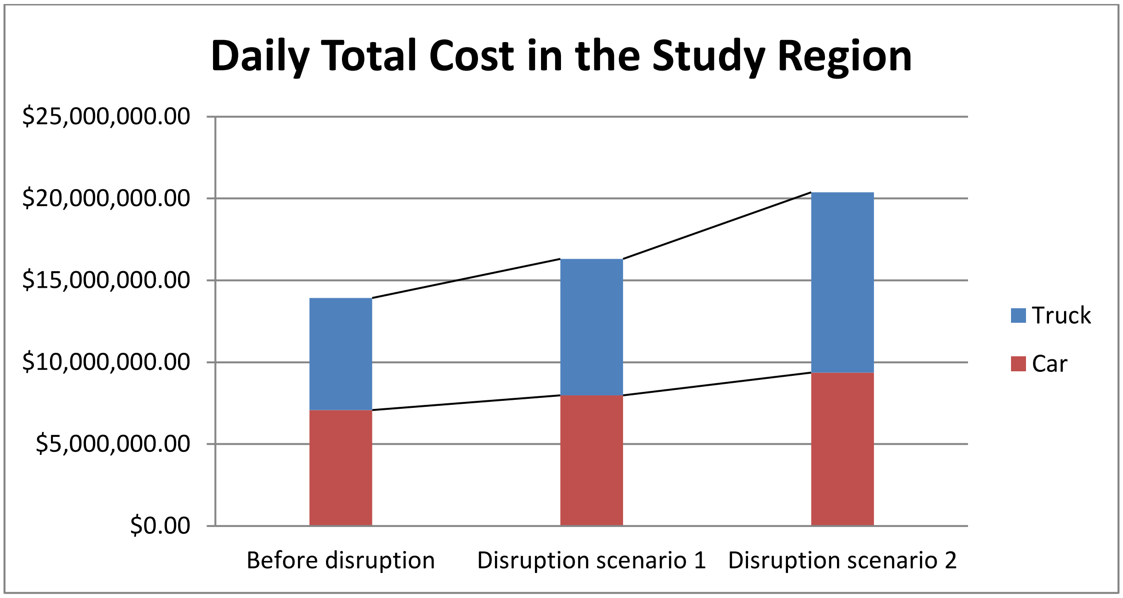


Figure 27. Daily Total Cost in the Study Region.

5.8 <u>Total Economic Impact Due To Freight Disruption</u>

For each type of the impacts described above, there are direct, indirect, and induced impacts. The direct impacts are the losses attributed to loss of business sales in the study region. These direct impacts cause indirect damage to suppliers and customers. These indirect impacts create additional impacts as decreased spending and lower efficiency cascades through the region's economy. These economic impacts affect employment, personal income, government revenue, such as taxes, and other economic activities across the region. The changes in the economic activities resulting from decrease in household expenditures from loss of income are the induced impacts. The total economic impact is the sum of the direct, indirect, and induced impacts.

The flood related highway closures wields a significant economic impact on the economy of Northwest Indiana. The total economic loss from the delay in shipments of commodities in the study region (Table 17) is $11.2 million in output (value of sales), 60 jobs, $3.4 million in labor income (employee compensation and proprietor income), $1.2 million in taxes, and an estimated $5.45 million in value added consisting of employee compensation, proprietor income, indirect business taxes, and other property type income such as payments from interest, rents, royalties, dividends, and profits.

Table 17. Total Economic Impact (in 2013 dollars)

Output Impact ($ millions)	Employment Impact (number of jobs)	Labor Income Impact ($ millions)	Tax Impact ($ millions)	Value-Added Impact ($ millions)
$11.19	59.7	$3.43	$1.22	$5.45

5.8.1 Output Impact

The loss of direct output is $7.53 million in sales revenue (Table 18). The wholesale trade sector has the largest output impact with $2.5 million followed by the trucking sector with $1.51 million.

Table 18. Direct Output Impact (in 2013 dollars)

Industry	Direct Loss of Output
Wholesale trade businesses	$2,499,261
Transport by truck	$1,506,832
Ornamental and architectural metal products manufacturing	$1,172,521
Mechanical power transmission equipment manufacturing	$827,280
Pottery, ceramics, and plumbing fixture manufacturing	$675,817
Flour milling and malt manufacturing	$508,594
Medicinal and botanical manufacturing	$235,624
Other animal food manufacturing	$66,252
Waste management and remediation services	$34,227
Total (Millions of Current Dollars)	$7,525,848

In addition to these direct output impacts, the loss in sales revenue generated indirect revenue losses of $1.89 million on the other industrial sectors as shown in Table 19. The direct impacts to freight-dependent industries caused indirect damage to suppliers and customers. These indirect impacts created additional impacts as decreased spending and lower efficiency cascades through the region’s economy.

The largest indirect output impact is in the petroleum refineries (15.8%), closely followed by the iron and steel mills manufacturing sector (12.5%), and wholesale trade sector (9.18%).

Table 19. Loss in Output in Other Major Industries (in 2013 dollars)

Major Industry	Indirect Impacts
Petroleum refineries	$297,543
Iron and steel mills and ferroalloy manufacturing	$235,959

Major Industry	Indirect Impacts
Wholesale trade businesses	$173,076
Grain farming	$79,854
Transport by truck	$76,760
Management of companies and enterprises	$66,966
Electric power generation, transmission, and distribution	$61,757
Real estate establishments	$58,780
Telecommunications	$45,769
US Postal Service	$39,799

The total loss in induced output impact as measured by the household expenditures is $1.78 million (Table 20). The largest percentage of the induced impact from household expenditures is in health and social services (21%) followed by the government (17%), retail trade (16%), and information, finance, and real estate (13%).

Table 20: Induced Output Impact on Major Industries (in 2013 dollars)

Industry	Indirect Impacts
Imputed rental activity for owner-occupied dwellings	$324,423
Offices of physicians, dentists, and other health practitioners	$123,591
Private hospitals	$122,819
Food services and drinking places	$102,062
Real estate establishments	$79,518
Wholesale trade businesses	$57,121
Petroleum refineries	$55,484
Monetary authorities and depository credit intermediation activities	$46,748
Retail Stores - Food and beverage	$45,790
Medical and diagnostic labs and outpatient and other	$43,047

Industry	Indirect Impacts
ambulatory care services	

5.8.2 Employment Impact

The total number of jobs that are directly impacted due to loss in output is 34 jobs (Table 21). The wholesale trade sector has the largest direct employment impact with 12.9 jobs followed by the trucking sector with 10.6 jobs.

Table 21. Direct Jobs

Industry	Direct Jobs
Wholesale trade businesses	12.9
Transport by truck	10.6
Ornamental and architectural metal products manufacturing	5.0
Mechanical power transmission equipment manufacturing	2.7
Pottery, ceramics, and plumbing fixture manufacturing	1.9
Medicinal and botanical manufacturing	0.4
Flour milling and malt manufacturing	0.3
Waste management and remediation services	0.2

In addition to these direct jobs, the loss in sales revenue resulted in loss of 10.3 indirect jobs (Table 22).

Table 22. Indirect Jobs

Industry	Indirect Jobs
Employment services	1.0
Wholesale trade businesses	0.9

Industry	Indirect Jobs
Transport by truck	0.5
Food services and drinking places	0.5
US Postal Service	0.5
Real estate establishments	0.4
Grain farming	0.4
Services to buildings and dwellings	0.4
Management of companies and enterprises	0.4
Couriers and messengers	0.3
Accounting, tax preparation, bookkeeping, and payroll services	0.3
Business support services	0.3
Investigation and security services	0.2
Scenic and sightseeing transportation and support activities for transportation	0.2
Warehousing and storage	0.2
Monetary authorities and depository credit intermediation activities	0.2
Maintenance and repair construction of nonresidential structures	0.2
Architectural, engineering, and related services	0.2
Iron and steel mills and ferroalloy manufacturing	0.2
Civic, social, professional, and similar organizations	0.2
Legal services	0.2
Automotive repair and maintenance, except car washes	0.1
Advertising and related services	0.1
Management, scientific, and technical consulting services	0.1
Commercial and industrial machinery and equipment repair and maintenance	0.1
Securities, commodity contracts, investments, and related activities	0.1
Other support services	0.1
Newspaper publishers	0.1

Industry	Indirect Jobs
Telecommunications	0.1
Ball and roller bearing manufacturing	0.1
Electric power generation, transmission, and distribution	0.1

5.8.3 Tax Impact

The study region lost $655,066 of federal, state, and local tax revenues from the direct, indirect, and induced impacts of freight disruptions (Table 23).

Table 23. Total Tax Impact (in 2013 dollars)

Employee Compensation	Proprietary Income	Household Expenditures	Enterprises (Corporations)	Indirect Business Taxes	Total
$330,446	$21,017	$187,148	$61,887	$54,568	$655,066

Table 24 to Table 27 provide a summary of top ten industries affected by output, employment, value added, and labor income respectively due to the highway closures.

Table 24. Top Ten Industries Affected By Output

Sector	Description	Output
319	Wholesale trade businesses	$2,729,458
335	Transport by truck	$1,599,123
187	Ornamental and architectural metal products manufacturing	$1,173,980
224	Mechanical power transmission equipment manufacturing	$827,829

Sector	Description	Output
153	Pottery, ceramics, and plumbing fixture manufacturing	$675,820
43	Flour milling and malt manufacturing	$508,860
115	Petroleum refineries	$352,468
361	Imputed rental activity for owner-occupied dwellings	$324,423
170	Iron and steel mills and ferroalloy manufacturing	$236,501
132	Medicinal and botanical manufacturing	$236,070

Table 25. Top Ten Industries Affected By Employment

Sector	Description	Employment
319	Wholesale trade businesses	14.1
335	Transport by truck	11.2
187	Ornamental and architectural metal products manufacturing	5.0
224	Mechanical power transmission equipment manufacturing	2.7
413	Food services and drinking places	2.5
153	Pottery, ceramics, and plumbing fixture manufacturing	1.9
382	Employment services	1.2
397	Private hospitals	1.0
360	Real estate establishments	1.0
394	Offices of physicians, dentists, and other health practitioners	1.0

Table 26. Top Ten Industries Affected By Value Added

Sector	Description	Value Added
319	Wholesale trade businesses	$1,772,437
335	Transport by truck	$835,034

Sector	Description	Value Added
187	Ornamental and architectural metal products manufacturing	$457,464
153	Pottery, ceramics, and plumbing fixture manufacturing	$397,653
361	Imputed rental activity for owner-occupied dwellings	$215,422
224	Mechanical power transmission equipment manufacturing	$187,537
360	Real estate establishments	$107,153
394	Offices of physicians, dentists, and other health practitioners	$90,238
31	Electric power generation, transmission, and distribution	$71,937
413	Food services and drinking places	$65,406

Table 27. Top Ten Industries Affected By Value Added

Sector	Description	Labor Income
319	Wholesale trade businesses	$1,034,487
335	Transport by truck	$625,725
187	Ornamental and architectural metal products manufacturing	$334,228
153	Pottery, ceramics, and plumbing fixture manufacturing	$296,555
224	Mechanical power transmission equipment manufacturing	$136,233
394	Offices of physicians, dentists, and other health practitioners	$77,774
397	Private hospitals	$59,397
427	US Postal Service	$45,767
413	Food services and drinking places	$44,082
382	Employment services	$32,919

CHAPTER 6. CONCLUSIONS

This project presents a framework to estimate short-term economic impacts due to disruptions in freight transportation systems. The framework is build upon state-of-the-art databases, i.e., Freight Analysis Framework version 3 (FAF3), and transportation software, i.e. TransCAD.

Likewise, the proposed framework integrates recognized traffic flow models, e.g., multiclass OD matrix estimation and multiclass traffic assignment, into an economical analysis that estimates the short-term disruptions.

Several limitations related to the use of FAF3 data are addressed in order to mitigate estimation errors.

The framework is applied in a real world scenario, i.e., 2008 highway closures due to floods in the north of Indiana, and the economic impacts associated to this disruption are estimated.

The Multiclass Traffic Assignment Data used in the input-output model to estimate the freight-related economic impacts involves multiplying the number of trucks delayed on the road by a predetermined value-of-time factor, to establish an economic value of the delay incurred. However, a statistically valid survey of affected freight related businesses could have quantified the actual costs incurred by freight-dependent firms as a result of the highway closures. While our current approach is based on high-level assumptions (such as, use of vehicle delay as a proxy for true economic impacts, use of county level data instead of zip level data), at least a survey of affected firms could have captured revenue losses accounted for a larger percentage of total business losses from road closures.

Therefore, the economic impacts reported in this study may be lower than estimated because the study did not capture the actual direct costs and lost sales incurred by trucking firms during the highway disruptions; it also did not document similar losses in freight dependent industries such as manufacturing, agribusiness, construction, timber and wood products, retail and wholesale goods, and the trade and logistics sectors. This study likewise does not include local business economic impacts related to the closures, unless they were caused by disruption of the freight systems.

This study can be improved by estimating the additional direct losses. Losses of firms who could not deliver products for their customers in time, including losses associated with perishable goods. Losses could also be incurred because firms did not receive the orders their customers had placed. Examples include costs associated with delay, detour, use of alternative modes of delivery, and other actions, which caused additional costs. Such costs encompass increased fuel charges, increased wages and overtime pay for drivers, additional communication costs, higher costs of using alternative methods for delivery of goods, and other operational costs.

A distributional impact analysis could also as also conducted to describe who was impacted by the closures, where the impacts were, and what the intensities of the impacts were. This analysis could help generate additional understanding of the economic impacts of the closure.

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8. ANNEXES

8.1. Commodity groups in the Freight Analysis Framework 3

Table 28. Commodity groups in the Freight Analysis Framework 3.

ID	Commodity group	ID	Commodity group	ID	Commodity group	ID	Commodity group
01	Live animals/fish	12	Gravel	23	Chemical prods.	34	Machinery
02	Cereal grains	13	Nonmetallic minerals	24	Plastics/rubber	35	Electronics
03	Other ag prods.	14	Metallic ores	25	Logs	36	Motorized vehicles
04	Animal feed	15	Coal	26	Wood prods.	37	Transport equip.
05	Meat/seafood	16	Crude petroleum	27	Newsprint/paper	38	Precision instruments
06	Milled grain prods.	17	Gasoline	28	Paper articles	39	Furniture
07	Other foodstuffs	18	Fuel oils	29	Printed prods.	40	Misc. mfg. prods.
08	Alcoholic beverages	19	Coal-n.e.c.	30	Textiles/leather	41	Waste/scrap
09	Tobacco prods.	20	Basic chemicals	31	Nonmetal min. prods.	43	Mixed freight
10	Building stone	21	Pharmaceuticals	32	Base metals	99	Unknown
11	Natural sands	22	Fertilizers	33	Articles-base metal		

8.2. Truck Equivalency Factors in the Freight Analysis Framework 3

Table 29. Truck Equivalency Factors – Single Unit (SU) (Battelle 2011).

Commodity	Auto	Livestock	Bulk	Flatbed	Tank	Day Van	Reefer	Logging	Other
1	0	0	0.0066	0.04922	0.00111	0.00419	0.00173	0	0
2	0	0	0.02675	0.0086	0.00103	0.00032	0.00003	0	0.00003
3	0	0	0.01069	0.01981	0.00102	0.00996	0.00942	0	0.00147
4	0	0	0.01463	0.02657	0.00562	0.00334	0.00137	0	0.00034
5	0	0	0.00004	0.00089	0	0.03835	0.04837	0	0.00033
6	0	0	0	0.00025	0	0.15767	0.00216	0	0.00011
7	0	0	0.00001	0.00032	0.00073	0.02096	0.02048	0	0.02192
8	0	0	0	0.00002	0	0.02133	0.00286	0	0.02956
9	0	0	0	0	0	0.06785	0.04242	0	0.01498
10	0	0	0.01399	0.01865	0.00029	0.00115	0	0	0.00185
11	0	0	0.02362	0.00638	0	0.00107	0	0	0.00058
12	0	0	0.02337	0.00292	0	0	0	0.00002	0.00034
13	0	0	0.02393	0.00255	0.00119	0.0008	0.00002	0	0.00048
14	0	0	0.01773	0.01261	0	0	0	0	0
15	0	0	0.01973	0.00307	0	0	0	0	0.001
16	0	0	0.00685	0.02455	0.01041	0.00086	0	0	0.01333
17	0	0	0	0.00186	0.02298	0.02755	0	0	0.00225
18	0	0	0.00026	0.00328	0.03386	0.00038	0	0	0.00261
19	0	0	0.00116	0.01074	0.0466	0.00273	0	0	0.00122
20	0	0	0.00171	0.02421	0.0146	0.01697	0	0	0.00266
21	0	0	0	0	0	0.10537	0.0122	0	0
22	0	0	0.01074	0.00974	0.01882	0.00302	0	0	0.00063
23	0	0	0.00145	0.01277	0.00987	0.03153	0	0	0.00539
24	0	0	0.00109	0.04904	0.00199	0.04913	0.00147	0	0.00863
25	0	0	0.0177	0.0167	0	0.00013	0	0.00831	0.00291
26	0	0	0.01437	0.03091	0.00002	0.01721	0	0.00017	0.00205
27	0	0	0	0.00142	0	0.07422	0	0	0
28	0	0	0.00262	0.00222	0	0.06609	0.00109	0	0.00223
29	0	0	0	0.00909	0	0.0857	0	0	0.00038
30	0	0	0.00154	0.0146	0	0.09299	0.00181	0	0.00251
31	0	0	0.00404	0.00588	0.00034	0.00436	0	0	0.01456
32	0	0	0.00076	0.06023	0	0.01594	0	0	0.01038
33	0	0	0.004	0.03186	0.00005	0.02246	0	0.00005	0.02908
34	0	0	0.00271	0.03187	0	0.03959	0	0.00002	0.00814

Commodity	Auto	Livestock	Bulk	Flatbed	Tank	Day Van	Reefer	Logging	Other
35	0	0	0.00033	0.01488	0	0.08017	0.00164	0	0.01258
36	0	0	0.00041	0.0073	0	0.00756	0	0	0.0548
37	0	0	0.00649	0.0228	0	0.00782	0	0	0.0141
38	0	0	0.00064	0.04872	0	0.11375	0	0	0.0006
39	0	0	0.00007	0.00432	0	0.11805	0.00166	0	0.00382
40	0	0	0.00027	0.01702	0.00117	0.07196	0.00051	0	0.01452
41	0	0	0.01372	0.00869	0.00221	0.00069	0.00011	0	0.01908
42	0	0	0.00215	0.01208	0.02291	0.00117	0	0	0.00181
43	0	0	0	0.00415	0	0.09378	0	0	0

Table 30. Truck Equivalency Factors – Truck Trailer (TT) (Battelle 2011).

Commodity	Auto	Livestock	Bulk	Flatbed	Tank	Day Van	Reefer	Logging	Other
1	0	0	0.00236	0.09792	0	0.01831	0	0	0.00305
2	0	0	0.03312	0.00683	0.00121	0	0	0	0
3	0	0	0.01643	0.05417	0.00043	0.00965	0	0	0.00557
4	0	0	0.0024	0.0652	0.00229	0.01552	0	0	0.0026
5	0	0	0	0.01384	0	0	0.2178	0	0
6	0	0	0	0.06766	0	0.52158	0.02743	0	0
7	0	0	0	0.01609	0.00255	0.167	0	0	0.02212
8	0	0	0	0	0	0	0	0	0.09053
9	0	0	0	0	0	0	0	0	0
10	0	0	0.04803	0.00814	0.00047	0	0	0	0
11	0	0	0.03288	0.01714	0	0	0	0	0
12	0	0	0.03672	0.00355	0.00002	0	0	0	0.00136
13	0	0	0.04044	0.00133	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0
15	0	0	0.01956	0.02797	0	0	0	0	0
16	0	0	0.01529	0	0.01659	0	0	0	0
17	0	0	0	0.06287	0.0246	0	0	0	0
18	0	0	0.00047	0.02735	0.01863	0	0	0	0
19	0	0	0.00855	0	0.01411	0.03128	0	0	0
20	0	0	0	0	0.04058	0.0037	0	0	0
21	0	0	0	0	0	0	0	0	0
22	0	0	0.00321	0.02528	0.03006	0.03581	0	0	0.0015
23	0	0	0.00466	0.01526	0.00955	0.15924	0	0	0
24	0	0	0	0.25704	0	0	0	0	0
25	0	0	0.0087	0.00147	0	0	0	0.02241	0.01327
26	0	0	0.09538	0.03896	0	0.00107	0	0.00071	0.01724
27	0	0	0	0	0	0.06453	0	0	0
28	0	0	0	0	0	1.03919	0	0	0
29	0	0	0	0	0	1	0	0	0
30	0	0	0	0	0	0.43478	0	0	0
31	0	0	0.0194	0.01707	0	0	0	0	0.01178
32	0	0	0.00386	0.0495	0	0.00575	0	0	0.09511
33	0	0	0.02786	0.04576	0	0.125	0	0	0.04695
34	0	0	0.03163	0.03692	0	0.00129	0	0.00044	0.00078
35	0	0	0	0.13673	0	0.3511	0	0	0
36	0	0	0.02531	0.07947	0	0.03572	0	0	0.00623
37	0	0	0.02199	0.05941	0	0	0	0	0.00491

Commodity	Auto	Livestock	Bulk	Flatbed	Tank	Day Van	Reefer	Logging	Other
38	0	0	0	0.5	0	0	0	0	0
39	0	0	0.04346	0.02042	0	0.07936	0	0	0
40	0	0	0	0.06769	0	0.02033	0	0	0.02866
41	0	0	0.06573	0.02041	0	0	0	0	0.00178
42	0	0	0	0.00708	0.05154	0.00145	0	0	0
43	0	0	0	0	0	0.15382	0	0	0

Table 31. Truck Equivalency Factors – Combination Semitrailer (CS) (Battelle 2011).

Commodity	Auto	Livestock	Bulk	Flatbed	Tank	Day Van	Reefer	Logging	Other
1	0	0.02634	0.00087	0.00628	0.00046	0.00116	0.00061	0	0
2	0	0.00006	0.03127	0.00162	0.00124	0.00056	0.00004	0	0
3	0	0.0005	0.00636	0.0114	0.00062	0.00443	0.01419	0	0
4	0	0.00028	0.00873	0.00598	0.01261	0.00691	0.00257	0	0
5	0	0	0	0.00071	0	0.00449	0.03397	0	0
6	0	0	0	0	0.00389	0.03253	0.00495	0	0
7	0	0	0	0.00023	0.00373	0.01631	0.01912	0	0
8	0	0	0	0.00045	0.00021	0.04709	0.00137	0	0
9	0	0	0	0	0	0.0333	0.00725	0	0
10	0	0	0.012	0.02245	0.00221	0.00072	0	0	0
11	0	0	0.03032	0.00064	0.00423	0.00016	0	0	0
12	0	0	0.03249	0.00175	0.00032	0.0001	0	0.00002	0
13	0	0	0.01708	0.00104	0.01462	0.00124	0	0	0
14	0	0	0.02508	0.00955	0	0.00143	0	0	0
15	0	0	0.03109	0	0	0.00053	0	0	0
16	0	0	0.00055	0	0.03505	0	0	0	0
17	0	0	0	0	0.02918	0.00044	0	0	0
18	0	0	0.00005	0.00033	0.02883	0.00059	0	0	0
19	0	0	0.0003	0.00153	0.03075	0.00344	0	0	0
20	0	0	0.00004	0.00467	0.0281	0.0054	0	0	0
21	0	0	0	0	0	0.02969	0.01779	0	0
22	0	0	0.01042	0.00925	0.01569	0.00166	0.00025	0	0
23	0	0	0	0.0013	0.0266	0.00896	0.0003	0	0
24	0	0	0.00033	0.00511	0.00599	0.03019	0.00065	0	0
25	0	0	0.00172	0.00586	0	0.00117	0	0.02563	0
26	0	0	0.00529	0.02031	0	0.00905	0.0001	0.00109	0
27	0	0	0	0.00495	0	0.02996	0.00046	0	0
28	0	0	0	0.00031	0	0.03765	0.0005	0	0
29	0	0	0	0.00071	0	0.03842	0.00187	0	0
30	0	0	0	0.00096	0	0.03345	0.00069	0	0
31	0	0	0.00288	0.01613	0.01163	0.00331	0.00005	0.00024	0
32	0	0.00027	0.00144	0.03045	0.00017	0.00344	0.00018	0.00036	0
33	0	0	0.00048	0.02839	0.0001	0.00839	0	0	0
34	0	0.00009	0.0001	0.03017	0	0.00621	0.00018	0	0
35	0	0	0	0.00344	0	0.03622	0	0	0
36	0.01607	0	0.00038	0.00722	0	0.01871	0	0	0
37	0.0003	0	0.00022	0.0187	0	0.0167	0	0.00102	0

Commodity	Auto	Livestock	Bulk	Flatbed	Tank	Day Van	Reefer	Logging	Other
38	0	0	0	0.00625	0	0.03851	0	0	0
39	0	0	0	0.00233	0	0.03413	0.00171	0	0
40	0	0	0.00006	0.00374	0	0.03022	0.00159	0	0.00478
41	0	0	0.02326	0.00207	0.00785	0.00289	0.00013	0	0
42	0	0	0	0.0015	0.03183	0.00323	0	0	0
43	0	0	0	0.0009	0	0.04007	0.00082	0	0

Table 32. Truck Equivalency Factors – Combination Double (DBL) (Battelle 2011).

Commodity	Auto	Livestock	Bulk	Flatbed	Tank	Day Van	Reefer	Logging	Other
1	0	0.02963	0	0	0	0	0	0	0
2	0	0	0.02166	0.00434	0.0003	0	0	0	0
3	0	0	0.00363	0.02674	0.00057	0.00214	0	0	0
4	0	0	0.0114	0.01572	0.00081	0.00436	0	0	0
5	0	0	0	0	0	0	0.0625	0	0
6	0	0	0	0	0	0.05882	0	0	0
7	0	0	0	0.01003	0.00116	0.00546	0.01426	0	0
8	0	0	0	0	0	0	0.06061	0	0
9	0	0	0	0	0	0	0	0	0
10	0	0	0.01584	0	0.01808	0	0	0	0
11	0	0	0.02342	0	0	0	0	0	0
12	0	0	0.02123	0	0.00041	0	0	0	0
13	0	0	0.00567	0.00066	0.01929	0	0	0	0
14	0	0	0.00851	0	0.0177	0	0	0	0
15	0	0	0.01622	0	0.00158	0	0	0	0
16	0	0	0	0	0.03043	0	0	0	0
17	0	0	0	0	0.00862	0.03876	0	0	0
18	0	0	0	0	0.02204	0	0	0	0
19	0	0	0.01252	0	0.01619	0	0	0	0
20	0	0	0.00395	0.01861	0.00758	0	0	0	0
21	0	0	0	0	0	0	0	0	0
22	0	0	0.00749	0.02477	0.00117	0	0	0	0
23	0	0	0	0	0	0	0.02186	0	0
24	0	0	0	0.01595	0	0.05582	0	0	0
25	0	0	0	0	0	0	0	0.02353	0
26	0	0	0.00151	0.02389	0	0.00368	0	0	0
27	0	0	0	0	0	0	0	0	0
28	0	0	0	0.0413	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0.13793	0	0	0
31	0	0	0.00429	0.00411	0.01484	0	0	0	0
32	0	0	0.00232	0.01454	0	0	0	0.19078	0
33	0	0	0	0	0	0.0339	0	0	0
34	0	0	0	0.00878	0	0.03608	0	0	0
35	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0.06667	0	0	0
37	0	0	0	0.02857	0	0	0	0	0

Commodity	Auto	Livestock	Bulk	Flatbed	Tank	Day Van	Reefer	Logging	Other
38	0	0	0	0	0	0.11765	0	0	0
39	0	0	0	0	0	0.03463	0	0	0
40	0	0	0	0	0	0.05285	0	0	0
41	0	0	0.01953	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0.04439	0.00003	0	0

Table 33. Truck Equivalency Factors – Combination Triple (TPT) (Battelle 2011).

Commodity	Auto	Livestock	Bulk	Flatbed	Tank	Day Van	Reefer	Logging	Other
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0
12	0	0	0.02454	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0
31	0	0	0.02181	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0

Commodity	Auto	Livestock	Bulk	Flatbed	Tank	Day Van	Reefer	Logging	Other
34	0	0	0	0.01752	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0
37	0	0	0	0.01986	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0.02557	0	0	0

8.3. Illustration: The Simple Input-Output Model

Definition or Identities:

Inputs = Sum of purchases from other local industries and from final payment sectors

$$q_1 = x_{11} + x_{12} + v_1 + m_1$$

$$q_2 = x_{12} + x_{22} + v_2 + m_2$$

i.e.

$$q_j \equiv \sum_i x_{ij} + v_j + m_j$$

where x_{ij} denotes the sales of industry i to industry j, q_i is the sales of industry i to final demand (ultimate consumers), v_j is the value of other local final payments for industry j, m_j is the import of industry j, and $\sum_i x_{ij}$ is the aggregate purchases by industry j over all industries i.

In matrix terms,

$$q = x_i^T + v + m$$

where x^T is a transpose and i represents the summing vector

Outputs = Sum of sales to other local industries and final users

$$z_1 = x_{11} + x_{12} + y_1 + e_1$$

$$z_2 = x_{12} + x_{22} + y_2 + e_2$$

or, in matrix terms,

$$z = x + y + e$$

Behavioral or technical assumptions:

Constant production coefficients

$$p_{ij} =_t x_{ij}/q_j$$

or

$${}_t x_{ij} = p_{ij} q_j$$

Constant regional purchase coefficients

$$r_{ij} = ({}_t x_{ij} - m_{ij})/{}_t x_{ij}$$

Equilibrium condition:

Inputs = Outputs, therefore, $q_i = z_i$, The solution is by substitution:

Problem: Given final demands (y and e), reduce the number of unknowns to equal the number of equations.

Let $a_{ij} = p_{ij} r_{ij}$

Then,

$$a_{ij} = ({}_t x_{ij}/q_j)({}_t x_{ij} - m_{ij})/{}_t x_{ij} = ({}_t x_{ij} - m_{ij})/q_j = x_{ij}/q_j$$

or

$$x_{ij} = a_{ij} q_j$$

Substituting into the output equations,

$$z_1 = a_{11} z_1 + a_{12} z_2 + y_1 + e_1$$

$$z_2 = a_{21} z_1 + a_{22} z_2 + y_2 + e_2$$

Or, in matrix terms,

$$z = Az + y + e$$

$$z - Az = y + e$$

$$(I - A)z = y + e$$

or

$$z = (I - A)^{-1}(y + e)$$

Output Multipliers:

$$dz_i/de_i = r_{ij}$$

where r_{ij} is an element of $R = (I - A)^{-1}$.

Each of these partial output multipliers shows the change in local output i associated with a change in exports (e_j) by industry j. Their sum over i is the total output multiplier for industry j.

Income Multipliers:

$Income_i = Sum(r_{ij} * v_{i(h)}/q_i)$, where $v_{i(h)}$ is household income.

Each of these income multipliers shows the change in household income caused by a change in exports by industry j.