Retrospective Theses and Dissertations

Iowa State University Capstones, Theses and Dissertations

1-1-1998

Multimodal statewide freight transportation modeling process

David Thomas Preissig
Iowa State University

Follow this and additional works at: https://lib.dr.iastate.edu/rtd

Part of the Engineering Commons

Recommended Citation

Multimodal statewide freight transportation modeling process

by

David Thomas Preissig

A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Civil Engineering (Transportation Engineering)

Major Professor: Dr. Reginald R. Souleyrette

Iowa State University

Ames, Iowa

1998

Graduate College

Iowa State University

This is to certify that the Master's thesis of

David Thomas Preissig

has met the requirements of Iowa State University

Signatures have been redacted for privacy

To my mother, Karen, and my father, Ronald.

TABLE OF CONTENTS

LIST OF FIGURES

vi

LIST OF TABLES

ACKNOWLEDGEMENTS

CHAPTER 1 — INTRODUCTION

1.1 – Freight Transportation Planning

The purpose of this thesis is to present a multimodal, policy sensitive, freight transportation modeling technique. In the 1970's, the Iowa DOT attempted to model statewide flows with the Urban Transportation Passenger System (UTPS), but without a freight component. Later, freight-related planning activities began, but focused on rail grain movements so as to ascertain decision-making data related to railroad branchline abandonment. The Iowa DOT expanded its freight concerns and became jointly involved in a planning process with the Army Corps of Engineers for investment in the Mississippi River locks and dams.

In 1988, the Iowa Legislature mandated that the Iowa Transportation Commission identify a Commercial and Industrial Network (CIN), a system that when maintained, would improve the flow of commerce, and better connect Iowa with regional, national, and international markets (1, p. 33). In response to a federal mandate in 1991, the Iowa DOT designated the state's share of the National Highway System, by requesting inclusion of the Interstates, CIN, and selected additional routes.

Iowa DOT involvement with rail freight transportation also expanded in the 1980's to include assistance with rail line acquisition, economic development, rail/highway crossings, and intermodal facilities (1, p. 49). Two state rail freight transportation programs included 1) Iowa Rail Assistance Program to identify and preserve service on economically viable rail lines, as well as 2) Iowa Railway Finance Authority, providing financial assistance in maintaining essential rail service.

Recent federal transportation policy requires the inclusion of freight in regional transportation planning programs. With the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), freight transportation must be explicitly considered as one of the fifteen factors in developing transportation plans and programs pursuant to Section 1024 of the policy statement: "11. Methods to enhance the efficient movement of freight." (2).

Implicitly, freight transportation may also be considered in reference to the policy's statements for intermodal and efficient transportation.

Iowa responded to the federal freight planning needs in part with Iowa in Motion, the state's comprehensive transportation plan. The report notes that freight transportation within Iowa is dominated by the rail and truck modes (1, p. 11). The condition of highway facilities is a key factor in the movement of Iowa products to regional, national, and international markets (1, p. 11). As outlined in this plan, investment in the highway system will focus on maintaining, preserving, and rebuilding the interstates and commercial industrial network. Additionally, the railroad's ability to haul large volumes as an energy-efficient, environmentally sound network will continue to be a major factor for its use in moving freight and improving the economy of Iowa (1, p. 63). Investment in the rail system will focus on rehabilitation of branchlines as well as construction or improvement of spur tracks for economic development projects.

Transportation agencies, like the Iowa DOT, make freight transportation policy in three areas: regulation, taxation, and investment (3). The main goals of policy action in the freight transportation system are to promote efficiency, equity, and finance (4, p. 35). However, transportation policy may result in inequitable modal benefits and inefficient resource consumption. A lack of data and user-friendly analysis tools makes quantifying the effects of these policies difficult.

Several recent studies have presented approaches useful in assessing freight transport policy. National Cooperative Highway Research Program Report 388 (5) and the U.S. Department of Transportation's Quick Response Freight Manual (6) specify a number of factors that influence freight transportation demand and coincidentally alter transportation costs and service. A change in any of these factors affects the modal transport demand and traffic shares on the transportation system (6, p. 2-1). These issues are summarized as follows:

- Transportation infrastructure
- Taxes, fees, and user charges
- Heavier vehicle policies
- International agreements
- Entry and exit barriers
- Rate regulations
- Safety regulations
- Subsidies
- Mergers
- Transport technology
- Intermodal operations
- Supply and product prices

In Iowa in Motion, the freight transportation issues relevant to Iowa are not specifically addressed or analyzed. However, a process for obtaining these issues from public meetings is outlined (1, p. 93). One example of this public process is the Freight Roundtable Discussion, held in August 1997. At this meeting, freight transportation providers of all modes met to express their beliefs for where the Iowa DOT should focus its freight planning efforts. Several of the issues listed above were emphasized at this meeting, such as truck and rail size and weight regulations (i.e. heavier vehicle policies). Identification of analysis techniques to quantify the impacts of these issues was not an objective of this meeting.

1.2 – Freight Transportation Modeling

A better understanding of regional commodity flow movements and how freight policy affects them can lead to more effective transportation policies and better allocation of limited resources. Bringing technical information to the policy decision-making table can also provide better planning (7, p. 50).

Numerous freight transportation research programs were initiated to develop analysis tools for freight planners. In 1983, National Cooperative Highway Research Program Report 260 developed a freight planning technique at a time when the freight transport industry was changing with deregulation policy. In 1997, National Cooperative Highway Research Program Report 388 provided a guidebook for freight planning issues, compiling

several freight transportation demand forecasting methods. Through the Travel Model Improvement Program, the U.S. Department of Transportation published the <u>Quick Response Freight Manual</u> in 1997 to assist planners with data collection and modeling efforts for this transportation sector. Several other studies were conducted by researchers in other programs to develop tools for freight planning at various levels of analysis, but were found to be too theoretical and data intensive for statewide implementation (8, p. 36).

Freight demand has been compared to passenger demand, and modeled with similar analysis methods. Recognizing the differences between the two sectors, several studies successfully implemented well-known modeling techniques to freight transportation that had originally been derived for passenger transportation. Freight demand is considerably different than passenger demand with respect to the following dimensions (5, p. 1-2):

1. Units of measure – freight is measured in units, weight, or volume, not simply passengers.
2. Value of time – substantial variances existing for different freight commodities are relatively large in comparison to value of waiting and travel time for passengers. This is also affected by just-in-time delivery practices.
3. Loading and unloading – freight requires a variety of specialized facilities and equipment for transfer, whereas passengers do not.
4. Types of vehicles – various freight transportation vehicles exist, from specific rail cars to containerized freight, as compared to passenger vehicles.
5. Number of decision makers – a fewer number of persons make freight decisions, such as shippers, forwarders, and brokers, as compared to the individual passenger decision.

In Iowa, freight flow modeling efforts have recently accelerated. With freight research funding available from ISTEA through the Midwest Transportation Center, several modeling programs have been developed. Multimodal grain flow models are currently being constructed for the Iowa DOT at the Economics Department of Iowa State University with this funding program. It would be useful to the Iowa DOT to have available several types of analysis tools for additional commodities.

A project aimed at coordination of model development efforts is currently being conducted by the Center for Transportation Research and Education at Iowa State University. Separate modeling programs would ideally attempt to use similar data, networks, and model designs, where appropriate. This coordination program directs the research conducted in this thesis.

In model development, several factors must be considered. Design of the model methodology, framework, and capabilities should consider end-user requirements. The following three modeling factors should be observed:

1. Data sources and data maintenance
2. Model accuracy and model output
3. Calibration and validation

1.3 – Research Objective

The Iowa DOT has a growing interest in freight transportation, and desires multi-commodity approaches to quantify the effects of various policy decisions, or "what if" scenarios, on the multimodal freight system. Nationally, there is a need for analysis tools that can examine freight planning issues and quantify their resulting effects on the freight transportation system (7, p. 11). Therefore, this thesis proposes a multimodal, multi-commodity, policy-sensitive modeling technique in response to this need. This research will build on the research and recommendations of recent NCHRP and the USDOT studies, as well as the successes of past modeling programs. The objectives of this research are summarized as follows:

1. Develop a state-level rail/truck/intermodal commodity distribution and assignment technique using readily available data and well-understood transportation planning methods.
2. Analyze a specific freight policy issue using the developed model.

The freight modeling process follows the well known, sequential, four-step urban transportation modeling system (UTMS), with some modifications. This research builds on past efforts that have succeeded in freight modeling with adjustments to this four-step process, but makes a unique adjustment to the UTMS for adaptation to multimodal freight modeling applications.

The study will focus primarily on truck and rail transportation, as freight transportation within Iowa is dominated by the rail and truck modes (1, p. 11). Freight planners should not address each mode individually when analyzing the freight transportation system impacts from policy implementation (9, p. 351). Therefore, this research will address the need to model the freight transportation system in its entirety, by including the intermodal interaction between truck and rail.

To be able to analyze freight transportation issues, like those listed previously, the model technique is policy-sensitive in three broad areas:

1. Changes in modal transportation costs, which is one likely effect of many freight policy and investment decisions
2. Changes in production and attraction which may result from changes in transportation or the economy
3. Infrastructure investment with construction, rehabilitation, or reconstruction of a freight transportation facility

The model will address the three modeling factors mentioned previously to ensure end-user satisfaction. (1) Using readily available data will limit data collection and maintenance efforts. (2) Accuracy of this modeling effort will recognize that freight planners are typically concerned with traffic volume magnitude in a corridor and how changes in the system will impact various economic sectors, not the unique decisions made by individual shippers or carriers. (3) This research will expose the modeling technique to various tests for calibration and validation, to ensure that the technique and its results satisfactorily depict actual statewide, modal freight traffic.

1.4 – Research Organization

Each chapter in this thesis will detail the steps of construction for the model methodology. The remaining chapters in this thesis are organized in the following manner: Literature Review, Model Methodology, Model Results and Case Study Application, and Conclusions.

Chapter 2 contains brief summaries and observations of relevant, professional studies concerning freight transportation modeling. This literature reviews is organized in two parts. The first section describes general freight studies, that is, the body of research that provides background information to more detailed freight modeling applications. The second section describes several freight modeling applications, and shows the history of modeling attempts over the last three decades. Strengths and weaknesses of the various modeling studies are then identified to assist in model development of this thesis.

Chapter 3 details the technique developed to address the defined problem, with each step in the modeling process described. The assumptions and simplifying measures are described. Calibration and validation methods are discussed.

The tangible results of the modeling process, such as the data output and analysis tools, are described in Chapter 4. Calibration and validation of the model, and problems encountered in the process, are outlined. With the working model, its applicability is tested in application to a case study scenario for increased truck size and weight, one of the Iowa-specific issues addressed at the Freight Roundtable Discussion.

Chapter 5 summarizes the results of the research and its validity to freight transportation modeling. Proposals to strengthen the modeling process are described. Estimation of the applicability of this model to several other study applications is outlined, to show that this model methodology could have many uses in freight transportation planning.

CHAPTER 2 — LITERATURE REVIEW

A review of past and present studies in freight transportation planning manifests an evolution of modeling procedures and methodology. As recognition of freight transportation's importance in national economic viability increased, research efforts progressed. This chapter outlines the progression of both freight planning studies and applied models over several decades.

This review is divided in three sections. Section 2.1 describes general studies of freight transportation, and Section 2.2 discusses freight flow models. General freight studies investigate issues, trends, and government action in freight transportation. Much of freight modeling is based on these far-reaching, background studies. Freight flow models estimate, invoking theory or assumption, the freight flows on various transportation networks. These studies are utilized by governing agencies with various objectives in estimating freight traffic levels and resulting demands on the transportation infrastructure. Section 2.3 summarizes the body of reviewed literature and assesses deficiencies in the research.

This review is not exhaustive, but provides brief summaries of several freight transportation planning studies, and notes their landmark contributions. This review emphasizes for each study the model methodology related to representation and analysis of the transportation network, specifically the intermodal aspects. For each study reviewed, the following points will be addressed:

1. Why and for whom this study was undertaken. This includes the objectives of the sponsoring agency, and directly relates to the geographic study region.

2. Analysis methodology: network representation, assumptions, data requirements, and analysis tools. Complexity of the modeling process is also stated.

3. Results of the study: modal traffic flow estimation and modal comparisons. The use of the study results is also discussed.

4. Deficiencies and implementation concerns. The documented or possible uses of the analysis procedures are considered.

2.1 – General Studies

2.1.1 – *National Cooperative Highway Research Program Report 260: Application of Statewide Freight Demand Forecasting Techniques (10)*

This report was prepared to assist state freight planners at a time when major changes were taking place in the freight transport industry (10, p. 1). Deregulation of the rail and motor carrier industries in the early 1980's, as well as an economy in recession, created greater intermodal competition, drastic changes in the number of carriers, and notable service and rate changes. As a user's manual, the report recognizes this demand for planning tools, and specifies a technique designed to handle a wide range of potential freight-oriented applications (10, p. 9). This freight planning study, first initiated as Project 20-17A, was conducted by Roger Creighton Associates.

The study is organized in four main parts. The first section describes identification of the freight transportation problem. The last three sections follow the four traditional steps to urban passenger transportation planning: freight generation, distribution, modal division, and traffic assignment. Case studies provide examples of the outlined methods.

The report notes that beginning any analysis requires defining the problem, structuring the analysis technique, and adapting the technique to produce the desired results (10, p. 11). In describing this process, the manual discusses the various points at which decisions must be made relating to level of analysis detail and availability of data. This will lead the user to effectively adapt the general technique that this report outlines.

The technique begins with freight traffic generation and distribution. While usually considered separately in the travel demand modeling process, these two activities can be estimated by two ways, depending on data availability. If commodity flow matrices can be produced from the given data, then freight generation and distribution are performed simultaneously. Lacking commodity flow data, freight generation is performed separately, utilizing simulation techniques based on industry production and consumption data or other economic statistics. Freight distribution is next performed using trade or gravity models with linear programming (10, p. 27).

Modal division is the next step developed in the freight demand forecasting technique. To simulate the traffic division among modes, past models have utilized comparative transport cost, rates, or total logistics cost (10, p. 43). Steps to determine modal unit costs and unit rates are clearly detailed for various applications and data sources.

Traffic assignment follows mode split in the outlined technique. Traffic assignment transforms pre-determined modal commodity flows, with origin and destination specified, to equivalent vehicle flows, allocating them to the transportation network (10, p. 73). Assignment techniques all serve the same purpose of calculating shortest distance or least cost routes through a network, but also provides vehicle volumes by segment and calculation of distance or traffic related costs (10, p. 73). The report recommends use of existing, computerized highway assignment techniques, developed for urban passenger transportation, with little modification.

The manual is very specific and detailed in outlining the freight transportation demand technique. It is intended for general applications, and allows tremendous flexibility and creativity on the part of the freight planning practitioner. The technique follows the methodology of the well-understood urban passenger transportation demand model. However, while the study does specify the data necessary for the various procedures, no account is taken for the difficulty in obtaining these data. For example, the data required for conducting the modal division analysis (unit costs and/or unit rates) are very difficult to attain for some modes.

2.1.2 – *National Cooperative Highway Research Program Report 388: A Guidebook for Forecasting Freight Transportation Demand (5)*

This report is the most comprehensive freight transportation study to date. As a guidebook, the report was designed as a reference document for use by transportation planners for forecasts of freight transportation demand, corridor planning, strategic planning, or knowledge of industry decision-making (5, p. 1). The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 placed great demand for freight transportation planning on the public planning sector. This study responds to that demand by providing detailed

information on the issues affecting the freight industry, and describing proven analytical methods. This freight planning study, initiated as Project 8-30, was primarily conducted by Cambridge Systematics, Inc., with assistance by Leeper, Cambridge & Campbell, Sydec, Inc., Thomas M. Corsi, and Curtis M. Grimm.

The report begins by characterizing the logistics process, analyzing factors that influence the freight system, and illustrating applications to planning activities. The study investigates the entire logistics process: those activities involved in the handling and movement of a product from its point of production to point of consumption or sale (5, p. 5). This includes the interaction between shippers and carriers, and the technology employed by each to perform their duties more efficiently.

Next, the report lists and thoroughly characterizes important factors that directly or indirectly affect freight transportation demand, either of which results in changes in transport costs, rates, and of services offered (5, p. 7). Issues with direct influence include national or regional economic activity, industrial location patterns, international trade agreements, and emerging practices in shipping, packaging, and transport. Those issues with indirect influence include government controls by regulation, taxation, subsidization, and transport policy, and as well as carrier operating agreements, transport technology, and congestion.

The report next describes proven methodology for estimating the freight-handling capabilities, and economic effects, of various modal and intermodal facilities, whether existing or proposed. A primary activity in any planning process is collection of data, and the report describes the applicability of special surveys and other data collection procedures. A thorough list of forecasting procedures and general description of the required steps for each, provide a tremendous resource for estimating demand on the facility, and the extent of the freight market it serves.

Lastly, the Guidebook provides a broad analysis of procedures for assessing the impacts of government policies on freight demand (5, p. 36). A framework for policy impact analysis provides a general approach by which to structure research for this purpose. The report details steps necessary for estimation of base-case conditions, and subsequent

estimates of the effect of policies on costs and service characteristics. The outcomes of this analysis are to estimate the policy-related changes in modal demand (5, p. 39).

The Guidebook provides a very useful resource for freight planners tackling many pressing issues. However, the study does not specifically address many of the freight planning problems that concern state departments of transportation. The most practical section of this study, policy-related changes in modal demand, does not prescribe specific activities, data collection procedures, or analysis techniques for estimating changes in freight transportation demand. Aspects and applications of modal network analysis, a common objective of state and regional freight planning practitioners is vaguely addressed in the report, but numerous studies are lightly summarized in an appendix.

2.2 – Network Flow Analyses

Methods used to model freight transportation demand can be categorized into two general types: spatial price equilibrium and network equilibrium (8, p. 11). Spatial price equilibrium methods use a simplified transportation network to estimate both flow between production and consumption regions, as well as commodity selling and purchasing prices. Network models are typically used to analyze flow among origin-destination pairs connected by a finite network of transportation facilities.

Innovative contributions have been made that build upon these methods. Following are brief descriptions of various freight flow studies.

2.2.1 – "Network Analysis of Highway and Intermodal Rail-Highway Freight Traffic" (11)

This study analyzes nationwide highway and highway-rail intermodal freight movement using a computer-generated, intermodal network. Building on past success with the Princeton railroad network model (PRNM) and graphic information system, this study adds the U.S. highway system and intermodal transfer points to its network. It appears the study was motivated solely by investigative curiosity, as no benefactor or sponsoring agency is mentioned in the study report.

Developed at a time when computer-aided modeling was at its primary stages, this study advances freight transportation demand modeling to a new level. Computer-based network representations were at minimum, and of poor quality (11, p. 61). A link-node railroad network was manually developed in the PRNM study with successful analysis and problem-solving capabilities. A compatible link-node highway network was manually created, and added to the existing railroad network with intermodal connections joining the two. Nodes attributes for both networks include coordinate values, place names and state, intermodal ramp code (if applicable), and standard point location code. Link attributes include distance, hazardous materials restriction, route designation, and route type (interstate, toll, divided with limited-access, and non-divided).

Data were gathered from various sources, locating the best, publicly available data sources for that time (11, p. 61). Sufficient network representations for rail and highway did not exist, and were consequently created manually by the research team. Additional data sources for network attributes (number of lanes, divided vs. undivided) must have been used, but are not mentioned in the report. Highway origin-destination flows were attained from the 1977 Census of Transportation, while rail flows were found in the 1981 One-Percent Waybill Sample. No data were available for intermodal traffic. For purposes of the case study, the commodity data were limited to chemical traffic (STCC 28).

Routing of traffic on the rail and highway network is achieved by a "standard" traffic assignment procedure based on a minimum-cost, unconstrained, path-finding algorithm (11, p. 65). Modal link costs are based on user-specified mileage rates. Link data can be adjusted to any function, dependent only on data availability.

The methods used in this study provided the first example of network flow analysis with a graphic information system. Integration of the modeling results produced traffic density maps for understanding distribution patterns and performing freight planning activities. The highway flow analysis is "believed to be the first computer-generated U.S. highway traffic density map." (11, p. 66). The graphic information software used in this study is a predecessor to modern-day GIS network analysis.

These study results were a milestone for this era. However, the study fails to describe the steps to network development, mentioning instead that existing networks are proprietary. It is clear that these study results are reproducible only with enormous effort. While the maps produced a greater understanding of freight flow on the network, these values were not validated in any way. Lastly, the report does not mention data availability beyond the public resources of the Census of Transportation and rail waybill sample, an impediment that troubled freight planning researchers of that decade.

2.2.2 – "A Multimode Multiproduct Network Assignment Model for Strategic Planning of Freight Flows" (12)

This study presents a network model for simulation of multimodal freight flows on the Brazilian transportation network. The objective of this study is to develop a network assignment model suitable for modeling national and regional freight transportation systems. Brazilian freight planners required this analysis in several applications.

The developed model considers the competition among modes of transport, wherever it is present, and assumes that goods are shipped at minimum total generalized cost (12, p. 26). Demand and mode choice are exogenous in this model. The freight flow data specifies both freight generation and distribution, through a set of origin-destination pairs, as well as valid options for mode split, by specifying a subset of allowable modes for transport. The study does not identify shipper and carriers explicitly, rather it aggregates these data into analysis zones.

The freight transportation network is defined with parallel links between nodes used to represent the available modes for transport between them. Intermodal movements are represented as link to link permitted movements. Appropriate, simplified cost functions for links and intermodal transfers determine the impedance for travel on that segment (12, p. 26-31). Multiproduct assignment is achieved by varying the cost functions according to actual commodity transportation costs by that mode.

The model employs a shortest path routine using the Gauss-Seidel Linear Approximation algorithm. This mathematical formulation minimizes the objective function

(sum of all arc and transfer costs for all commodities) subject to flow conservation and non-negativity constraints.

Several case study applications of this model demonstrate its utility and versatility (12, p. 36). In the first study, characterizing a specific region within the Brazilian freight transportation system, the commodity flows determined by the model were found to closely reproduce the mode and route distribution patterns identified by other data sources (12, p. 36). The second application analyzes development of a specific corridor, and results in measures manifesting the desirability of different transport facilities. The third study analyzes the import and national distribution of coal on the Scandinavian freight network.

The model is applied to several freight transportation applications, which is a testament to its flexibility. However, the data collection efforts for these various studies are not described. The specific data requirements and model inputs are vaguely mentioned, making suspect the applicability of this model in the United States. The model has been used in Brazil, where governing authorities has a greater span of control over transportation operations and regulation. Nonetheless, the network development and mathematical modeling are notable points for any future freight model.

2.2.3 – *Transport Flows in the State of Indiana: Commodity Database Development and Traffic Assignment (13)*

This study was undertaken primarily to develop a database of commodity flows into and out of the state of Indiana many of the industries important to Indiana. This database would form the foundation of a freight transportation model for Indiana that would assist state decision-makers in evaluating various freight planning alternatives (13, p. ix). This study was commissioned by the Indiana DOT with funding provided by the Federal Highway Administration.

This report includes a series of models for estimating the production and attraction levels of the industry traffic groups. Nineteen different commodity groups, as well as flows of mail by the U.S. Postal Service and express mail of companies such as Federal Express (13, p. 26). Data for commodity flows used elements of the 1977 Census of Transportation,

1993 Commodity Flow Survey, County Business Patterns, and the Carload Waybill Sample. This study includes a thorough discussion of each commodity and its relevant attributes that affect its freight transportation requirements.

The network included in the study involves only the highways and rail lines. The highway network includes all state highways, provided by the Indiana State Roadway Inventory, and circular rings of highways outside the state, as provided by the FHWA network. The railway network included all rail lines within the state, as provided in the U.S. Geological Survey TIGER files, as well as the entire network produced by the Federal Railroad Administration. The waterway and airway networks were not included in this study, as movements incidental to water and air freight transportation are included as highway or railway movements in this model (13, p. 16).

Modeling of the freight flows for each commodity was performed in a process similar to the urban transportation modeling system. Traffic generation equations were developed for the various commodity groups, assuming a close relationship between traffic production and industrial production indicators, as well as a relationship between traffic attraction and local market indicators. Data used for commodity production and attraction was found in the Census of Transportation and Commodity Flow Survey, while industrial and market data were attained from U.S. Census and County Business Patterns. Traffic distribution is achieved through a fully-constrained gravity model. Model parameters, such as the friction factors, were specific to commodity attributes, such as length of haul. Modal split is based on the commodity attributes and length of haul, attempting to replicate the divisions expressed in the Commodity Flow Survey (13, p. 57). Traffic assignment on the highway network was based on a redefined travel time, allowing reasonable allocation of traffic across the various classifications of roadways (13, p. 80). Traffic assignment on the railway network was based on a measure directly proportional to length of line segment, and indirectly proportional to the sum of rail line traffic density (i.e. rail line classification) and spatial separation (13, p. 102).

Forecasts of freight flows are projected for the years 2005 and 2015. The basis for these forecasts would be projections developed by Woods and Poole Economics, Inc. from

the "1992 State Profile of Indiana". The same trip distribution, mode split, and traffic assignment procedures were followed.

Over 130 data files were generated from the project's analysis procedures. These data are intended for use in the analysis of economic and planning questions. The study also mentions possible uses with transport analysis and policy formulation.

This report describes in detail the steps necessary to gather the freight flow data and construct a transportation network representation. The modeling process is easily adapted from the urban transportation model. Additionally, the data utilized in model development are readily available. The overall magnitude of this research project is notable, as recognized by NCHRP Report 388 (13, p. ix and 5, p. 63).

However, the modeling process is never checked for accuracy. The author recognizes that only the relative magnitude of different freight flows is of interest in most state-level planning decisions (13, p. xi). The modeling applications that the author mentions, however, often rely on accurate assessments of freight traffic levels.

2.3 – Conclusions

The general freight transportation studies provided a detailed perspective of this transportation sector. Numerous, relevant issues and planning concerns are addressed. The need for effective freight transportation planning models is strongly expressed within these studies.

However, a review of the freight transportation network models revealed a lack of methodology in addressing these issues. For example, the freight transportation system should be viewed in a multimodal context, yet many of these modeling efforts analyzed modes based on their specific capabilities, not on their interaction with other modes.

In the network analyses, it has been shown that the four-step urban transportation model can be adapted to freight modeling applications. With simple modifications, this well-known process can reflect the behavior of the freight transport industry and its derived demand. While several of the methodologies following this format can be applied when appropriate data and resources are available, difficulty lies in tailoring these methodologies

to specific planning problems. By adjusting the freight network representation based on freight transport objectives, such as minimum travel time or restriction to certain facilities, the typical actions of the transport modes can be modeled in the mode split and traffic assignment phases

It is apparent in some of the network studies that their derived modeling processes can be very complex and would be time-consuming to replicate. Clearly, when operating with resource constraints, freight planning agencies desire an effective modeling process with reasonable effort. The model should provide adequate data, understandable methodology, and comprehensible results at a minimum expense.

CHAPTER 3 — MODEL METHODOLOGY

The purpose of this chapter is to outline the policy-sensitive, multimodal freight transportation modeling methodology and how it may help to address some immediate decision-making needs. The specific steps to construct and evaluate the model are described. Additionally, a case study scenario that depicts a relevant freight policy issue, tests its applicability. The freight modeling process follows the well known, sequential, four-step urban transportation modeling system (UTMS), with some modifications. This research builds on past efforts that have succeeded in freight modeling with adjustments to this four-step process. However, this methodology makes a unique adjustment to the UTMS for adaptation to multimodal freight modeling applications.

This chapter consists of six sections. Section 3.1 describes the general framework for the multimodal freight transportation model and the alterations made to the sequential, four-step UTMS. Section 3.2 describes available data and their use in the model methodology. Section 3.3 discusses the multimodal network representation, including the assumptions made and steps performed in its construction. Model performance and network analyses are described in Section 3.4. Section 3.5 outlines the calibration and validation methods employed to check the model results. Lastly, Section 3.6 describes the steps needed to apply the model to the case study in Iowa.

3.1 – General Layout of Methodology

This section describes the technique proposed for multimodal analysis of statewide freight flows, based on well-known modeling procedures and readily available data. The procedure can be summarized in the following steps:

1. Identify commodity tonnage produced or attracted to each zone.
2. Construct a multimodal network representing all feasible routes for freight movements to, from, and within the state.
3. Assign freight flows to the network with the objective of minimizing total logistics cost for each movement.
4. Calibrate and validate the resulting traffic assignment with other data sources.

These four steps are illustrated in Figure 3.1.

This modeling process closely follows that of the conventional, four-step UTMS as a starting point for model development. The UTMS process involves: 1) trip generation to determine zonal productions and attractions, 2) trip distribution to predict zone to zone flows, 3) mode split to determine the type of transport, and 4) traffic assignment to theorize the path on which the trip will be made.

It is well documented that freight transportation is very dissimilar to passenger transportation for which the UTMS was derived (5, p. 1-2). However, three specific steps of the UTMS procedure have been redefined in this thesis for analysis of freight transportation.

Trip generation, the first step in the UTMS procedure, does not occur in the traditional manner. Measures of trip production and attraction already exist in the available commodity flow data. Thus, theoretical trip production and attraction rates are avoided. However, these data are not sensitive to changes in production and attraction that may result from implementation of some freight policy. This is overcome by aggregating all origins or destinations for each commodity in every zone, providing respectively, general production or attraction levels for each commodity. Production and attraction figures, rather than origin-destination pairs, allow flexibility in addressing the effects of freight policy on industry production, industry or public consumption, as well as transport logistics decisions. The process of data manipulation is further detailed in Section 3.2.

Mode split determination and traffic assignment are performed with a new approach. Modal choice is available only where 1) intermodal competition physically exists, 2) carriers provide services differentiated by price and service quality, and 3) commodity attributes are conducive to transport by competing modes (10, p. 43). Past studies have estimated mode split based on predetermined mode split percentages (13). However, shipping decisions for mode choice are often based on a combination of commodity requirements, modal options, rates, and carrier reliability (15, p. IV-14 to IV-17). Thus, this analysis combines mode split and traffic assignment in a single step. The multimodal network provides two transportation choices (rail or truck) and allows the intermodal movement between these two. The network is attributed with modal rates ($ per ton-mile). Thus, the shipper objective of minimized
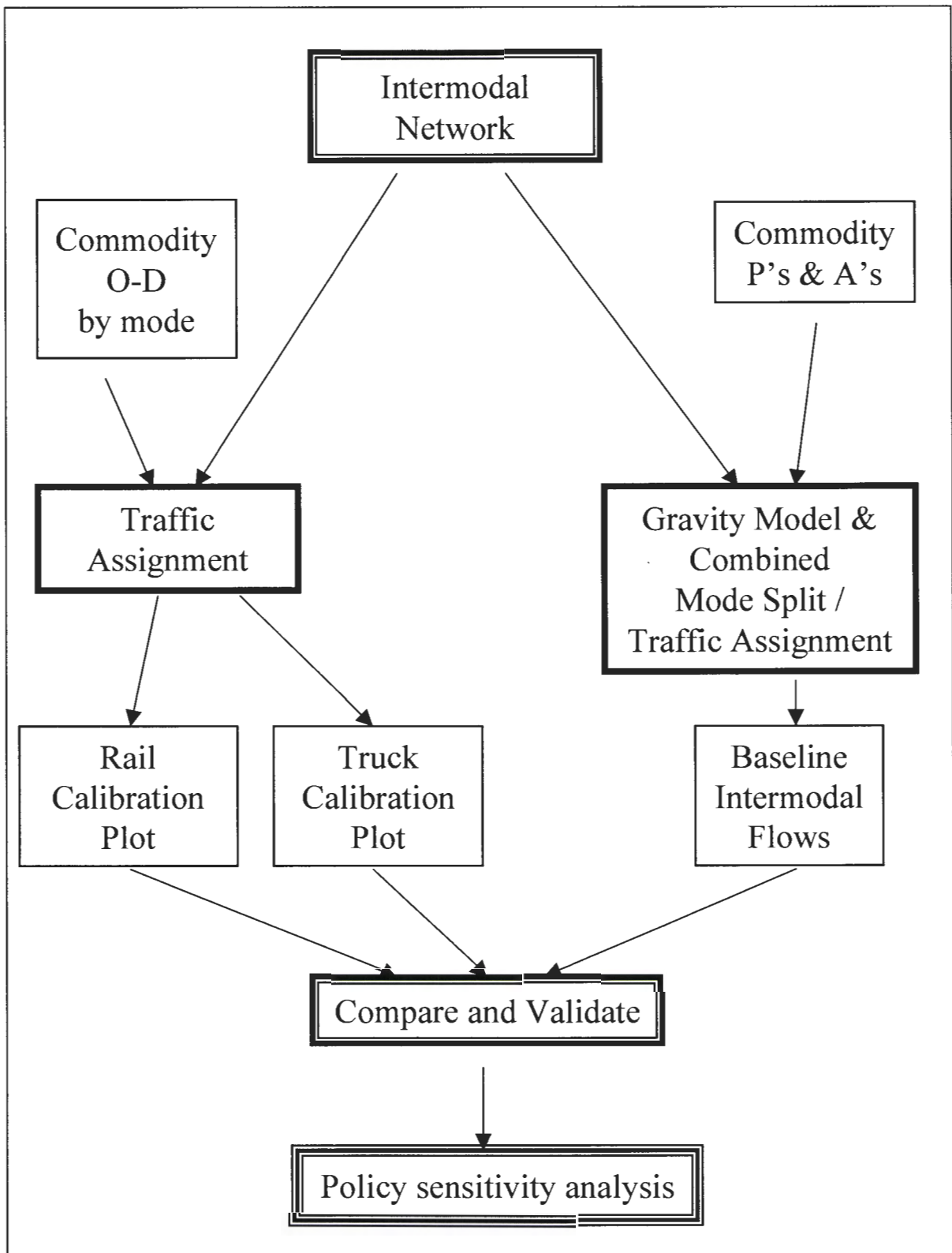
Figure 3.1. Model Methodology

logistics cost for each movement is achieved by assigning traffic to the minimum cost path, which may involve only rail or truck movements, and/or an exchange at intermodal transfer points. This research thus assumes that mode split is incorporated in the minimized cost objective. The application of these assumptions to the modeling process will be described further in Section 3.4.

Recognizing commodity attributes is critical to the model methodology. Each commodity group, by nature of its attributes, has different transportation requirements. Shippers base freight transportation decisions on both market conditions and commodity attributes, and shippers of similar goods will have similar transportation requirements. It is also assumed that freight movements of different commodities interact independently with the transportation system. Therefore, this research approach separately models each commodity in individual layers, with each layer representing goods moved by a specific industry or economic sector. After developing the layers for each economic sector, these layers can be overlaid to result in a comprehensive summary of state-level freight transportation flows.

To effectively address freight transportation planning concerns, the model technique not only must provide a baseline estimate of freight flows, but also be sensitive to policy and infrastructure changes. Policy changes usually have the effect of changing modal transportation costs. This may in turn alter trip distribution, and ultimately, industry production and consumption levels. Changing the link costs on the network, specific to mode, reflects changes in transportation costs for each mode as a result of the policy, as described in Section 3.6. Altering the model's network representation can simulate infrastructure changes. Links can be added to the multimodal network, if a new facility is constructed, or link attributes can be changed, if an existing facility is modified.

3.2 – Data and Zonal Structure

The freight data element in greatest deficiency is commodity flow data (8, p. 40). To overcome this deficit, the Iowa DOT purchases data for commodity flow movements from Reebie Associates (Stamford, CT). The Transearch database is commercially provided to

the freight transportation planning community. This database is purchased by the Iowa DOT and thus will be available for their future analyses.

Information provided in the Transearch data includes origin state, origin BEA, destination state, and destination BEA – for each origin-destination pairing. The data are further classified by Standard Industrial Commodity (SIC) code and volume of freight by shipping mode in short tons (2,000 lbs.). Transearch data provides information on the volume of freight traffic by commodity moving between all U.S. market areas (16, p. 1). However, the database purchased by the Iowa DOT shows only those movements with origins and/or destinations within Iowa.

Construction of the Transearch database uses several primary sources of data. A partial list includes: 1) Railroad Waybill Sample, 2) Commodity Flow Survey, 3) U.S. Census Survey of Manufactures, 4) annual motor carrier industry financial and operating statistics, and 5) annual county employment and population data (16, p. 9). The 1990 version of Transearch was the first to use actual truckload traffic flow data as reported by major truckload motor carriers (16, p. 14). These data are then converted into the common Transearch framework, while ensuring the elimination of any potential double-counting from partially overlapping data sources.

These data were produced in 1992, therefore, all other model assumptions and data sources are based on this date, to ensure accuracy of model results for that base year. Employment and population statistics, as well as truck and rail freight rates, are based on 1992 data.

3.2.1 – TAZ Definition

The first step in this model development is to define regions representing the traffic analysis zones (TAZ). Measures of travel demand are aggregated to these zones. The zonal structure of the provided Reebie Transearch database defines a beginning geographic level of aggregation. For Iowa and its neighboring states, the Business Economic Area (BEA) is the smallest zone at which data are presented. Further from Iowa, states and combinations of states, become the zonal level of data aggregation.

The size of the TAZ depends on the desired accuracy of commodity flow analysis. For detailed analysis of freight flows within the state, the level of aggregation at which these data are presented is insufficient. Iowa data are aggregated to the BEA level, providing only six complete zones and several partial zones within the state boundaries. This large TAZ definition would not allow accurate assignment of freight flows to the network. The number of possible highway and railroad routes and connections within a TAZ of this size would be too numerous to estimate flows on the network within that region.

Therefore, for freight flows originating and/or destined in the state, the 99 county regions were logical TAZ definitions. The number of routes within this area is minimized to a few primary highways and railroad branch lines. This method provided a total of 144 zones (99 counties in addition to 45 external zones). Figure 3.2 shows the Iowa counties and Reebie TAZs.

3.2.2 – Data Disaggregation

Data as provided in the larger BEA format for Iowa must be disaggregated to the smaller county level. Production and attraction estimates for each county are proportioned from the BEA according to the contribution by that county. Data disaggregation for originating freight observes the following underlying premises: (10, p. 15)

1. Manufacturing plant output is correlated with the number of employees.
2. All plants in same industry (i.e. same commodity group) have equal productivity.
3. All plants in same industry share proportionately in resulting commodity flows.

Thus, for a given commodity movement originating in Iowa, data aggregated at the BEA level can be apportioned to a county level by using county and BEA employment data for the relevant industry:

County Origin Tons = BEA Origin Tons • [County Employment / BEA Employment]

Likewise, attractions must also be disaggregated to the county TAZ level. An input-output table could be used if that commodity is distributed to other various manufacturing industries or directly to consumers (10, p. 22-23). However, the two commodities chosen in

this study (Meat Products {SIC 201} and Farm and Garden Machinery {SIC 352}) are assumed to be final products, and are therefore distributed directly to the consumer. As a result, trips destined to Iowa are proportioned according to a measure of consumption for that commodity as follows:

County Destination Tons = BEA Destination Tons • [County Consumption / BEA Consumption]

Measures of consumption are specific to the industry or commodity group. For Meat Products (SIC 201), population is assumed to statistically identify the demand for meat products in that region. For Farm and Garden Machinery (SIC 352), the farmed acreage in each county is assumed to describe the demand for that commodity. A FORTRAN program performs the data disaggregation and prepares the commodity trip table for TRANPLAN computer modeling and analysis (Appendix A).

Statewide economic and demographic data to perform this disaggregation are available from several government agencies. At the county level, detailed, confidential employment data by industry are obtained from the Iowa Department of Workforce Development (IDWD). Confidentiality agreements are registered with IDWD for permissible use of the data. Population statistics are publicly available from the U.S. Census Bureau. Agricultural statistics, including farmed acreage in each county, are available from the U.S. Department of Agriculture.

Data for each TAZ are condensed to one location, a centroid node. For each zone, centroids are closely placed geographically to the center of economic activity for that TAZ. These economic hubs are located using GIS data sets from the Bureau of Transportation Statistics (BTS) for large urbanized areas, as well as U.S. Census data for smaller population centers.

3.3 – Multimodal Network Definition

The next step is to delineate a network that simulates the transportation network of both the rail and truck modes. A simplified, multimodal network that meets the needs of analysis within Iowa is desired. The coverage must be sufficient in detail, accuracy, and

Figure 3.2. Traffic Analysis Zones

completeness to well represent the existing network by which Iowa commodity movements occur.

The network for analysis is constructed within a geographic information system (GIS) software package. MapInfo is the chosen platform for this requirement. Using a GIS provides a quicker means to construct the network of nodes and links. Additionally, the GIS can display and manipulate output from the analysis tools for effective visualization.

3.3.1 – Highway Network Definition

The Iowa DOT only has jurisdiction, and therefore a principal interest, in the Iowa primary roadway system. This classification includes all interstate, U.S., and State highways. Therefore, the highway network, at a minimum, must focus on these roadways. Beyond Iowa boundaries, the network can be thinned to essential routes that would primarily be used in long-distance freight movements, such as the interstate system. It can be assumed that for long distance hauls, trucks will be attracted to the high-speed, access-controlled interstate system. Also, it can be assumed that within a short distance from state borders, trucks will try to access the interstate system by way of primary highways in adjacent states.

As a result, the highway network used in this study includes all primary roadways within Iowa, select principal highways in neighboring states, and interstate highways throughout (Figure 3.3). The primary system within Iowa is available as a GIS coverage in its most current, updated version from the DOT. Interstate highways and principal highways in neighboring states are identified through the National Highway Planning Network GIS coverage included in the BTS National Transportation Atlas Database.

Each centroid of each TAZ is connected to the highway network. The primary highway system allows sufficient access to each county from several directions. Centroid connectors are directed from the centroid node to one or more adjacent highways.

3.3.2 – Cost of Transportation on Highway Network

Transport of commodities on the highway network, by way of truck transport, has a certain associated charge per ton-mile, which is assessed to the shipper. This cost of

transportation varies by commodity, often dictated by time-sensitivity and packaging requirements. Truck transportation is very cost effective for short-distance hauling, but can be very cost prohibitive for long-distance movements. As a result, the average truck shipment distance was approximately 410 miles in 1992 (14, p. 42). Therefore, cost of truck transport on a highway link was assumed to be a function of distance.

For the first, rough modeling attempt, truck transportation is assumed to be five times the cost of truck transportation. With rail revenue per ton-mile around 2.6 cents (see Section 3.3.5), truck revenue per ton-mile is assumed to be 12.9 cents. Even though this figure will vary by commodity, shipment size (i.e. bulk rates) and type (LTL versus TL), no specific rates could be attained for this research that identified these price differences.

3.3.3 – Railroad Network Definition

Of the entire national system of railroads, the Iowa DOT is most concerned with the active rail lines in Iowa, as these facilities service the state industries. Therefore, the network of railroads must focus on these facilities. Beyond Iowa boundaries, this network can by thinned to mainline routes of major railroad operators, as smaller operators will not usually intercept movements of long-distance rail hauls.

The railroad network for the entire nation is available in GIS format in the BTS National Transportation Atlas Database. Reported traffic levels classify these rail lines as mainline and branch line.

Within Iowa, the railroad network consists of all rail lines in the BTS data set that correspond to those lines present in the 1992 Iowa Railroad Service Map from the DOT. From these maps and discussions with DOT planners, it is evident that many Iowa rail facilities in the BTS map had long ago been removed from service (abandoned or rail banked). Thus, the BTS data could not be used in Iowa without modification and forensic analysis.

Outside of Iowa borders, the mainline tracks of several major railroad operators are included in the rail network. Of all the nationally operating, Class 1 railroad companies, only those that operate within Iowa are included in this network. These selected railroad
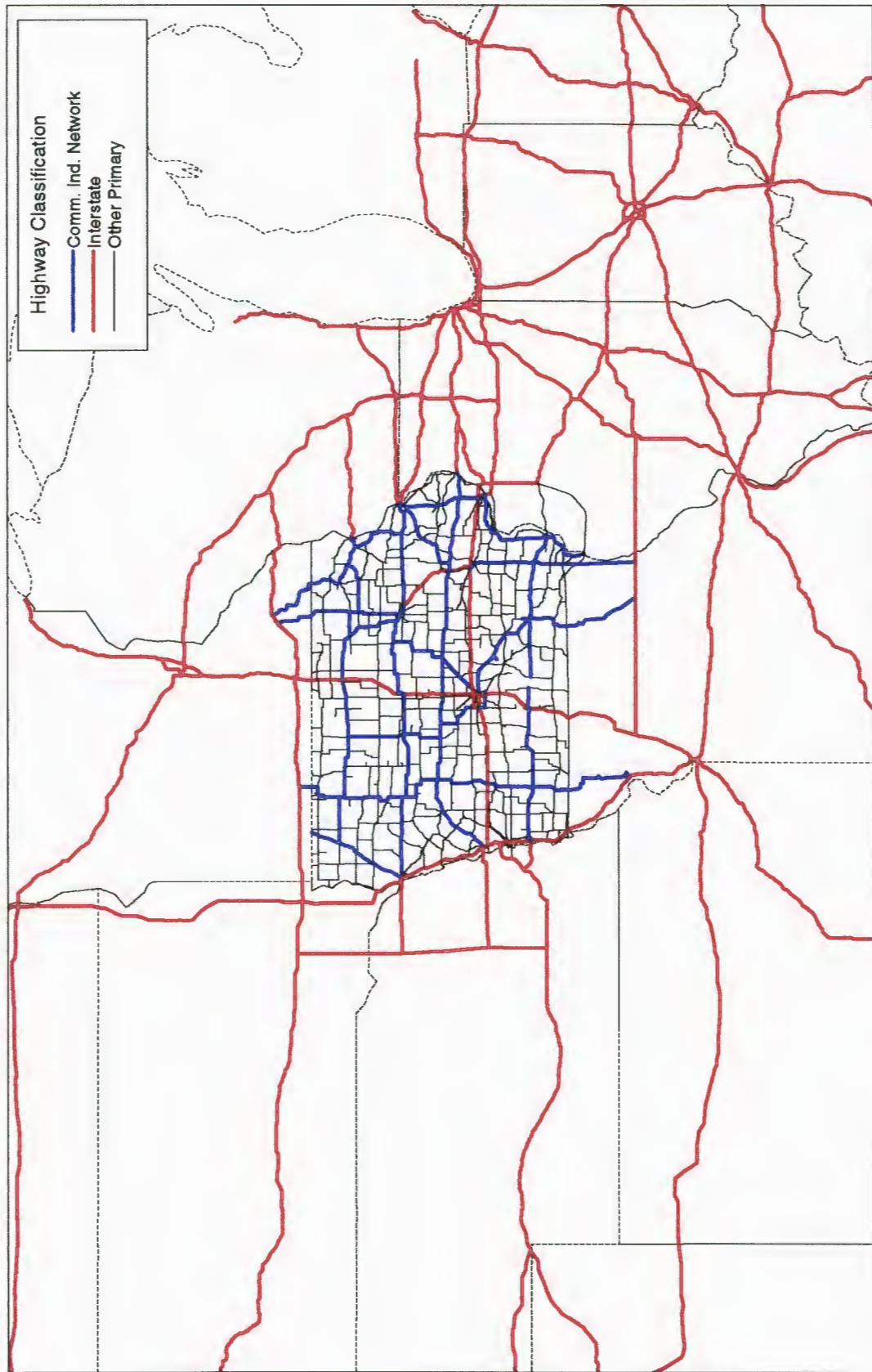
Figure 3.3. Highway Network

operators include Burlington Northern-Santa Fe Railway (BNSF), Union Pacific Railroad (UP), CSX Transportation (CSX), and Norfolk Southern Railway Company (NS). System maps available from these companies allow identification of the remaining rail network. Using these maps and the BTS mainline rail classification, rail network links were digitized for these carriers along the identified routes. Including smaller operators within Iowa, a total of eight railroad companies are included in this rail network. Using this number of railroad operators provided a geographically dense coverage for a railroad network reaching all TAZs (Figure 3.4).

Not every centroid for each TAZ is connected to the rail network. This is only observed in Iowa, where rail availability in each county is determined by the existence of a rail line within that region. In addition, each industry group within that TAZ may not have access to that rail link. This latter point is ignored in this study, as it is assumed that where a rail line exists in that zone, it is also accessible to each industry in that zone.

3.3.4 – Railroad Network Assumptions

Railroad mergers after 1992 are reflected in this network's railroad operator attribute. Comparing the 1992 Rail Service Map to the 1997 Rail Service Map, both provided by the DOT, the only changes observed between the two include the mergers of Chicago Northwestern with Union Pacific, and the switch from Soo to IMRL. However, these changes should not affect the model, which uses 1992 data, since rail density and the associated, assumed service quality, have not changed in that time period.

In meetings with Iowa DOT planning experts, it was stated that Class 1 railroad operators are not likely to transfer shipments to or from other major railroad operators at locations other than large freight hubs. At other locations, these major carriers may transfer loads with smaller Class 1 or Class 2 operators, if the larger operator does not service the points of origin or destination, and a classification yard exists there for those two operators. To simulate these assumptions, specific locations were selected throughout the network where inter-operator transfers are permissible. Appendix B includes the table of assumed

inter-operator transfers. This table of locations will be checked by DOT planning personnel to assess the validity of the assumed transfer points.

3.3.5 – Cost of Transportation on Railroad Network

Shippers transporting commodities on the railway network are assessed a certain charge per ton-mile. Like truck transport rates, this cost of transportation varies by commodity, often affected by bulk quantity, time-sensitivity, and packaging requirements. Rail transportation is most cost effective for long-distance hauling, as rail access and time (cost) of loading and unloading both displace any benefits to short movements. This is reflected in a longer average length of haul, 763 miles (14, p. 53). Cost of rail transport was also assumed to be a function of distance.

For the first, rough modeling attempt, rail revenue per ton-mile is estimated at 2.6 cents (17, p. a6). Even though this figure, like truck transport rates, will vary by commodity, shipment size, and car type, no specific rates could be attained for these different conditions.

3.3.6 – Intermodal Transfer Definition

The transportation system represented in this study is multimodal, reflecting the behavior of various interactions between rail and truck modes. Intermodal transfers between rail and truck will occur only at specific locations in the system. These locations, operating as intermodal terminals, have the equipment and facilities available to efficiently transfer shipments between these two modes. Rail intermodality includes a broad range of services; the most common are 1) trailer-on-flatcar (TOFC), also commonly referred to as "piggyback", 2) container-on-flatcar (COFC), 3) double-stack train (DST), and 4) carless technologies (18, p. 47). For the purposes of this study, an intermodal movement of any kind may occur at a designated intermodal transfer.

Intermodal terminals for this transportation network are located from the GIS TOFC/COFC coverage in the BTS NTAD. There are 367 locations given in the original table. Selecting those locations that are specifically noted in the data as being operated by one of the eight selected railroad operators provided a smaller list. Next, this list was
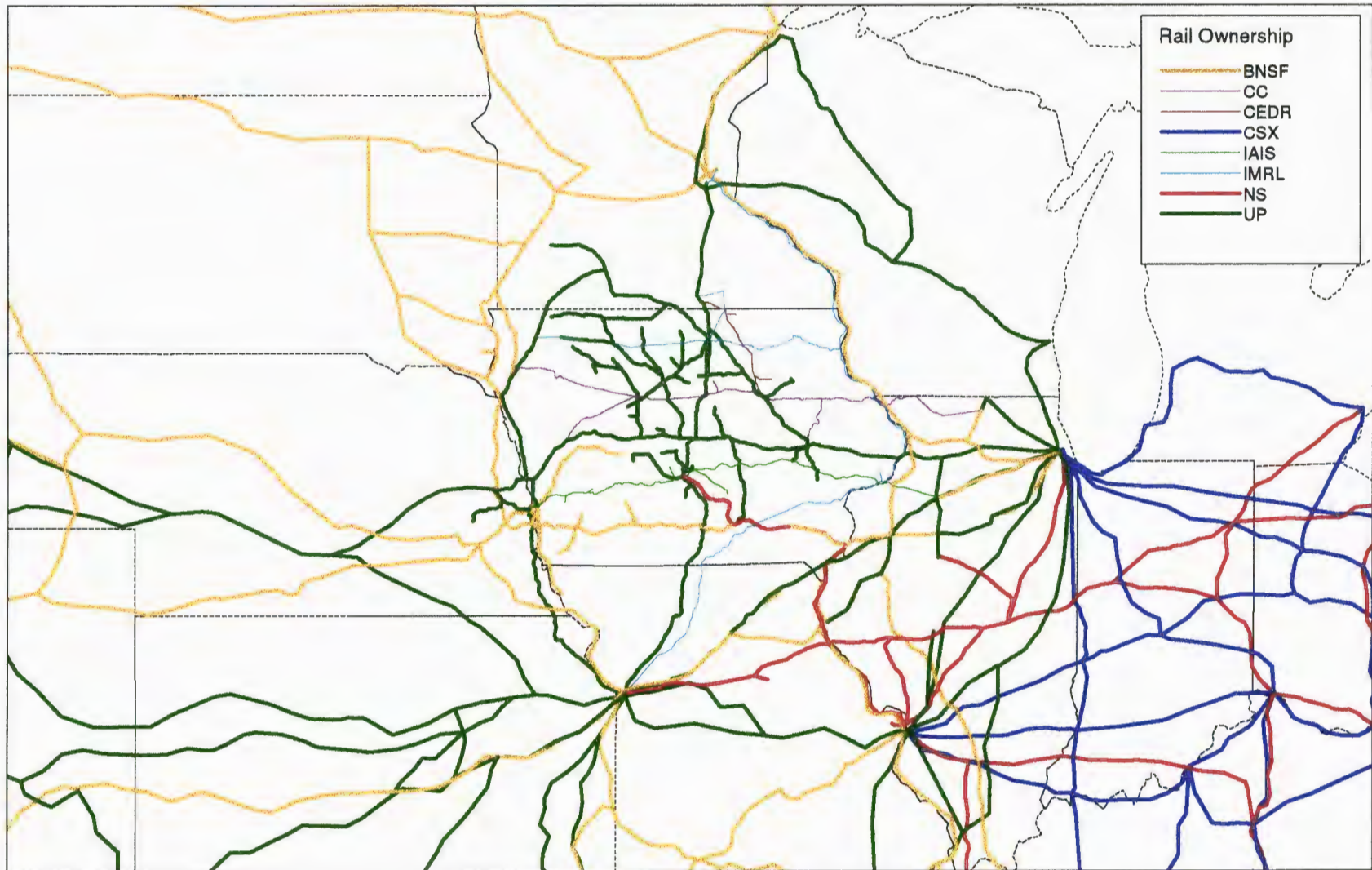
Figure 3.4. Railroad Network

narrowed further to one transfer point per operator in each TAZ. The only exception to this selection criterion is Memphis, Tennessee, a known, high-volume intermodal transferlocation for the selected four, nationally operating, Class 1 railroad operators (Birmingham, AL is the other intermodal terminal located in this TAZ) (18, p. 46). All intermodal terminals included in the NTAD database within Iowa are included in this network. This elimination process left 55 intermodal terminals remaining (Figure 3.5).

The two networks of rail and highway are joined only at these intermodal connections points. For each intermodal facility, the nearest rail line coinciding with that intermodal operator is located. Intermodal connectors are then drawn from this rail line and connected to the nearest primary highway.

3.3.7 – Cost of Transportation Through Intermodal Terminals

Revenue charges for intermodal transfers are incurred when carriers transfer shipments through these terminals. Relative to the costs associated with transport by rail or truck alone, typical costs per ton are associated for a freight transfer through an intermodal facility.

A rough estimates of intermodal freight charges are derived for this study. Drayage costs consistently represent 15% to 20% of the total cost to the shipper of an intermodal movement (18, p. 53). Drayage hauling is typically less than 100 miles (19, p. II-3). Additionally, intermodal movements are unlikely to occur with rail line haul distances of less than 500 miles (18, p. 55). Using these facts related to hauling distance and the assumed rates for rail and truck transport per ton-mile, an intermodal transfer anywhere on this simulated network will cost roughly $50 per ton. Although this rate would undoubtedly vary by commodity and type of intermodal movement, this situation is ignored in the model.

3.4 – Network Analysis Process

Following construction of the multimodal network, freight flow simulation can be performed, assisted with computer applications. TRANPLAN software, commercially available for travel demand modeling, was chosen for this analysis process for several
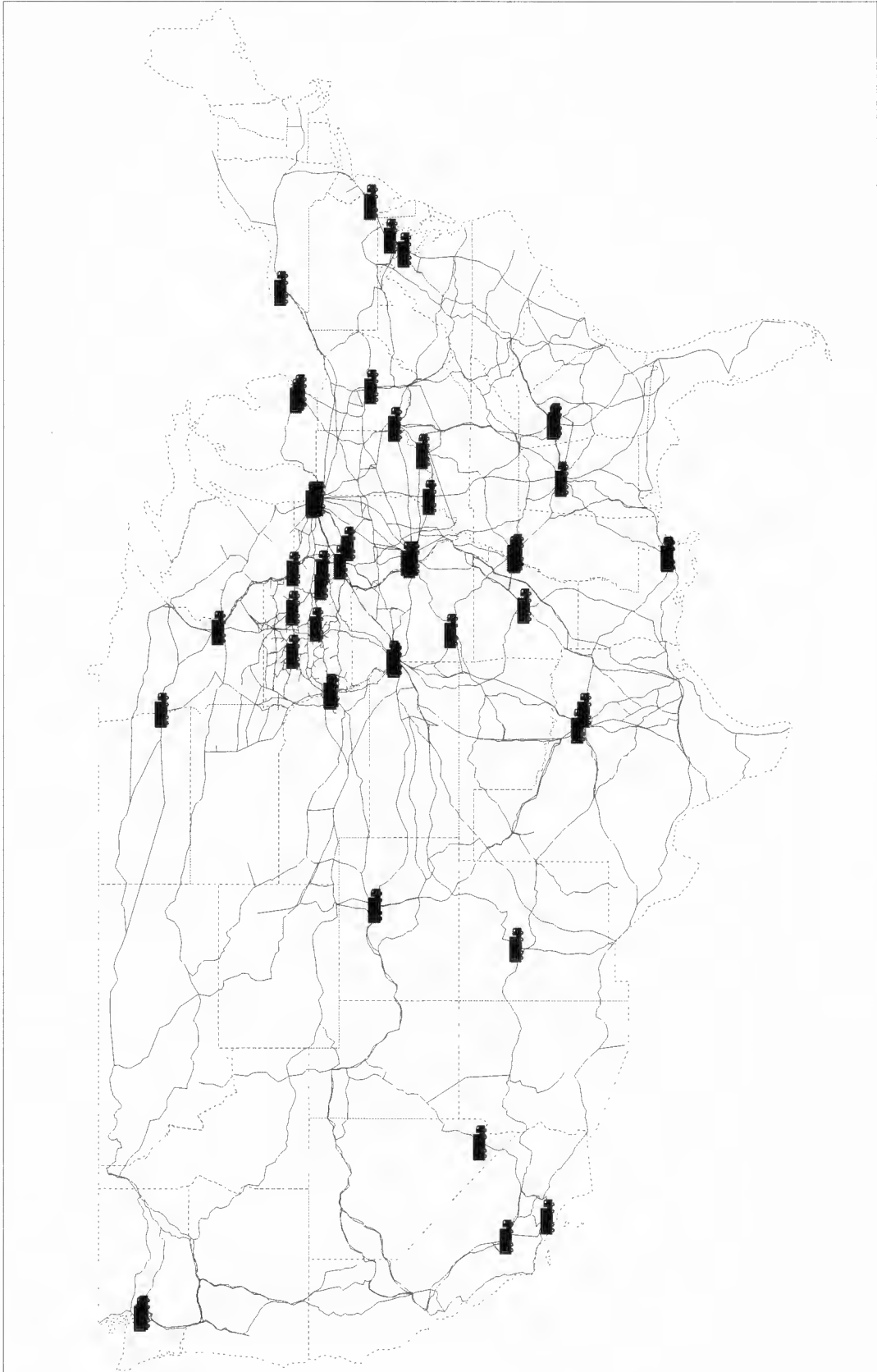
Figure 3.5. Intermodal Transfer Locations

reasons. The Iowa DOT uses this software regularly for its transportation modeling needs. Additionally, the State of Iowa has a statewide educational license for TRANPLAN software.

Other reasons for selecting TRANPLAN for this analysis include the existence of interface programs that allow import and export to the selected MapInfo GIS software. TRANPLAN accepts only text files for description of the node and link network. In TRANPLAN, node data includes node numbers and coordinate information. Link data consists of, as an example, beginning and ending node numbers, distance, speed, and grouping (e.g. railroad and highway). A GIS can generate and edit this information quickly, and export the required information as input to TRANPLAN. After TRANPLAN has completed its network flow calculations, the output can be imported back to the GIS for display and analysis.

The following subsections describe modifications to the UTMS as adapted to this freight modeling application:

3.4.1 – Trip Generation

Trip generation is already present in the commodity flow data. However, this study combines origins or destinations for each chosen commodity in every zone to provide estimates of productions or attractions, respectively. Trip generation rates, typically used in UTMS applications, are avoided for this research.

3.4.2 – Trip Distribution

Several freight models reviewed in the literature utilized a gravity model, or adaptation thereof, to distribute freight flow productions and attractions (6, 10, 13). Thus, having calculated commodity production and attraction levels, a gravity model of the following form is used in this research:

$$V_{ij} = \frac{P_i \cdot A_j \cdot F_{ij} \cdot K_{ij}}{\sum_x A_x \cdot F_{ix} \cdot K_{ix}}$$

V_{ij} = Volume of freight from zone i to zone j
P_i = Freight volume produced at zone i
A_j = Freight volume attracted to zone j
F_{ij} = Trip impedance factor from zone i to zone j
K_{ij} = Interzonal adjustment factor from zone i to zone j

Several parameters in the gravity model, such as the friction factors (Fij) and interzonal adjustment factors (Kij), need to be calculated to simulate freight distribution on the transportation network. Following is a discussion of these two variables, and how this methodology will adapt them to freight transportation.

3.4.2.1 – Friction Factors

For urban passenger transportation, friction factors have typically been based on travel time. For freight transportation, distance or transport cost is used instead (10, p. 29). Two studies reviewed each used friction factors based on this assumption.

Using travel time (6, pp. 4-19)
Four-tire commercial vehicles:
$$F_{ij} = e^{-0.08*t_{ij}}$$
Single unit trucks (6+ tires):
$$F_{ij} = e^{-0.1*t_{ij}}$$
Combination trucks:
$$F_{ij} = e^{-0.03*t_{ij}}$$
where t_{ij} = travel time (minutes) from origin i to destination j.

Using length of haul (13, Table G-1):
Food and Kindred Products (SIC 20)
$$F_{ij} = e^{-0.0048*D_{ij}}$$
Machinery, except electrical (SIC 35)
$$F_{ij} = e^{-0.0023*D_{ij}}$$
where D_{ij} = travel distance (miles) from origin i to destination j.

The friction factor estimations based on transport distance are used in this research. The use of commodity-specific parameters seems to compliment the layered approach of modeling each commodity separately.

3.4.2.2 – K factors

Another parameter in the gravity model formula is the sector to sector bias factor, or more commonly called the socioeconomic interchange adjustment. The purpose of this variable is to increase or decrease the attractiveness of specific sectors to trip allocation. In adapting the gravity model to freight distribution, this parameter is usually discarded (10, p. 29). However, the Reebie data in its original format specify only those trips with origins and/or destinations within Iowa. Having derived productions and attractions from this data, the gravity model should not produce trips having both origins and destinations in any zones other than Iowa TAZ's. Thus, K-factors of zero are used to prohibit these undesired trips for zones 100-144 (zones 1-99 correspond to the 99 Iowa counties).

3.4.3 – Mode Split and Traffic Assignment (Combined)

Modal division follows trip distribution in the sequential, four-step modeling technique. Traffic split among competing modes would then be assigned to the appropriate modal network. Shippers of freight minimize the total cost of shipment, possibly employing several modes to achieve the delivery. In addition, carriers of freight, especially the long-haul trucking companies, may rely on intermodal rail service to complete the line haul transport on time-insensitive commodities.

To address these behaviors of shippers and carriers in mode choice and routing, mode split and traffic assignment have been combined in this research to reflect the intermodal nature of rail and highway freight transportation. Link impedance values for both rail and highway networks reflect typical transport charges, and intermodal connections are attributed with typical transfer charges. Assigning traffic to the shortest path that minimizes transport cost allows an implicit modal division based on the assumed shipper decision-making process.

Beyond the link impedance values, other costs must be assessed in an attempt to accurately simulate freight transport on the network. Turn penalties have been used in urban transportation modeling to simulate resistance to specific turning movements at major intersections. These penalties are added to routes' total impedance in the least-cost paths.

Similarly, turn penalties are necessary in the modeled freight network to simulate the following conditions:

- Intermodal transfer. The movement from rail to truck, or truck to rail, is a fixed penalty of $50 per ton, as mentioned previously. This movement is coded as a turn penalty, rather than link impedance, because the links are coded with cost per ton-mile rates, not fixed costs.

- Interchange between railroad operators. Railroad freight carriers attempt to handle a shipment completely from its origin to its destination. Where service coverage prohibits this to be achieved, transfers to other rail carriers are performed at locations with classification yards. An invalidated, fixed cost of $100 per ton (twice the cost of an intermodal transfer) is assumed for this movement.

- Industry rail access. In a given TAZ with an existing rail line, rail transport may not be accessible for every industry in that zone. Should this critical fact be ascertained, this movement would likely be coded as a turn prohibitor where rail access does not exist.

Traffic is placed on the network using an "all or nothing" assignment. With this method, there is no consideration given to the network link capacity or travel time as affected by congestion. Congestion is usually not a key issue for intercity freight transportation. Freight traffic, especially by truck, is indeed impacted by congestion, but a change in the freight sector usually leads to very small changes in congestion.

3.4.4 – Model Output

TRANPLAN is used to perform the trip distribution and traffic assignment/mode split phases. Appendix C includes the TRANPLAN control file for this process. MapInfo GIS software is used to display and analyze the results. Included in the output are maps identifying network links with their associated commodity flows. This visual aspect allows decision-makers to quickly recognize statewide freight volumes by rail and motor carriers for inspection of important freight corridors.

Other data to be output from the model process is the modal shares of traffic predicted by the gravity model. In aggregating the data to general production and attraction levels, mode split in the data is lost. The results of the model methodology unifying mode

split and traffic assignment will be compared to the modal percentages estimated in the origin-destination commodity flow data, as described in the following section.

3.5 – Calibration and Validation of Modeling Methodology

Calibration of the modeling methodology is essential to determine the soundness of the freight planning technique. Calibration of the mode split results is of primary concern in this study. Model results with production and attraction level data should replicate the mode split as set forth in the mode-specific, origin-destination commodity flow data.

The Transearch database, without modification, is used initially to determine truck traffic and rail traffic distributions. These data specify trip ends (origin and destination), volume, and mode. Thus, trip generation, distribution, and mode split are already performed, and provide a trip table that can be directly assigned. Assignment of this traffic to the network, restricted to a particular mode, will provide truck and rail baseline calibration plots. The model results, using the summed production and attraction data (mode split lost), can be tested against these calibration plots. The resulting accuracy of the mode split results using the combined mode split/traffic assignment technique can be investigated. Appendix D includes the TRANPLAN control file for this process.

Model parameters can be revised to bring the modeling discrepancies of the two approaches within a tolerable level. The gravity model equation for trip distribution contains variables, such as the K factor and friction factor, that can be changed to affect the model results. Traffic assignment utilizes link costs and turn penalties, which are coded first with predetermined values for modal transport cost, but can be reevaluated with different freight rates or include link travel time.

To ensure that the model methodology not only replicates the given data, but also the true behavior of the system it represents, validation of model results is performed. Data sources for modal commodity movements other than Transearch provide a system of checks and balances for the model results. The Iowa Truck Weight Survey provides estimates of highway freight flows throughout the state. The 1993 Commodity Flow Survey is often

used as the primary data source for commodity flow movements, but is already incorporated in the Transearch database (16, p. 14). Specific to rail freight transport, the Rail Carload Waybill Sample could be used to validate annual commodity flow estimates on the railroad and intermodal links; however it too is already a data source to the Transearch database (16, p. 14). Thus, the Iowa Truck Weight Survey provides the only readily available, external data source to check the model results.

3.6 – Case Study Application

This multimodal, policy sensitive modeling approach is demonstrated through a policy issue case study. Increased truck size and weight limits is a timely issue that will affect Iowa freight transportation. The effect of this issue on highway and rail transportation is demonstrated on the meat products and farm machinery industries in Iowa.

Implementation of increased truck size and weight standards will influence the total logistics cost in several ways. Transport cost for shipments made via the larger vehicles will likely decrease, since more weight or volume will be permitted in a single shipment. Additionally, warehousing and distribution costs are apt to be affected by this more efficient truck transportation. Rail charges for modally competitive freight will change as well, responding to the pricing advantages of the trucking competition.

Although many of these policy effects could be reflected in the model technique, decreased cost of truck transport is the sole focus of this case study application. One possible truck configuration that could be permitted by new Federal standards would decrease line haul costs by 12 percent (21, p. 3, 49). Therefore, in this modeling process, cost of truck transportation for any commodity is lowered to 11.4 cents per ton-mile from the original 12.9 cents per ton-mile. This reduction of 1.5 cents per ton-mile is consistent with another study that estimates diversion of 1 cent per ton-mile of freight from existing trucks (21, p. 49). The new link costs are incorporated into the network and the modeling process of trip distribution and mode split/traffic assignment is rerun. The resulting changes in modal distribution of freight are measured. Statistics on tons carried by the rail and truck modes can then be obtained.

CHAPTER 4 — MODEL ANALYSIS

The purpose of this chapter is to demonstrate the capabilities of the multimodal model methodology in two analyses: 1) a baseline scenario, and 2) a case study application. The final result of the modeling procedure in each case is the estimated commodity tonnage, by mode, on each link of the network.

This chapter consists of three sections. Section 4.1 discusses the baseline application of the modeling technique. The complete modeling process is performed for both commodity groups. Section 4.2 describes the calibration and validation steps for this technique. The baseline results, in addition to other commodity flow sources, are used to test the model validity. Section 4.3 outlines a freight policy scenario of increased truck weight limits and how this multimodal modeling process can be applied.

4.1 – Baseline Application

The baseline scenario uses the Transearch commodity flow data in two ways, and will be referenced as the following: 1) aggregated, mode independent, zonal productions and attractions, referred to as P-A data, as well as 2) original, modal-assigned, origin-destination pairs, heretofore called O-D data. P-A data are processed through the modeling process of trip distribution and combined mode split/network assignment. O-D data supply a check on resulting modal distribution of the proposed modeling process by providing rail and truck calibration plots. The accuracy of the modeling technique with unified mode split/traffic assignment using P-A data is assessed from this examination.

4.1.1 – P-A Data Assignment

The first step in evaluating the modeling technique is to model the aggregated zonal productions and attractions (P-A data). These production and attraction levels are formulated into a trip table based on gravity model trip distribution. In this assignment method, the commodity shipments are unrestricted to any particular mode such that the shipment route is the least-cost path comprised of any or a combination of truck and highway links, accessing any intermodal connections between the two.

4.1.1.1 – Meat Products

According to the Transearch database, 6,293,300 tons of meat products moved by the truck and highway modes. The model assigned 6,160,170 tons for these two modes (approximately 98 percent of actual). This slight discrepancy is a result of proportioning the commodity flow data from the larger BEA level to the smaller TAZ (county) level of the model, then having to round these values in the TRANPLAN trip table.

Quantifying the modal distribution of this freight traffic among the truck and rail modes is determined using the GIS query capabilities. The volume of freight flowing on all the centroid connectors for a specific mode are added, then halved, thereby averaging the two-way volumes on each link. Table 4.1 shows the resulting modal distribution of meat traffic tonnage. Figure 4.1 shows this distributed meat traffic on the highway network, and Figure 4.2 shows the rail traffic distribution. Ton-mile estimations, by highway classification and railroad operator, are shown in Table 4.2, and 4.3, respectively.

Table 4.1. Meat Products Tonnage Distribution by Mode

Mode	Tons
Truck	4,197,690
Rail	1,497,925
Intermodal	1,226,125

Table 4.2. Ton-miles (SIC 201) by Highway Classification with P-A Data

Highway Classification	Ton-miles
Interstate	1,795,208,098
CIN	300,985,439
Other Primary	354,759,848
Total	2,450,953,385
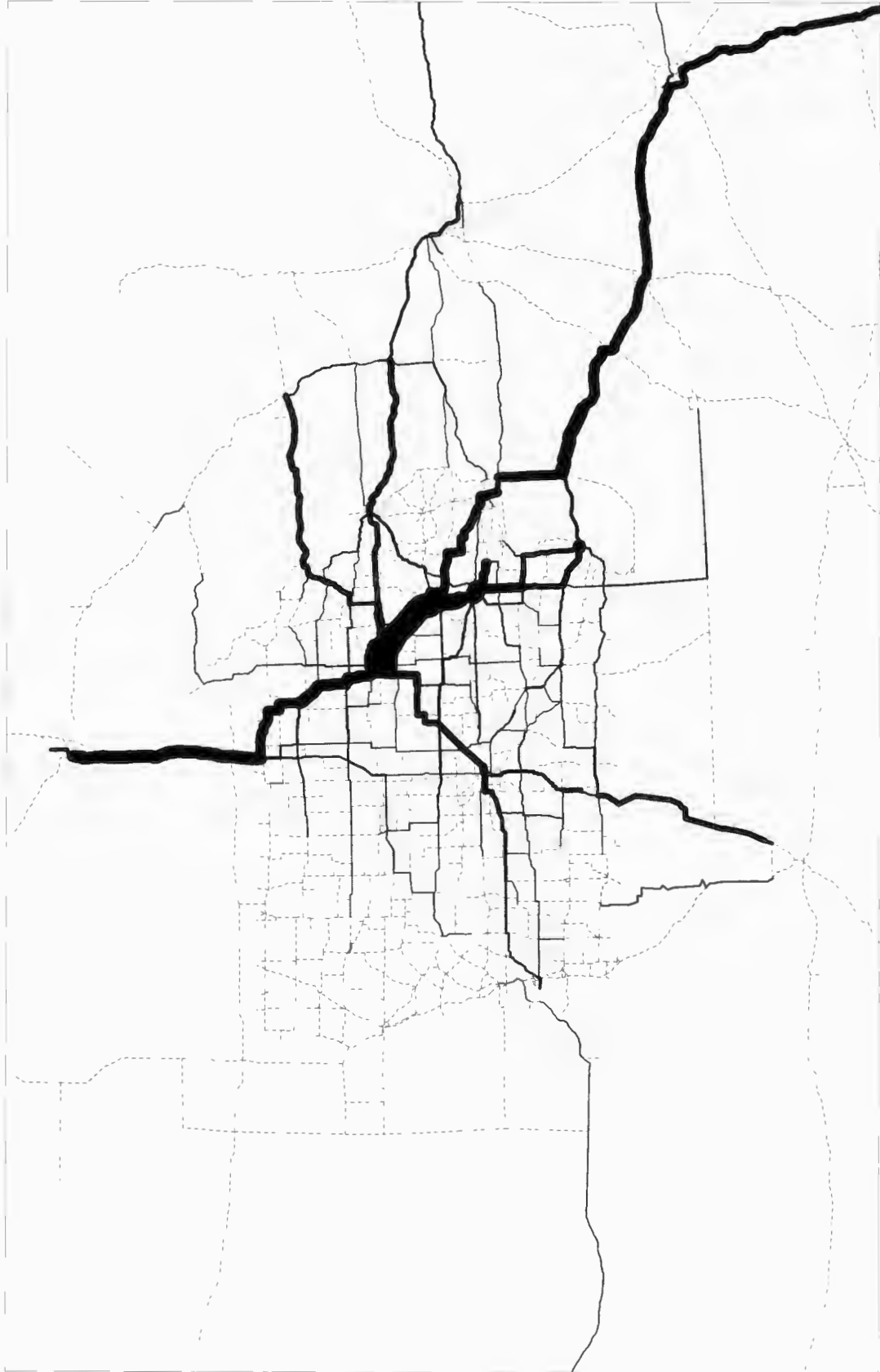
Figure 4.1. Meat Truck Traffic with P-A Data

Figure 4.2. Meat Rail Traffic with P-A Data

Table 4.3. Ton-miles (SIC 201) by Railroad Operator with P-A Data

Railroad Operator	Ton-miles
BNSF	792,278,283
UP	376,494,603
CSX	86,648,536
NS	513,517
CC	32,379,241
IMRL	15,335,608
IAIS	1,445,580
CEDR	560,298
Total	1,305,655,666

4.1.1.2 – Farm and Garden Machinery

According to the Transearch database, 502,953 tons of farm and garden machinery were shipped by the truck and highway modes. The model assigned 267,005 tons for these two modes (approximately 53 percent). This discrepancy is again a result of proportioning and rounding the commodity flow data for the TRANPLAN trip table. The much larger discrepancy is a result of two points: 1) very few tons being moved through the state, thus proportioning and rounding loses a greater percentage, and 2) concentration of employment for this industry to just a few counties, such that the diaggregation routines falsely allocate some trips to low employment counties, and lose them to rounding. No consistent method could be derived that would provide a better proportioning of trips.

The modal distribution of farm and garden machinery is shown in Table 4.4. Figure 4.3 shows the distributed machinery traffic on the highway network, and Figure 4.4 shows the rail traffic distribution. Ton-mile estimations, by highway classification, are shown in Table 4.5, and by railroad operator in Table 4.6.

Table 4.4. Machinery Tonnage Distribution by Mode

Mode	Tons
Truck	179,265
Rail	87,675
Intermodal	45,125
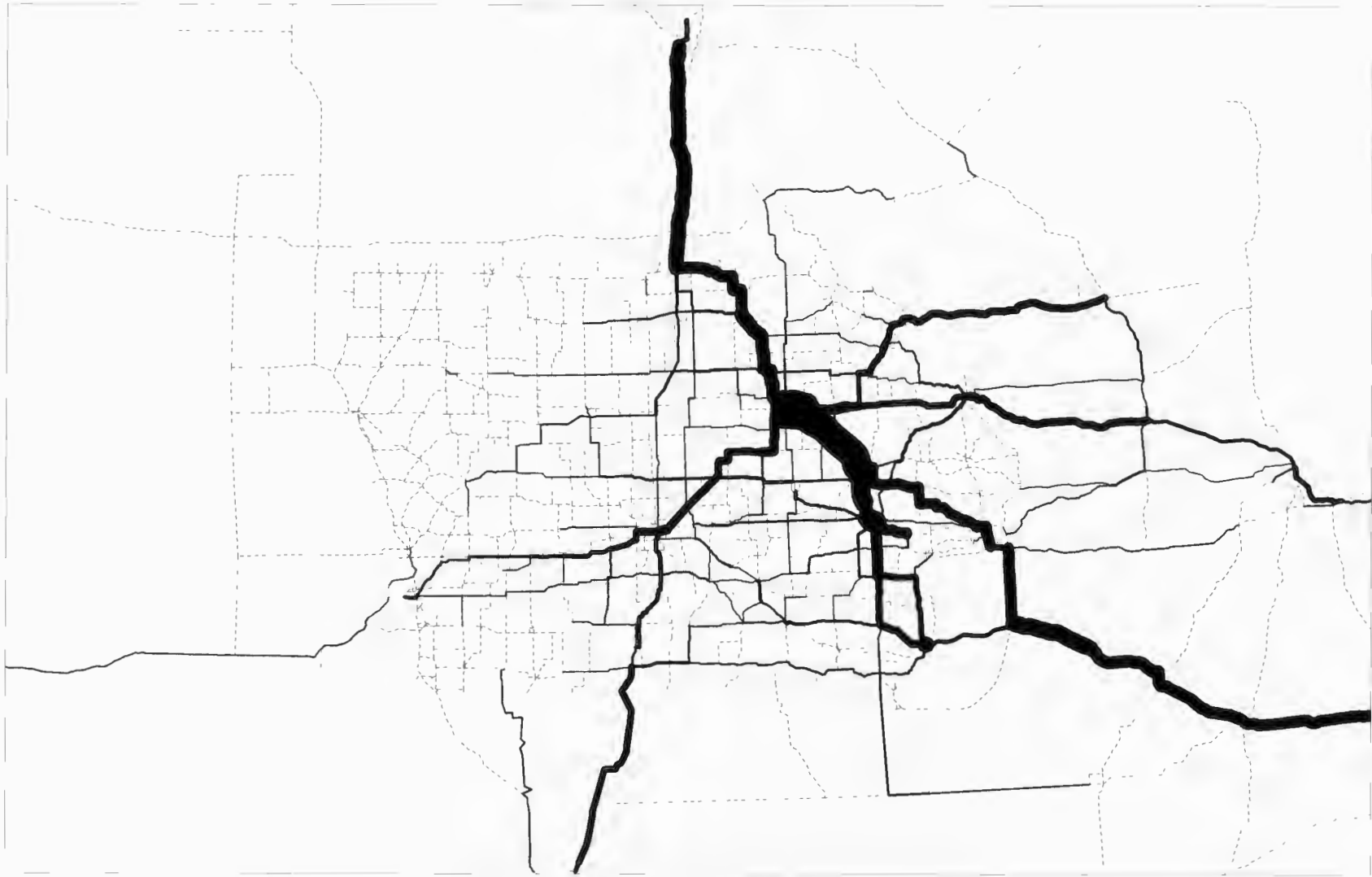
Figure 4.3. Machinery Truck Traffic with P-A Data

Figure 4.4. Machinery Rail Traffic with P-A Data

Table 4.5. Ton-miles (SIC 352) by Highway Classification with P-A Data

Highway Classification	Ton-miles
Interstate	46,987,158
CIN	12,396,313
Other Primary	14,424,567
Total	73,808,038

Table 4.6. Ton-miles (SIC 352) by Railroad Operator with P-A Data

Railroad Operator	Ton-miles
BNSF	17,057,321
UP	184,695
CSX	2,026,513
NS	52,678
CC	3,200,066
IMRL	221,589
IAIS	1,441,433
CEDR	127,759
Total	24,312,054

4.1.2 – Origin-Destination Trip Assignment

The next step in testing the modeling technique is to assign the O-D data to the network to construct baseline calibration plots. The origin-destination pairs for each single-mode commodity shipment are restricted to that particular mode (i.e., no mode choice or intermodal transfers possible), thereby providing baseline corridor volume estimates with which to examine the P-A data assignment.

4.1.2.1 – Meat Products

Figure 4.5 shows the results of the O-D data meat flow on the highway network. Ton-mile estimations, by highway classification, are shown in Table 4.7. Figure 4.6 shows the results of the O-D data meat flow on the railway network. Ton-mile estimations with the O-D data, by railroad operator, are shown in Table 4.8.

Table 4.7. Ton-miles (SIC 201) by Highway Classification with O-D Data

Highway Classification	Ton-miles
Interstate	2,901,869,668
CIN	370,835,168
Other Primary	343,249,481
Total	3,615,954,317

Table 4.8. Ton-miles (SIC 201) by Railroad Operator with O-D Data

Railroad Operator	Ton-miles (000's)
BNSF	262,655,604
UP	194,351,233
CSX	5,981,711
NS	596,715
CC	19,917,273
IMRL	15,189,357
IAIS	5,831,369
CEDR	1,857,778
Total	506,381,041

4.1.2.2 – Farm and Garden Machinery

Figure 4.7 shows the results of the machinery traffic assignment on the highway network. Ton-mile estimations, by highway classification, are shown in Table 4.9. Figure 4.8 shows the results of the O-D data machinery flow on the railway network. Railroad operator ton-mile estimations, are shown in Table 4.10.

Table 4.9. Ton-miles (SIC 352) by Highway Classification with O-D Data

Highway Classification	Ton-miles
Interstate	78,994,122
CIN	16,992,440
Other Primary	14,730,426
Total	110,716,988

Figure 4.5. Meat Truck Traffic with O-D Data

Figure 4.6. Meat Rail Traffic with O-D Data
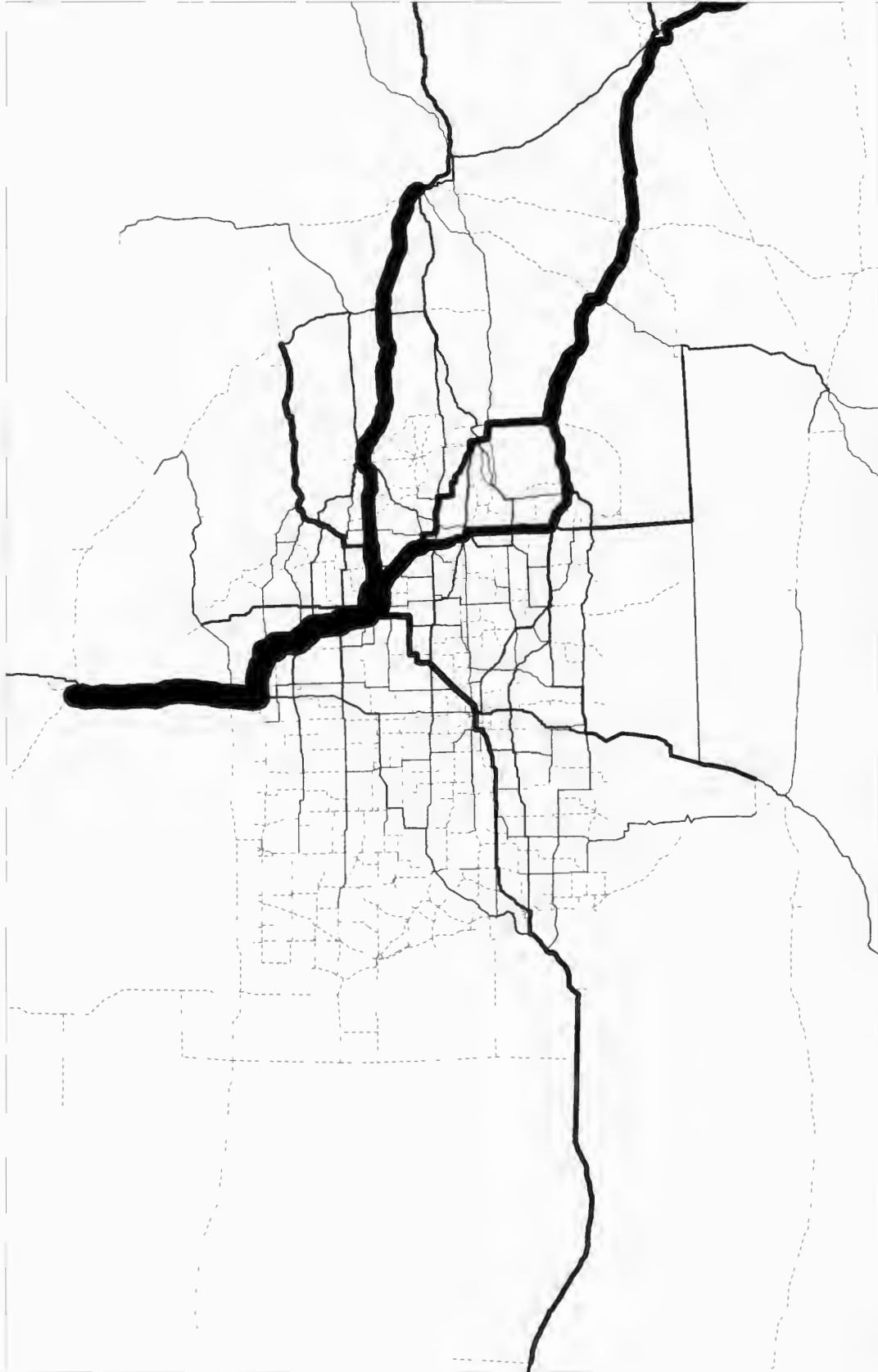
Figure 4.7. Machinery Truck Traffic with O-D Data
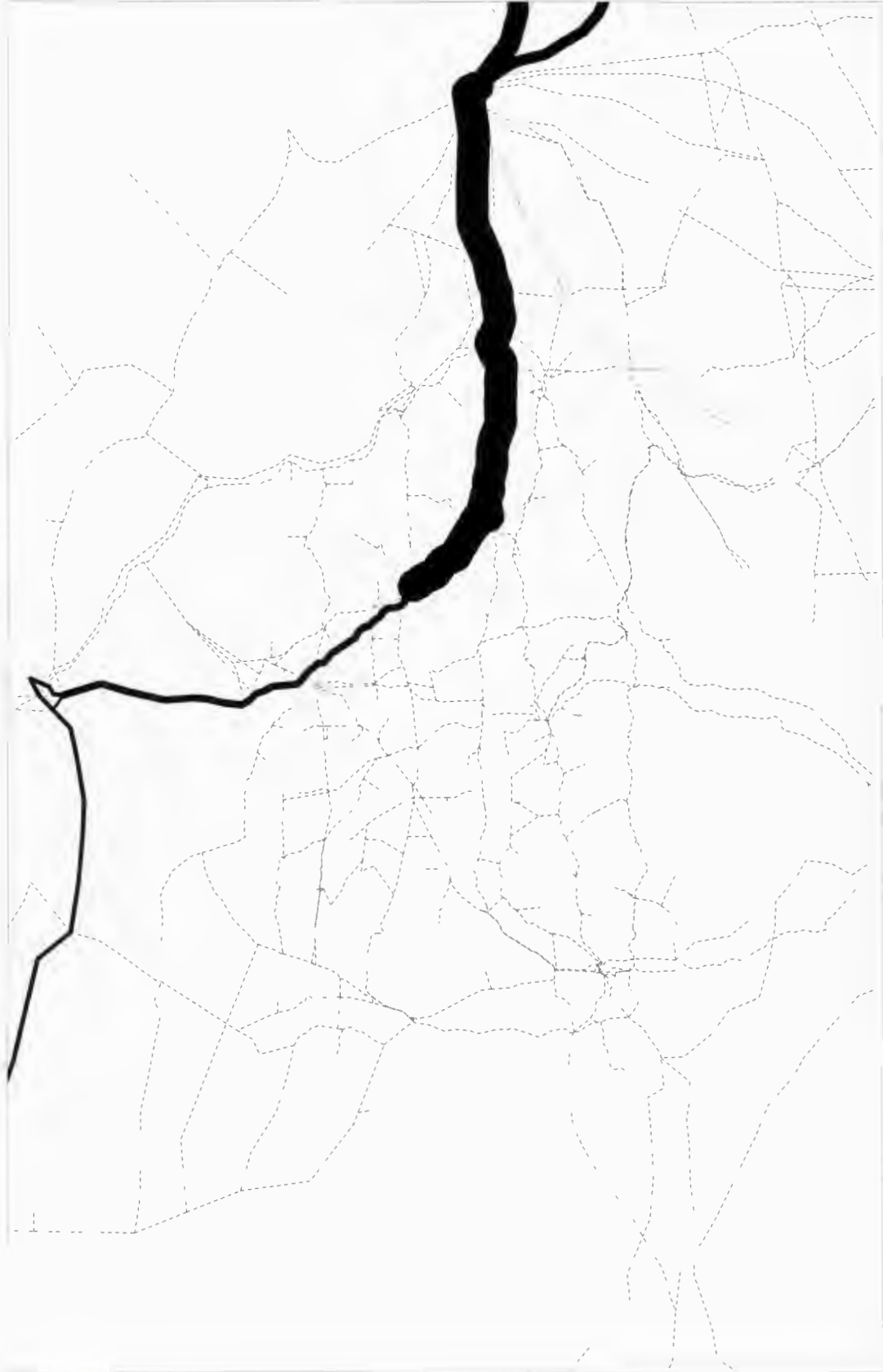
Figure 4.8. Machinery Rail Traffic with O-D Data

Table 4.10. Ton-miles (SIC 352) by Railroad Operator with O-D Data

Railroad Operator	Ton-miles
CSX	5,585,233
UP	2,327,797
BNSF	1,735,712
NS	0
IMRL	14,595
CEDR	0
CC	0
IAIS	0
Total	9,663,337

4.2 – Calibration and Validation

4.2.1 – Calibration

The model results from the baseline estimation procedures of Section 4.1.2 are the first input to the calibration procedure. These maps estimate the ability of the modeling technique to replicate the origin-destination pairs and modal split as provided in the Transearch commodity flow data.

Already, this part of the calibration process has at least one inherent flaw. The commodity flows estimated in the Transearch database, upon which this study is built, may be innately inaccurate. Data collection procedures are well documented in the database reference manual (16). The Transearch approach to trip distribution may differ from the gravity model approach employed in this research. The trip table that results from the modeling technique may never match the origin-destination pairs of the commodity flow database.

Nonetheless, the calibration plots are the best measures of mode split available in this research. For each of the two industries, P-A data distribution and network assignment are compared to O-D data traffic assignment in the following subsections.

4.2.1.1 – Meat Products

Table 4.11 shows that meat traffic distributed and assigned with P-A data closely matches the tonnage reported in the Transearch O-D data. Figure 4.9 shows the model comparisons for meat products P-A data versus O-D data on the multimodal network. Table 4.12 shows the differences in allocation of truck traffic, classified by highway type. Overall, these tables and figures indicate a slight underestimation of truck traffic.

Table 4.13 shows that since truck flow was underrepresented, the rail volumes were greatly overestimated. Figure 4.10 shows this same observation on the network assignment comparisons. Table 4.14 lists the variations in ton-miles by railroad owner in allocation of meat traffic between the two data sets, again showing a notable overestimation of rail traffic.

Table 4.11. Comparison of Truck Tons Allocated (SIC 201)

O-D Data Tonnage	P-A Data Percent Difference
5,549,360	-24.4

Table 4.12. Highway Ton-mile Comparison (SIC 201)

Highway Classification	Percent Difference with O-D Data
Interstate	-38.1
CIN	-18.8
Other Primary	3.4
Total	-32.2 *

* Value is an <u>average</u> percent difference over the entire highway network

Table 4.13. Comparison of Rail Tons Allocated (SIC 201)

O-D Data Tonnage	P-A Data Percent Difference
612,820	144.4
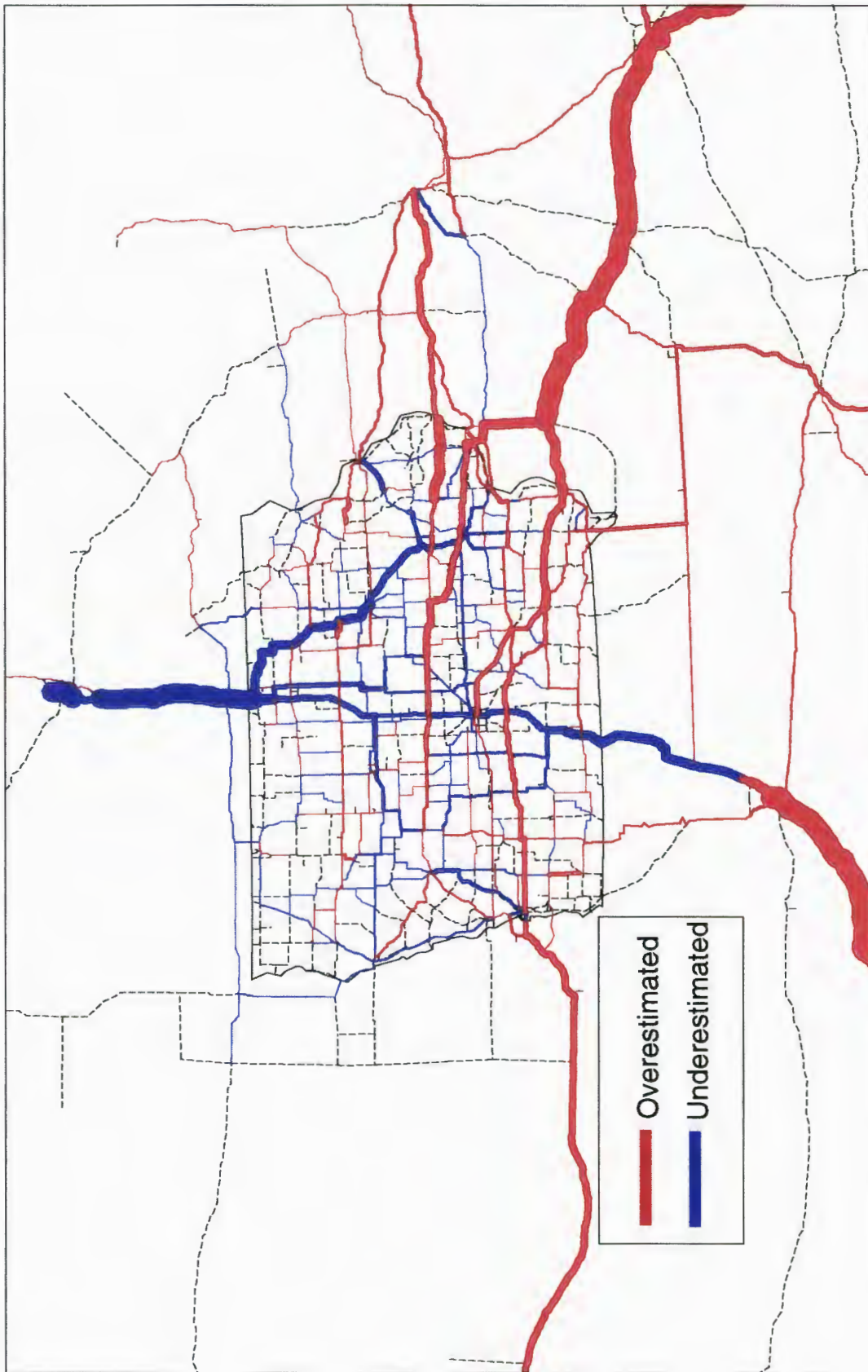
Figure 4.9. Meat Truck Traffic Comparison
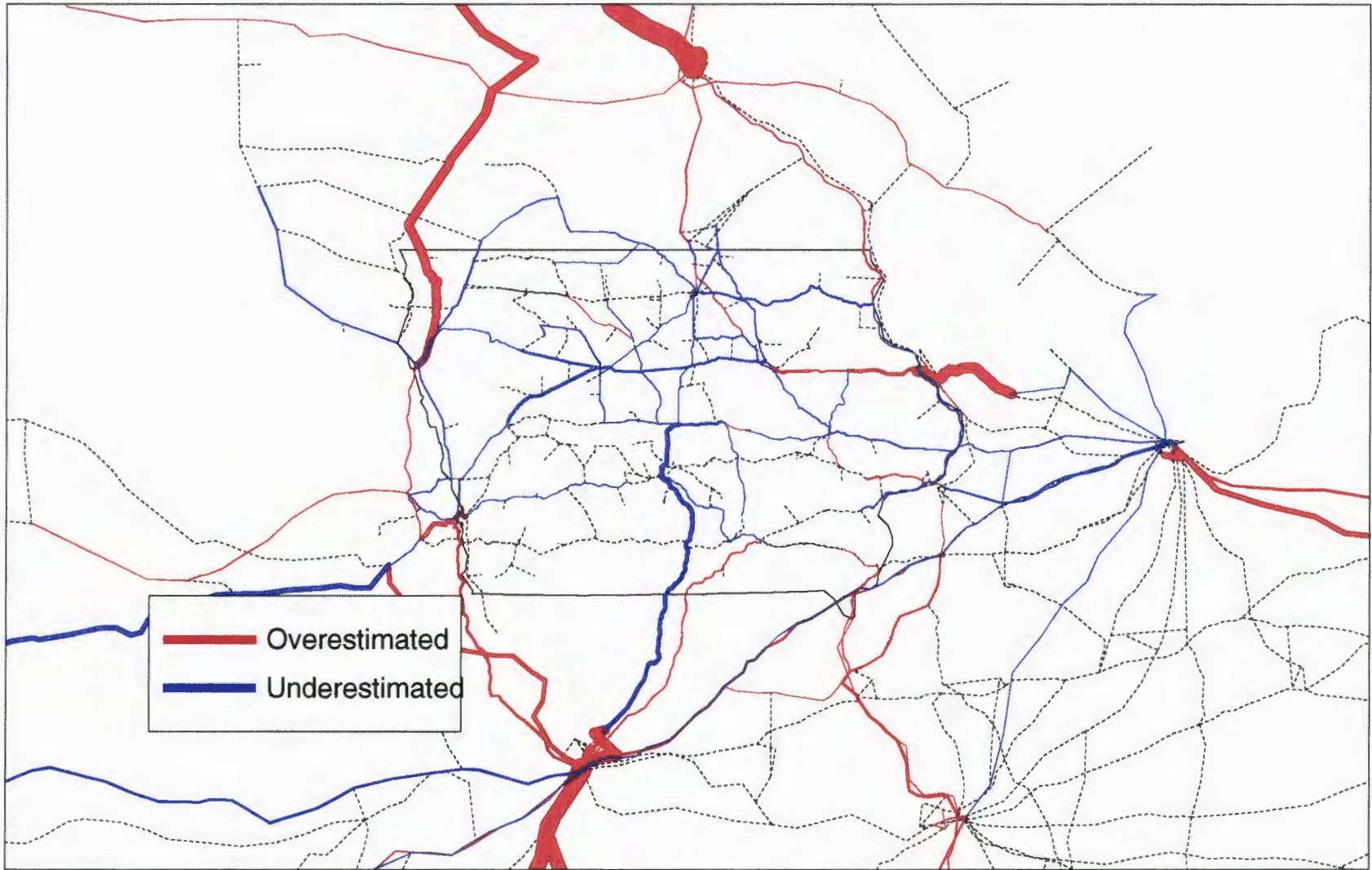
Figure 4.10. Meat Rail Traffic Comparison

Table 4.14. Railroad Ton-mile Comparison (SIC 201)

Railroad Operator	Percent Difference with O-D Data
CSX	1348.5
UP	93.7
BNSF	201.6
NS	-13.9
IMRL	1.0
CEDR	-69.8
CC	62.6
IAIS	-75.2
Total	157.8 *

* Value is an <u>average</u> percent difference over the entire railroad network

4.2.1.2 – Farm and Garden Machinery

Table 4.15 compares that traffic distribution of the O-D data to that of the P-A data for the farm and garden machinery. As with meat products, fewer tons of truck freight were distributed on the highway network. Figure 4.11 depicts this underestimate on the network. Table 4.16 shows the allocation discrepancies of traffic by highway type.

Table 4.15. Comparison of Truck Tons Allocated (SIC 352)

O-D Data Tonnage	P-A Data Percent Difference
310,940	-42.3

Table 4.16. Highway Ton-mile Comparison (SIC 352)

Highway Classification	Percent Difference with O-D Data
Interstate	-40.5
CIN	-27.0
Other Primary	-2.1
Total	-33.3 *

* Value is an <u>average</u> percent difference over the entire highway network
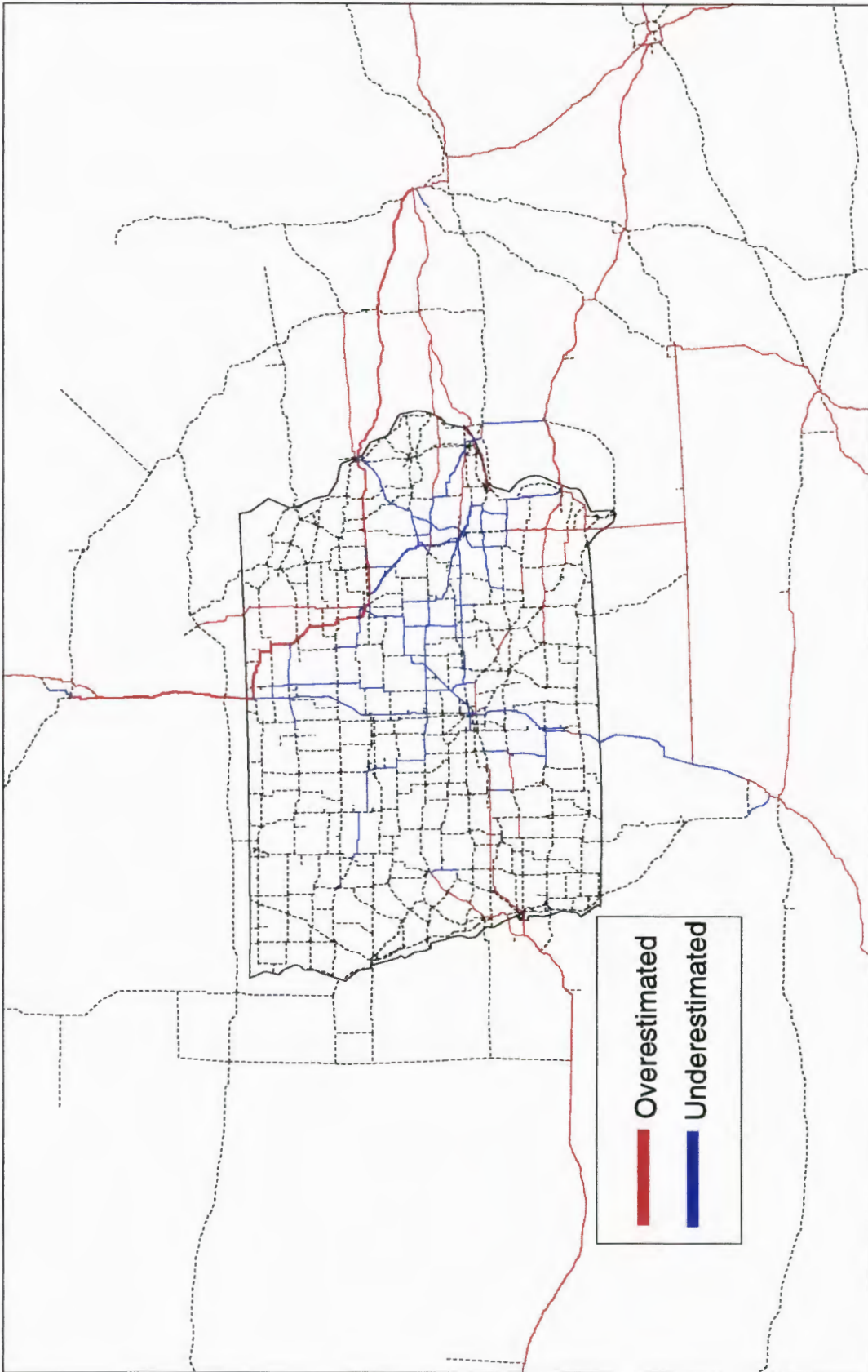
Figure 4.11. Machinery Truck Traffic Comparison

As the truck traffic was sparingly distributed, rail traffic should be greatly overestimated. Rail trips for this commodity are very few, as shown in the O-D data assignment, so that an overestimate would result in large errors. Table 4.17 quantifies the large percentage in overestimation of rail volumes, while Figure 4.12 shows this same observation on the railway network. Table 4.18 shows the railroad owner variations in ton-miles, concluding a vast difference in mode split.

Table 4.17. Comparison of Rail Tons Allocated (SIC 352)

O-D Data Tonnage	P-A Data Percent Difference
9,320	840.7

Table 4.18. Railroad Ton-mile Comparison (SIC 352)

Railroad Operator	Percent Difference with O-D Data
CSX	-63.7
UP	-92.1
BNSF	882.5
NS	--
IMRL	1418.3
CEDR	--
CC	--
IAIS	--
Total	151.6 *

* Value is an average percent difference over the entire railroad network.
-- No volume calculated with O-D Data

Several model parameters had been slightly adjusted to achieve these reported results and bring the initial, unreported discrepancies. Link costs and turn penalties can be adjusted to attract or deter a certain level of commodity movement. Specifically, transfer penalties for intermodal or railroad inter-operator interchanges can be adjusted to allow or discourage freight flow through these facilities. Rather than changing link costs, which were based on assumed, actual modal operating statistics, the centroid connector for rail transport was adjusted. This connector cost represents the cost to the shipper for initiating the commodity

Figure 4.12. Machinery Rail Traffic Comparison

movement on the railroad network. The ultimate value used to produce the above results was approximately $25 per ton, regardless of co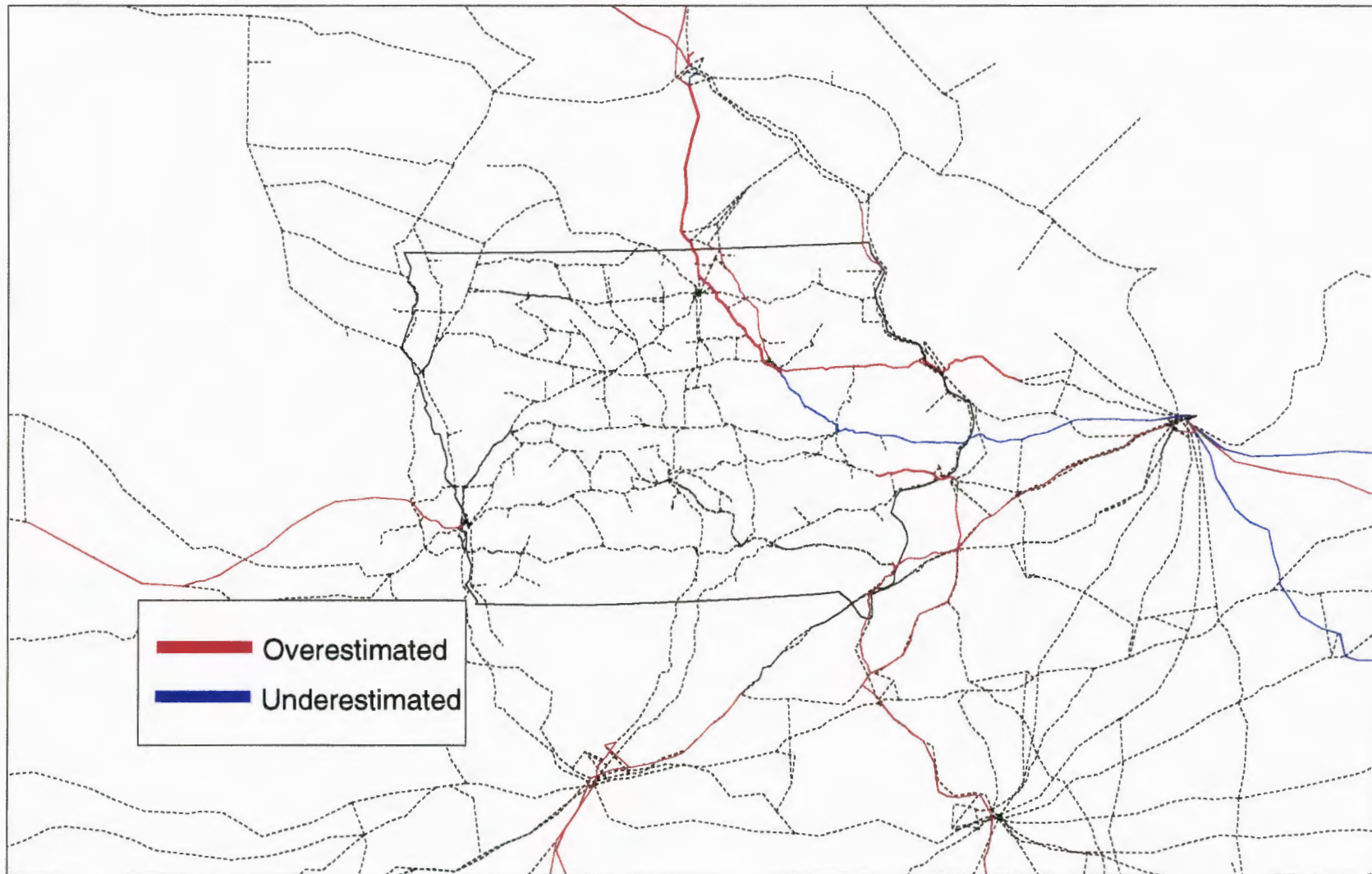mmodity. This value was used to bring the meat products (SIC 201) results to a tolerable level. This value was unchanged for model runs with the farm machinery (SIC 352) data, as shown by the larger modeling errors for that industry sector. This points to the need in the model technique for commodity specific modal performance data.

4.2.2 – Validation

Validation of model results is performed with other data sources to ensure that the estimated freight flows simulate freight flows on the actual network of railroads and highways. Available data sources other than Transearch include the 1993 Commodity Flow Survey (CFS), 1992 Annual Carload Waybill Sample, and the 1991 Iowa Truck Weight Survey. Both the CFS and Waybill Sample are primary inputs to the Transearch data, leaving only the Iowa Truck Weight Survey to validate the model results.

The Iowa DOT Office of Transportation Inventory conducts the Iowa Truck Weight Survey. The Survey provides a single day snapshot of highway freight flows at seventeen locations throughout the state, but only thirteen locations on primary roadways can be used (Figure 4.13). The Survey produces information on total vehicle weight, and weight of individual axles and axle groups, vehicle characteristics, and commodity loads (20, p. iv). Weighing operations are conducted biennially and provide information with regard to observed trends in weight, loading, vehicles, and commodities (20, p. 1). As these data only provide truck flows for one to two days, they cannot be accurately extrapolated through 365 days for an annual average freight flow estimate. Additionally, the truck weight survey collection procedure does not ascertain daily and seasonal variations in freight flows.

To obtain annual volumes from the survey data, one study reviewed suggests that a trucking year averages 306 days (13, p. 70). Thus, these daily volumes are multiplied to get a rough estimate of average annual truck traffic, and seasonal variations are ignored. The tare weight of the truck, obtained from Survey data by averaging the weight of all similar,
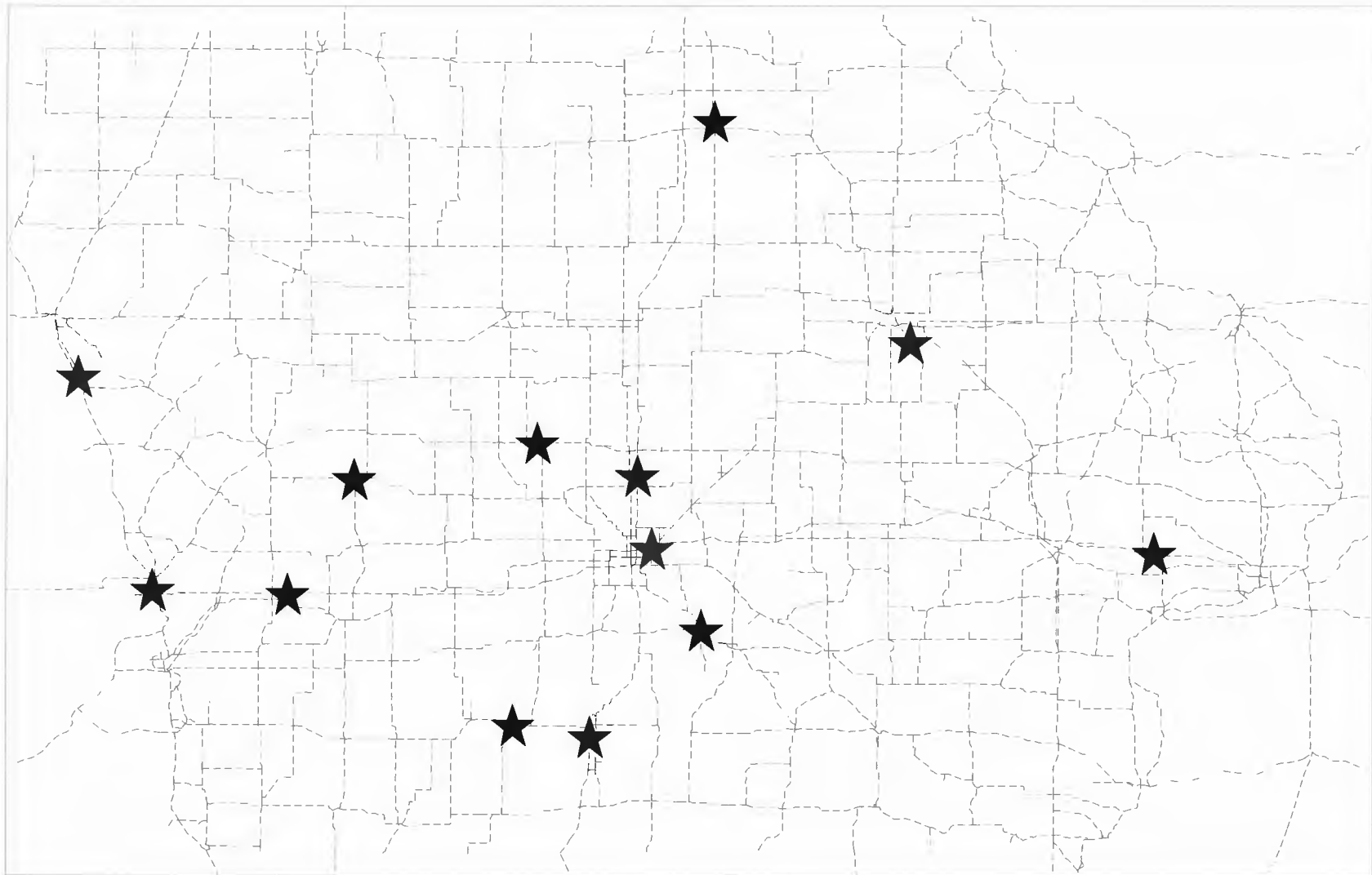
Figure 4.13. Truck Survey Locations

empty trucks, is subtracted from the total vehicle weight of a loaded truck to achieve an estimate of freight tonnage carried.

Figure 4.14 shows the comparison of the annualized Survey data to the Transearch O-D data for the meat products sector. The farm machinery industry volumes are shown in Figure 4.15. These maps show that even the baseline O-D data fall short of the expected volumes given in the Survey. This is largely a result of the Iowa-specific commodity flow data present in Transearch, that is, no through traffic is represented. Thus, interstates and other major corridors through the state observe a greater volume of traffic in the survey, as compared to the model results.

Figures 4.16 and 4.17 show the Survey volumes as compared to those from the P-A data distribution and assignment. Even greater disparities are observed with these model data, since the truck flows were greatly underestimated using this modeling procedure.

4.3 – Case Study Application

With a calibrated, validated model in place, its ability to respond to a relevant freight policy issue can be tested. Even though the model results as tested in the calibration phase show remarkable errors, the study proceeds to demonstrate how the methodology can be used in freight policy application. The policy issue chosen for this research is the future implementation of larger truck size and weight (TS&W) limits. It is assumed that this freight policy initiative will have the effect of reducing cost of truck transportation for any commodity by 1.5 cents per ton-mile from the original 12.9 cents per ton-mile. The effect on network modal volumes as a result of this policy decision is determined.

It was found that very few link flows changed with the decreased cost of truck transport. As seen in Table 4.18, only a slight diversion of freight to truck carriers was observed. This relatively small change is not entirely unanticipated, as nationwide diversion of freight from rail to truck is expected to be very small across the nation (22, p. 34). Other factors, such as warehousing and inventory costs, that may alter total logistics cost as a result of increased truck size and weight, were ignored. These factors may have contributed to a more noticeable change in modal freight flow distribution. Should a larger change have
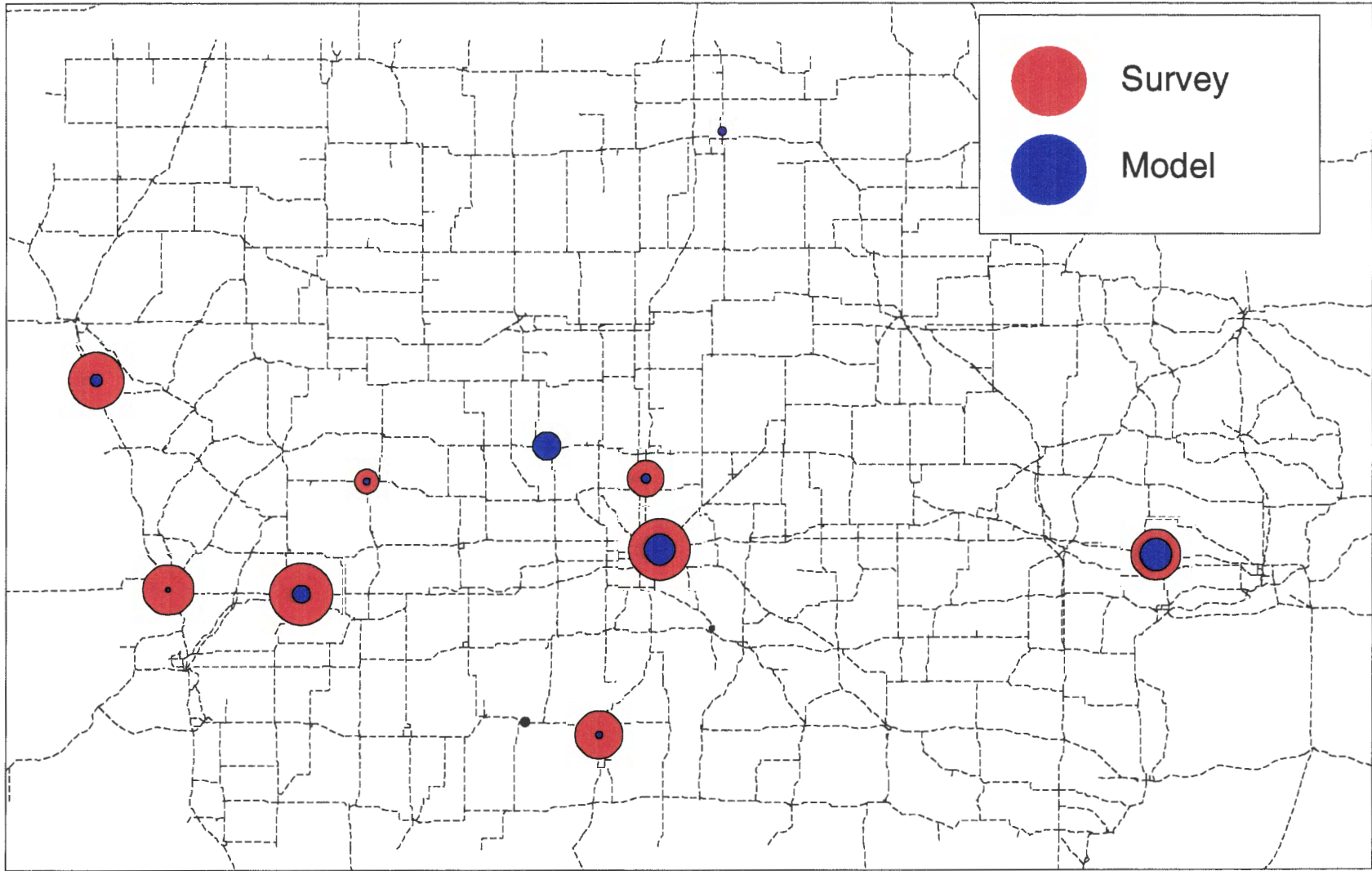
Figure 4.14. Survey versus Model with O-D Data (SIC 201)
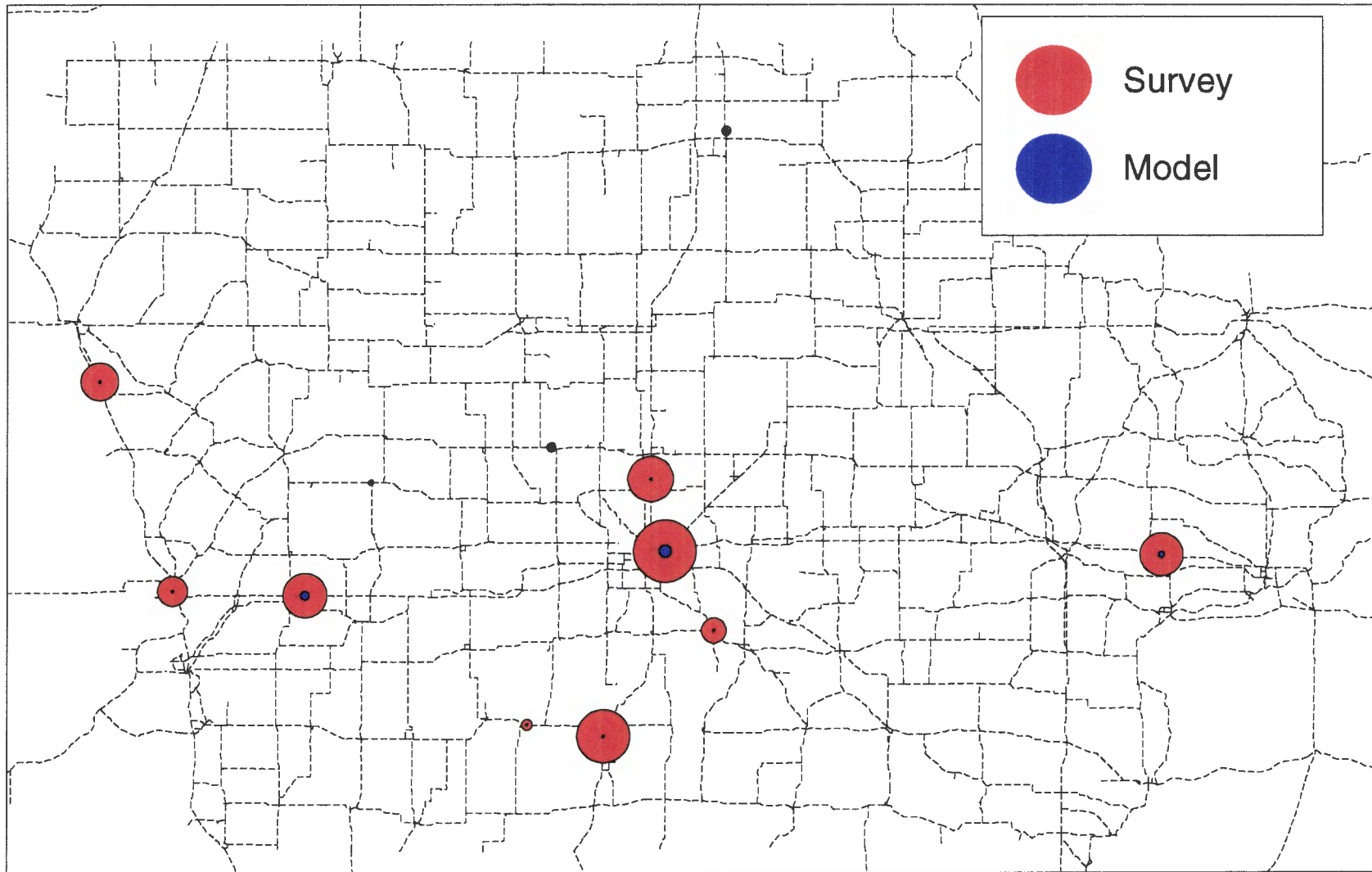
Figure 4.15. Survey versus Model with O-D Data (SIC 352)
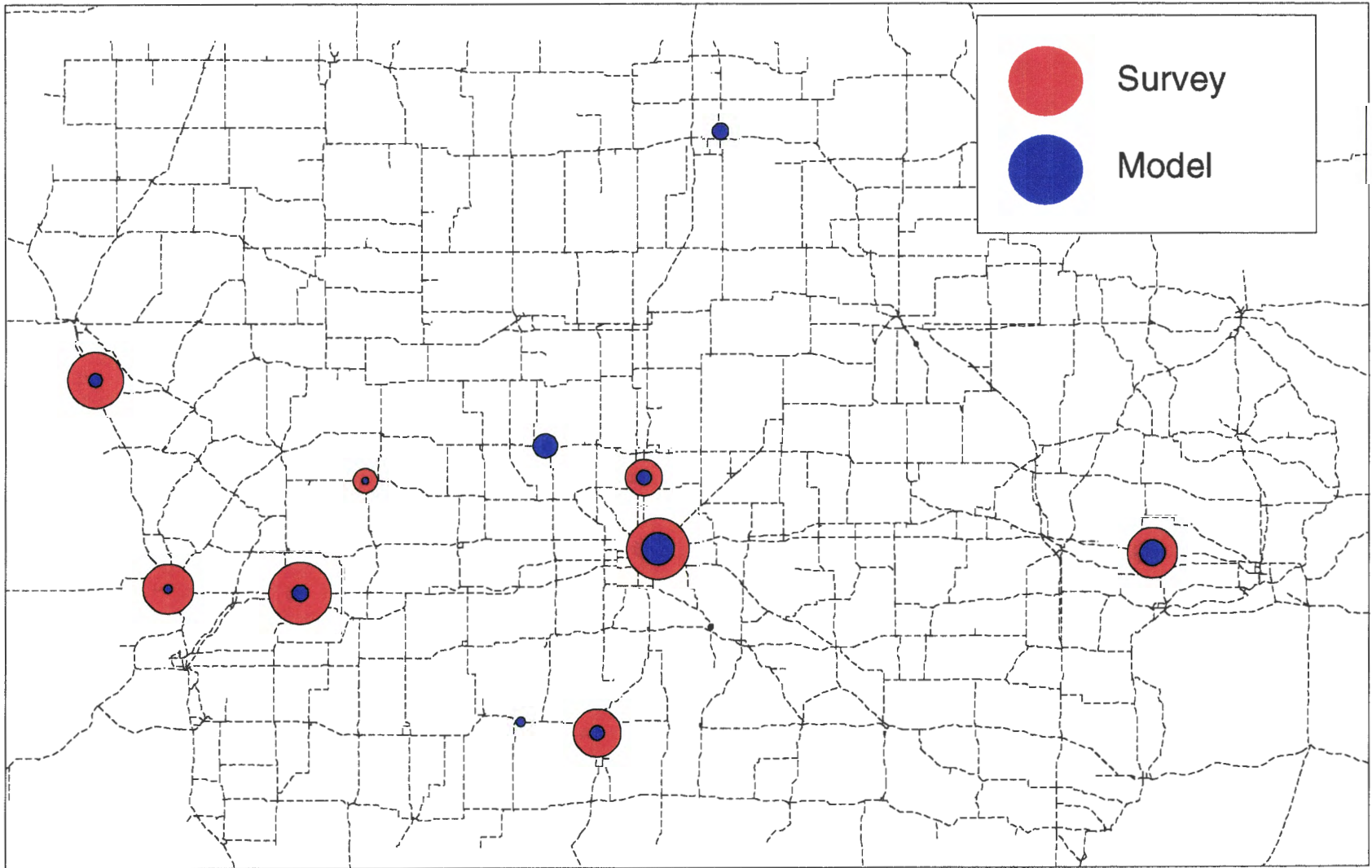
Figure 4.16. Survey versus Model with P-A Data (SIC 201)
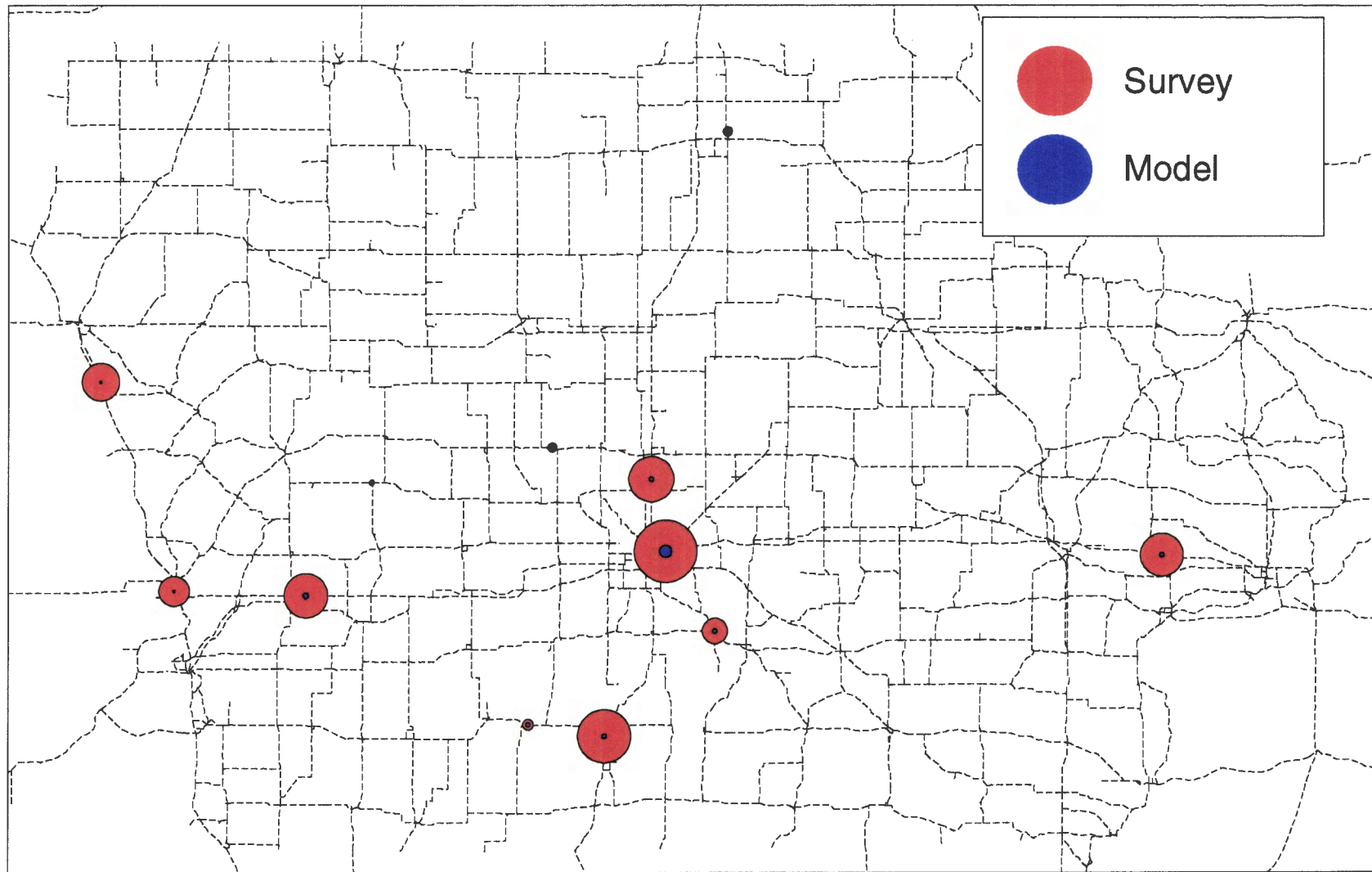
Figure 4.17. Survey versus Model with P-A Data (SIC 352)

been observed, the volume change by modal link type (interstate and CIN, or railroad operator) could have been classified.

Table 4.19. Truck Freight Flow Change with Increased TS&W

Commodity	Change (Tons) Allocated to Truck	Change in Truck Ton-Miles
SIC 201	1,750	11,802
SIC 352	50	337

CHAPTER 5 — CONCLUSIONS AND RECOMMENDATIONS

5.1 – Summary of Research

The objective of this thesis research was to develop a model that is sensitive to various freight policies. Transportation agencies typically influence freight policy through regulation, taxation, and infrastructure investment, but lack data and user-friendly tools to quantify the effects of such policy. These agencies may also wish to understand the effects of industry operations on freight transportation demand, even though they cannot usually control such events. Freight policy aimed at one mode often affects others as well. Therefore, this study presented a multimodal, policy sensitive, freight transportation modeling technique.

The model is constructed using commodity flow data that is readily-available to the Iowa DOT. The Iowa DOT purchased from Reebie Associates the Transearch database of commodity flows, which provides estimates of freight shipment to, from, and within Iowa.

These data provide freight flows classified by commodity and mode of shipment. The data are arranged in origin-destination pairs, indicating mode specific commodity movements between zones. The smallest zonal level at which the data are aggregated is a Business Economic Area (BEA). This level of aggregation is was too coarse by itself for effective statewide analysis. Therefore, steps were performed to disaggregate these data to the county level, which facilitated loading onto a state highway or rail network (see Section 4.2).

Using the Reebie origin-destination data, a model was constructed to assess the current state of freight transport in Iowa. The origin-destination pairs provide mode specific trip tables. These trips are then assigned to the specific modal network.

However, this mode specific approach with the origin-destination data was not policy sensitive. Since the origin-destination data were provided as inputs to the modeling process, estimates of freight transportation demand were taken as exogenous, and could not respond to freight policy change. As one example, taxation that increases transport costs for a

specific mode may impact trip distribution and mode choice. The mode specific trip table would not be able to indicate these system-wide effects.

To effectively quantify the effects of freight policy issues, the modeling approach had to be modified. Inputs that would affect freight generation, distribution, and mode split had to be components of the model. A key element in addressing policy change is the estimation of zonal production and attraction, allowing subsequent distribution, mode split, and assignment. Since the Transearch database contains zone-to-zone origin-destination pairs, summation of all truck and rail originating volumes in each zone provides the total level of commodity production for that zone. Similarly, summation of all destinations provides the total level of commodity attraction. Trip generation equations could also have been used, but development of these equations was beyond the scope of this research.

Although this data summation process assumes an initial, fixed level of freight demand, zonal estimates can be adjusted. Raising or lowering the zonal levels of production or attraction would simulate certain policy effects on production or consumption.

The next step in modifying the model process is to construct a multimodal network representation. This allows distribution of the estimated freight demand among several modes, incorporating the intermodal interaction among them as well. For this, the rail and highway link-node networks were combined. Intermodal movements between the two networks were permitted at identified intermodal terminal locations. The resulting network is described in Section 3.3.

Rail and highway link impedances, or link costs, were derived from rough estimates of ton-mile costs for movements by those modes. Turn penalties were given to intermodal transfers, reflecting the cost and time delay in transferring shipments between the rail and truck modes.

The model methodology assumes that mode choice is based strictly on transport cost. Minimizing total logistics cost of a shipment is one objective of freight shippers. Meeting this objective is similar to selecting transport mode and associated route simultaneously, choosing the combination that provides the smallest shipment cost. Therefore, this model process combines the mode split and traffic assignment phases of the conventional, four-step

approach. The freight traffic between zones is assigned to the least-cost path consisting of combinations of rail and highway links, accounting for an intermodal transfer cost upon transfer. The least-cost path is the route between two zones with the smallest summation of link impedances and turn penalties, expressed in modal ton-mile charges. The results of this modeling process were described in Section 4.1.

Mode split estimated by this multimodal process should replicate the mode split estimated in the mode specific, origin-destination trip table. The results of the multimodal traffic assignment process are compared to the original, mode specific trip assignment. This comparison showed notable disparities, as seen in Section 4.2.1.

The commodity flows by truck transportation were then compared to those observed in the 1991 Iowa Truck Weight Survey. The objective of this process was to estimate the accuracy of the model with respect to the actual traffic levels observed on the highway system. Since the freight volumes from the survey included through traffic, where the Transearch database did not, the estimated volumes from the model fell far short of the survey volumes, as described in Section 4.2.2.

5.2 – Model Applications

The truck size and weight case study shows the process of adapting this model technique to assess system-wide impacts of freight policy. The decrease in truck transport charges resulting from this policy change was the only impact addressed in this model. These cost decreases were expressed in the model by decreasing the highway link cost ($ per ton-mile). Holding production and attraction levels constant, the resulting mode split changes were observed.

With the small ($0.015 per ton-mile) decrease in truck transport cost per ton-mile, the model estimated only a slight modal diversion from rail to truck. Several other factors that were not included in the sensitivity analysis, such as lower warehousing/inventory costs or reactive changes in rail transport costs, could have contributed to a more noticeable change in modal freight flow distribution.

Modifying the model in a way similar to the case study scenario, three classifications of freight transportation issues can be addressed:

1. Changes in transport cost. This is the scenario depicted in the case study, which results from freight policy that changes the modal transport cost. The resulting change in transport cost for either mode is an input to the link costs, and freight traffic assignment can be redone to investigate changes in freight flow trends.

2. Changes in production or consumption. Growth factors can be applied to the general production or attraction levels determined from the commodity flow data, and trip distribution redone with the modified gravity model. Freight traffic is then assigned to the multimodal network to assess the traffic volume changes.

3. Changes in the transportation infrastructure. To represent a new facility, links can be added to the network. If a facility is improved, link costs can be adjusted. Traffic assignment on the new network is then performed to investigate the change in corridor traffic levels.

The modeling process provides various output data that will help users visualize the effects of "what if" questions in freight transportation policy. Display of freight flows on the network allows quick determination of major freight corridors. Measures of transportation consumption, such as ton-miles traveled or cost of routed shipment, can clearly be used to address questions of efficiency, equity, and modal performance.

5.3 – Model Limitations and Recommendations

The results of the modeling process provide an estimate of traffic levels as provided in the Reebie Associates Transearch database of commodity flows. However, these data only indicate flows that have origins and/or destinations in Iowa. Interstate 80, Interstate 35, and the UP and BSNF mainlines, carry large volumes of through traffic. These freight movements may contribute little to the economy of the state, but certainly affect deterioration of the freight transportation facilities. Through traffic is not modeled in this study, nor does this approach directly allow for such estimations.

The modeling technique needs to be refined to overcome a few modeling difficulties. For example, modeled freight traffic is free to make several intermodal movements in one shipment, if those movements comprise the least-cost path. In actuality, freight movements

may typically make no more than two intermodal movements near the points of origin and destination.

Additionally, it was observed that very little flow within Iowa was concentrated in the major corridors for each mode. It was assumed that truck traffic will desire the interstates for long, out-of-state movements, and that rail movements will concentrate on mainline tracks. Incorporating a measure of travel time into the link cost might reflect the desirability of interstates and mainlines. Interstates and mainlines, with higher allowable speeds, would have lower travel times, or lower penalties for using those facilities. Thus, higher speeds will attract more freight traffic to the major facilities in the assignment phase of the model.

The commodity flows estimated in the Transearch database, upon which this study is built, may be inherently inaccurate. Major suppliers of various commodities could be surveyed to determine dominant market areas for production or consumption, with the results used to qualitatively assess the accuracy of the Transearch database. Shipper surveys may also provide transport costs for specific commodity/mode combinations, as well as preferred modes for transport of specific commodities.

Gravity model parameters could be reformulated to better simulate distribution of freight provide in the commodity flow data. In this research, the distance impedance parameter, or friction factor, was based on commodity-specific, exponential equations, related to distance alone. For freight transportation, shipping rates are probably a more reasonable impedance than cost determined by only by distance. Rail and truck shipping rates based on distance and commodity could be plotted to formulate a better friction factor equation. Distribution of freight may not be solely related to distance or cost, as assumed in the gravity model methodology. Long-standing relationships among specific companies, or product differentiation between companies, may also play a role in the distribution of specific commodities. This latter point could not be reflected in the research.

To better estimate shipping costs, transport companies in the region, like the railroads, could be consulted. Railroad companies publicly disclose their information in published tariffs, while the trucking companies are not required to do the same. Previously,

company representatives provided rate information to interested parties, relying on these published tariffs. Using the Internet, rail companies such as Union Pacific and Burlington Northern-Santa Fe, now provide public and private rates and tariffs on-line. For example, Union Pacific Railroad's Public Price Inquiry system provides a frequently updated database of carload and hundred-count prices for specific commodities, equipment type, and user-specified origin-destination pairs (23).

Other model parameters were roughly calibrated to replicate the mode split reported in the Transearch commodity flow data. Some model parameters, such as modal link costs, were obtained or derived from rough estimates reported in other studies.

Model validation could be expanded to include professional opinion from industry freight transportation providers. Within the freight transport industry, freight logistics personnel recognize market forces and other factors that affect freight transportation demand. Their knowledge of approximate freight transport volumes and heavily traveled corridors could be used to validate the modeling technique, assumptions, link costs, and results. For example, trucking companies, while keeping costs and trade secrets confidential, may be able to provide information on predominant freight routes throughout the state.

The link cost representation on this multimodal network was simplified to a fixed rate of revenue charged per ton-mile for any commodity. For two reasons, this assumption grossly simplifies the true behavior: 1) modal choice is based on many more factors, such as service quality, shipper perceptions, and shipment transit time; and 2) assumed rates vary by commodity. The model is not presently able to replicate mode split estimates from the Transearch database. Assuming confidence in the commodity flow data, not being able to replicate the mode split estimates would discourage use of this model methodology. However, with further parameter adjustment and professional opinion on assumed link costs, the model results will undoubtedly begin to agree more closely with the supplied mode shares. Therefore, the model results could be used with closer examination of the model inputs.

APPENDIX A. FORTRAN DATA DISAGGREGATION PROGRAM

```
c      This program takes the TRANSEARCH commodity flow data for
c      both truck and rail flows and formats the data to that needed
c      by TRANPLAN.  Program written by Dr. Reg Souleyrette and Shirish
c      Pathak.  Modified by Preissig.
c

*      ---------------------- variable list -----------------------

       INTEGER ndata
       PARAMETER (ndata = 20000) !all possible records in REEBIE.TXT
       INTEGER ntaz
       PARAMETER (ntaz = 144)

       INTEGER origstate(ndata), origstate_BEA(ndata)
       INTEGER deststate(ndata), deststate_BEA(ndata)
       INTEGER railcont(ndata), railbulk(ndata), railinter(ndata)
       INTEGER hirecont(ndata), hirebulk(ndata), ltl(ndata)
       INTEGER privcont(ndata), privbulk(ndata)
       INTEGER totrail(ndata), tottruck(ndata), railtrck(ndata)
       INTEGER FIPS_CODE(ntaz), STATE_BEA(ntaz), taz(ntaz)
       REAL POP_RATIO(ntaz), EMPL_RATIO(ntaz)
       REAL trips(ntaz,ntaz),tottrps, ttrips(ntaz,ntaz),
     &      rtrips(ntaz,ntaz)
       REAL proda,prodt,prodr,attra,attrt,attrr
       INTEGER totn,n1,nt,nr

*      OPENING THE INPUT FILES

       OPEN(1,FILE='reebie.txt', STATUS = 'OLD')    !Reebie freight flows
       OPEN(2, FILE='taz.txt', STATUS = 'OLD')      !TAZ text file
       OPEN(11, FILE='aflows.txt', STATUS='UNKNOWN')   !O-D freight flows
       OPEN(21, FILE='tflows.txt', STATUS='UNKNOWN')   !Truck O-D flows
       OPEN(31, FILE='rflows.txt', STATUS='UNKNOWN')   !Rail O-D flows
       OPEN(41, FILE='sumpa.txt', STATUS='UNKNOWN')    !zonal P & A sums
       OPEN(51, FILE='sumtpa.txt', STATUS='UNKNOWN')   !Truck P & A sums
       OPEN(61, FILE='sumrpa.txt', STATUS='UNKNOWN')   !Rail P & A sums
       OPEN(71, FILE='aflows2.txt', STATUS='UNKNOWN')  !O-D in comma format
       OPEN(72, FILE='tflows2.txt', STATUS='UNKNOWN')  !truck ” ”    “ ”
       OPEN(73, FILE='rflows2.txt', STATUS='UNKNOWN')  !rail ” ”    “ ”


       WRITE(*,*) 'READING DATA'
c      Read Reebie data to get number of records
  105 READ (1,*,end = 110)
          nrecs = nrecs + 1
       GOTO 105
```

```
110 REWIND 1

      IF(nrecs .GT. ndata) THEN
          diff= nrecs-ndata
          WRITE(*,*) '!!@@  ',diff, ' REEBIE records will be lost  @@!!'
          nrecs = ndata
      ENDIF

      WRITE(*,*) 'Reading REEBIE data ...'

c     Read Reebie data of commodity flows
      DO 150 i = 1,nrecs
          READ (1,*,end =199) origstate(i), origstate_BEA(i),
     &        deststate(i), deststate_BEA(i),
     &        railcont(i), railbulk(i), railinter(i),
     &        hirecont(i), hirebulk(i), ltl(I),privcont(i), privbulk(i)

c         Some modifications to Reebie Data, where we combined BEAs
          !In NE, combined BEAs 144 and 145, assign all to BEA 144.
          IF (origstate_BEA(i) .EQ. 145) THEN
              origstate_BEA(i) = 144
          ELSEIF (deststate_BEA(i) .EQ. 145) THEN
              deststate_BEA(i) = 144
          ENDIF

          !In MN/ND, combined BEAs 149 and 150 into [FIPS 38 and BEA 999].
          IF (origstate_BEA(i) .EQ. 149 .OR. origstate_BEA(i) .EQ. 150)
     &        THEN
              origstate(i) = 38
              origstate_BEA(i) = 999
          ELSEIF (deststate_BEA(i).EQ.149.OR.deststate_BEA(i).EQ.150)
     &        THEN
              deststate(i) = 38
              deststate_BEA(i) = 999
          ENDIF

          totrail(i)  = railcont(i)+railbulk(i)+railinter(i)
          tottruck(i) = hirecont(i)+ hirebulk(i)+ltl(I)+privcont(i)+
     &                  privbulk(i)
          railtrck(i) = totrail(i) + tottruck(i)


  150 ENDDO
      GOTO 199
  145 FORMAT('railtrck(',I3,') = ', I7)

  190 WRITE(*,*) "**^^ Error in Reebie data.  Program Terminated ^^**"
      GoTo 999

  199 Continue
```

```
      i = 1

*     VERY IMPORTANT NOTE: WHEN TRYING TO RUN THIS PROGRAM MAKE SURE THAT
*     'taz.txt' IS SORTED IN AN ASCENDING ORDER BY THE TAZ COLUMN.
*     IF THIS PRECAUTION IS NOT FOLLOWED, THE PROGRAM WILL ALLOCATE TRIPS
*     TO THE WRONG TAZ'S.


      WRITE(*,*) 'Reading TAZ map data ...'
  401 READ (2,*,err=498, end = 415) FIPS_CODE(i),STATE_BEA(i),taz(i),
     &EMPL_RATIO(i), POP_RATIO(i)

      i = i + 1
      GOTO 401    !Loop to read next TAZ record

  415 If (taz(i) .gt. ntaz) THEN
          GOTO 498    !Too many TAZ records
      ENDIF
      Goto 501

  498 Write (*,*) "**^^ Error in TAZ Map data. Program Terminated ^^**"
      GoTo 999


*        BUILDING THE FLOW MATRIX

  501 WRITE(*,*) 'Building freight flow tables ...'

      DO 550 I = 1,ntaz    !Iterate through Origins
      DO 540 J = 1,ntaz    !Iterate through Destinations
      DO 530 K = 1,nrecs
        IF ( FIPS_CODE(I).EQ.origstate(K) .AND.
     &       STATE_BEA(I).EQ.origstate_BEA(K) .AND.
     &       FIPS_CODE(J).EQ.deststate(K) .AND.
     &       STATE_BEA(J).EQ.deststate_BEA(K)) THEN

           IF (origstate(K).EQ.19) THEN

              IF (deststate(K).EQ.19) THEN
                 !Proportion both Origins and Destinations
                 trips(I,J)  = railtrck(k)*EMPL_RATIO(I)*POP_RATIO(J)
                 ttrips(I,J) = tottruck(k)*EMPL_RATIO(I)*POP_RATIO(J)
                 rtrips(I,J) = totrail(k)*EMPL_RATIO(I)*POP_RATIO(J)

              ELSE
                 !Proportion only Origins
                 trips(I,J) = railtrck(k)*EMPL_RATIO(I)
                 ttrips(I,J) = tottruck(k)*EMPL_RATIO(I)
                 rtrips(I,J) = totrail(k)*EMPL_RATIO(I)
              ENDIF
```

```
            ELSE      !(origstate(K).NE.19), but deststate(K) MUST be equal to
19
                      !Proportion only Destinations
                      trips(I,J) = railtrck(k)*POP_RATIO(J)
                      ttrips(I,J) = tottruck(k)*POP_RATIO(J)
                      rtrips(I,J) = totrail(k)*POP_RATIO(J)
            ENDIF

        ELSE
          CONTINUE
        ENDIF

 530 CONTINUE
 540 CONTINUE
 550 CONTINUE


*      WRITING THE MATRIX

 801 WRITE(*,*) 'Writing freight flow tables ...'
     DO 850 I = 1,ntaz
         proda = 0
         prodt = 0
         prodr = 0
     DO 840 J = 1,ntaz
         tottrps = tottrps+trips(I,J)

c     Divide the flows by 10 and round to nearest integer
c     Tranplan is limited to 6 digit link flows and Netcard can't seem to
c     handle > 600,000 trips

     n1=NINT(trips(i,j)/10)
     IF(trips(i,j) .gt. 0 .and. trips(i,j) .le. 9) n1 = 1
     ENDIF   !If less than 5, would otherwise lose the trip

     nt=NINT(ttrips(i,j)/10)

         IF(ttrips(i,j) .gt. 0 .and. ttrips(i,j) .le. 9) nt = 1
C        !If less than 5, would otherwise lose the trip

         nr=NINT(rtrips(i,j)/10)
         IF(rtrips(i,j) .gt. 0 .and. rtrips(i,j) .le. 9) nr = 1
C        !If less than 5, would otherwise lose the trip

         totn = n1 + totn
         WRITE (11,855) I, J, n1
         WRITE (71,856) I, J, n1
         WRITE (21,855) I, J, nt
         WRITE (72,856) I, J, nt
         WRITE (31,855) I, J, nr
         WRITE (73,856) I, J, nr
```

```
c          Sum all productions in zone i (summed over all j's)
           proda = proda + trips(i,j)
           prodt = prodt + ttrips(i,j)
           prodr = prodr + rtrips(i,j)

  840 ENDDO
           WRITE(41,860) i,NINT(proda/10)
           WRITE(51,860) i,NINT(prodr/10)
           WRITE(61,860) i,NINT(prodt/10)

  850 ENDDO

  855 FORMAT(I5, I5, 2X,'1', I7)  ! $BUILD TRIP TABLE foramt in TRANPLAN
  856 FORMAT(I5, ',', I5,',',2X, I7)   !Comma delimited
  860 FORMAT('GP',1X,I4,1X,'1',1X,I7)
  870 FORMAT('GA',1X,I4,1X,'1',1X,I7)

      DO 885 J = 1,ntaz
          attra = 0
          attrt = 0
          attrr = 0
          DO 880 I = 1,ntaz
              attra = attra + trips(i,j)
              attrt = attrt + ttrips(i,j)
              attrr = attrr + rtrips(i,j)
  880     ENDDO
          WRITE(41,870) j,NINT(attra/10)
          WRITE(51,870) j,NINT(attrr/10)
          WRITE(61,870) j,NINT(attrt/10)

  885 ENDDO

  900 WRITE (*,905) tottrps
  905 FORMAT(1X,'Actual number of COMBINED trips =  ',F18.3)
      WRITE (*,910) totn
  910 FORMAT(1X,'Sum of ROUNDED - COMBINED trips = ',i15)

      WRITE (*,*) '**###  PROGRAM SUCCESSFULLY COMPLETED  ###**'
  999 END
```

APPENDIX B. POINTS OF INTERCHANGE BETWEEN RAIL OPERATORS

Birmingham, AL :   BNSF to NS, NS to BNSF, BNSF to CSX, CSX to BNSF, NS to CSX, CSX to BNSF

Chicago, IL :   UP to BNSF, BNSF to UP, UP to NS, NS to UP, BNSF to NS, NS to BNSF, UP to CSX, CSX to UP, BNSF to CSX, CSX to BNSF, (no NS to CSX or CSX to NS), CC to UP, UP to CC, CC to NS, NS to CC, CC to BNSF, BNSF to CC, CC to CSX, CSX to CC, IAIS to BNSF, BNSF to IAIS, IAIS to UP, IAIS to NS, NS to IAIS, IAIS to CSX, CSX to IAIS

New Orleans, LA :   BNSF to NS, NS to BNSF, BNSF to CSX, UP to CSX, CSX to UP, UP to NS, NS to UP, (no NS to CSX or CSX to NS, no BNSF to UP or UP to BNSF)

Kansas City, MO :   UP to BNSF, BNSF to UP, NS to UP, UP to NS, NS to BNSF, BNSF to NS, UP to IMRL, IMRL to UP, BNSF to IMRL, IMRL to BNSF, NS to IMRL, IMRL to NS,

Minneapolis, MN :   IMRL to UP, UP to IMRL, IMRL to BNSF, BNSF to IMRL (no UP to BNSF or BNSF to UP)

St. Louis, MO :   CSX to UP, UP to CSX, NS to UP, UP to NS, CSX to BNSF, BNSF to CSX, NS to BNSF, BNSF to NS, UP to BNSF, BNSF to UP (no CSX to NS or NS to CSX)

Omaha, NE :   IAIS to UP, UP to IAIS, IAIS to BNSF, BNSF to IAIS, CC to BNSF, BNSF to CC, CC to UP, UP to CC, (no UP to BNSF, or BNSF to UP, or CC to IAIS, or IAIS to CC)

Memphis, TN :   BNSF to NS, NS to BNSF, BNSF to CSX, CSX to BNSF, NS to CSX, CSX to BNSF, (no UP to BNSF or BNSF to UP)

Dallas / Fort Worth, TX :   BNSF to UP, UP to BNSF

Cedar Falls/Waterloo :   CC to CEDR, CEDR to CC, CC to UP, UP to CC, CEDR to UP, UP to CEDR

Des Moines, IA :   IAIS to NS, NS to IAIS, IAIS to UP, UP to IAIS, IAIS to BNSF, BNSF to IAIS (no UP to BNSF or BNSF to UP, no NS to UP or UP to NS, no BNSF to NS or NS to BNSF)

Mason City, IA :   IMRL to UP, UP to IMRL

Sioux City, IA :   BNSF to CC, CC to BNSF

**IANR haulage agreement with UP (from Worth to Linn counties) treated as UP ownership
**CIC as very small railroad (Iowa, Johnson, and Linn counties) treated as UP ownership

APPENDIX C. TRANPLAN CONTROL FILE FOR P-A DATA

```
$BUILD HIGHWAY NETWORK
$FILES
   OUTPUT FILE = HWYNET, USER ID = $network.bin$
$OPTIONS
   LARGE COORDINATES
$PARAMETERS
   NUMBER OF ZONES =    144
   MAXIMUM NODE =    5907
$DATA
(Node and link data would be included here)
$END TP FUNCTION

$BUILD COST USER NETWORK
$FILES
     INPUT FILE = CUSIN, USER ID = $NETWORK.BIN$
     OUTPUT FILE = CUSOUT, USER ID = $NETCOST.BIN$
$PARAMETERS
     COST LOCATION = COST
$DATA
     LINEAR SET = 1, UNIT TIME COST = 0, UNIT DISTANCE COST = 12.9
          ASSIGNMENT GROUP = 1
     LINEAR SET = 1, UNIT TIME COST = 0, UNIT DISTANCE COST = 2.6
          ASSIGNMENT GROUP = 2
$END TP FUNCTION

$HIGHWAY SELECTED SUMMATION
$FILES
     INPUT FILE = HWYNET, USER ID = $NETCOST.BIN$
     INPUT FILE = TRNDATA, USER ID = $penltz.txt$
     OUTPUT FILE = HWYSKIM, USER ID = $SKIM90.SKI$
$OPTIONS
     TURN FILE
$PARAMETERS
     IMPEDANCE = COST
$DATA
     TABLE = COST
$END TP FUNCTION

$GRAVITY MODEL
$FILES
   INPUT FILE = GMSKIM, USER ID =$SKIM90.SKI$
   OUTPUT FILE = GMVOL, USER ID =$GM90TOT.TRP$
$OPTIONS
   MERGED PURPOSE FILE
   PRINT TRIP ENDS
   PRINT TRIP LENGTH STATISTICS
   PRINT ATTRACTIONS
$PARAMETERS
   ATTRACTION CLOSURE = 5.0
   ITERATIONS ON ATTRACTIONS = 3
   IMPEDANCE = COST
   MAXIMUM PURPOSE = 1
   MAXIMUM TIME = 500
$DATA
$INCLUDE SUMPA.TXT
```

```
$INCLUDE FF###.TXT
$END TP FUNCTION

$MATRIX TRANSPOSE
$FILES
    INPUT FILE = TRNSPIN, USER ID =$GM90TOT.TRP$
    OUTPUT FILE = TRNSPOT, USER ID =$DUM.TRP$
$PARAMETERS
    SELECTED TABLES = 1
$END TP FUNCTION

$MATRIX MANIPULATE
$FILES
    INPUT FILE = TMAN1, USER ID =$GM90TOT.TRP$
    INPUT FILE = TMAN2, USER ID =$DUM.TRP$
    OUTPUT FILE = TMAN3, USER ID =$TOT90.TRP$
$DATA
    TMAN3,T1 = TMAN1,T1 + TMAN2,T1
$END TP FUNCTION

$MATRIX UPDATE
$FILES
    INPUT FILE = UPDIN, USER ID =$TOT90.TRP$
    OUTPUT FILE = UPDOUT, USER ID =$TOT90X.TRP$
$DATA
    T1,1-  144,1-  144, * .5
$END TP FUNCTION

$LOAD HIGHWAY NETWORK
$FILES
      INPUT FILE = HWYNET, USER ID =$netcost.BIN$
      INPUT FILE = HWYTRIP, USER ID =$TOT90X.TRP$
      INPUT FILE = TRNDATA, USER ID =$penltz.TXT$
          OUTPUT FILE = LODHIST, USER ID =$OUT.BIN$
$OPTIONS
   TURN FILE
$PARAMETERS
   IMPEDANCE = COST
$END TP FUNTION

$REPORT MATRIX
$FILE
      INPUT FILE = RTABIN, USER ID = $TOT90X.TRP$
$HEADERS
      ##***%%  TRIP TABLE REPORT %%***##
$OPTIONS
      PRINT TABLE
$PARAMETERS
      SELECTED PURPOSES = 1
      SELECTED ZONES = 1-144
$END TP FUNTION
```

APPENDIX D. TRANPLAN CONTROL FILE FOR O-D DATA

```
$BUILD HIGHWAY NETWORK
$FILES
   OUTPUT FILE = HWYNET, USER ID = $network.bin$
$OPTIONS
   LARGE COORDINATES
$PARAMETERS
   NUMBER OF ZONES =     144
   MAXIMUM NODE =    5907
$DATA
(Node and link data would be included here)
$END TP FUNCTION


$BUILD COST USER NETWORK
$FILES
      INPUT FILE = CUSIN, USER ID = $NETWORK.BIN$
      OUTPUT FILE = CUSOUT, USER ID = $NETCOST.BIN$
$PARAMETERS
      COST LOCATION = COST
$DATA
      LINEAR SET = 1, UNIT TIME COST = 0, UNIT DISTANCE COST = 12.9
            ASSIGNMENT GROUP = 1
      LINEAR SET = 1, UNIT TIME COST = 0, UNIT DISTANCE COST = 2.6
            ASSIGNMENT GROUP = 2
$END TP FUNCTION


$BUILD TRIP TABLE
$FILES
   INPUT FILE = SRVDATA, USER ID = $rflows.txt$
   OUTPUT FILE = VOLUME, USER ID = $TOT90X.trp$
$OPTIONS
   SIMPLE
$PARAMETERS
   NUMBER OF ZONES =     144
$END TP FUNCTION
```

REFERENCES

1. Iowa Department of Transportation. Iowa in Motion: State Transportation Plan. Ames, IA, 1997.

2. United States Congress. Intermodal Surface Transportation Efficiency Act. Public Law 102-240, 1991.

3. Paying Our Way: Estimating Marginal Social Costs of Freight Transportation. Transportation Research Board, Special Report 246, National Academy of Sciences, Washington, D.C., 1996.

4. Shaffer, J., Peterson, E. "Transportation Policy: Principles, Problems, and Processes." Transportation Policy Primer. National Extension Transportation Task Force, Oklahoma State University, Stillwater, OK, 1980.

5. A Guidebook for Forecasting Freight Transportation Demand. National Cooperative Highway Research Program Report 388, Transportation Research Board, National Research Council, Washington, D.C., 1997.

6. U.S. Department of Transportation. Federal Highway Administration. Quick Response Freight Manual. Washington, D.C., 1996.

7. "Statewide Transportation Planning." Transportation Research Circular 471. Transportation Research Board, National Research Council, Washington, D.C., 1997.

8. Smadi, Ayman Ghaleb. Development of a Procedure for the Statewide Distribution and Assignment of Truck Commodity Flows: A Case Study of Iowa. Ph. D. Dissertation, Iowa State University, Ames, IA, 1994.

9. "Intermodalism: An Eno Forum." Transportation Quarterly. Eno Transportation Foundation, Inc. Landsdowne, VA, Autumn 1994.

10. Application of Statewide Freight Demand Forecasting Techniques. National Cooperative Highway Research Program Report 260, Transportation Research Board, National Research Council, Washington, D.C., 1983.

11. Kornhauser, Alain L. and Bodden, Michael. "Network Analysis of Highway and Intermodal Rail-Highway Freight Traffic." Transportation Research Record 920. p. 61-68, Washington, D.C., 1983.

12. Guelat, Jacques; Florian, Michael; Crain Teodor Gabriel; "A Multimode Multiproduct Network Assignment Model for Strategic Planning of Freight Flows." Transportation Science, Vol. 24, No. 1, 1990.

13. Black, William R. Ph.D., <u>Transport Flows in the State of Indiana: Commodity Database Development and Traffic Assignment</u>. Transportation Research Center, Bloominton, IN, 1997.

14. U.S. Department of Transportation. Bureau of Transportation Statistics. Transportation Statistics Annual Report 1996. Washington, D.C., 1996.

15. United States Department of Transportation. Federal Highway Administration. <u>1997 Comprehensive Truck Size and Weight Study: Volume II</u>. Washington, D.C., 1997.

16. Reebie Associates. <u>Transearch Reference Manual</u>. Stamford, CT, 1992.

17. <u>Moody's Transportation Manual</u>. Moody's Investors Service, Inc., New York, 1996.

18. Muller, Gerhardt. <u>Intermodal Freight Transportation</u>. 3rd Ed. Eno Transportation Foundation, Inc. Landsdowne, VA, 1995.

19. Iowa Department of Transportation. <u>Intermodal Terminal User Manual</u>. Ames, IA, 1997.

20. Iowa Department of Transportation. Office of Transportation Inventory. <u>Truck Weight Survey Field Instructions</u>. May, 1997.

21. <u>New Trucks for Greater Productivity and Less Road Wear</u>. Transportation Research Board, Special Report 227, National Research Council, Washington, D.C., 1990.

22. United States General Accounting Office. <u>Longer Combination Trucks: Potential Infrastructure Impacts, Productivity Benefits, and Safety Concerns</u>. Washington, D.C., 1994.

23. <u>UPRR Public Price Inquiry – Tariff and Circular Prices</u>. Union Pacific Railroad Company. 15 April 1998 <http://my.uprr.com/pub/wppi/>.