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Development of a procedure for the statewide distribution and assignment of truck commodity flows: a case study of Iowa

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Development of a procedure for the statewide distribution and assignment of truck commodity flows: A case study of Iowa

by

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ABSTRACT

The purpose of this research is to develop a procedure for statewide planning of truck commodity flows and apply it to the State of Iowa. The methodology utilizes available relevant data sources at the state level and state-of-the-art freight transportation planning tools. A case study consisting of two manufacturing sectors and a simplistic transportation network is developed for Iowa to demonstrate the procedure. Difficulties encountered in the modeling process are identified and categorized by cause into modeling capability or data related. Data deficiencies having the greatest impact on the modeling process and the accuracy of the results are identified. Some methods to improve freight data are offered as are estimates of the effort entailed in improving and developing new data.

The procedure for the statewide distribution and assignment of truck commodity flows provides a practical tool for state level freight transportation planning. The procedure examines major commodity movements on dense corridors. The general scheme of the methodology is to: 1) identify major commodities shipped in the state; 2) identify producing and attracting zones of the major commodities in the state; 3) estimate truck shipments between origin-destination pairs; and 4) assign estimated truck trips onto the primary highways within the state.

Analysis zones within Iowa represent counties, while external analysis zones represent states. The total zonal freight tonnage generated is estimated using socioeconomic indicators, employment and population. Produced manufacturing freight is correlated with employment rates. Attracted freight is allocated to industrial inputs by employment and to consumption using population size. The truck freight share is estimated as the total freight generated less the freight tonnage shipped by rail. A gravity model is used to distribute the estimated truck tonnage among

major origin-destination pairs. The impedance factor in the gravity model is equal to the inverse of travel time on links. Estimated truck tonnage is converted to vehicle trips using typical vehicle equivalent weights. Truck trips are assigned to shortest paths calculated using a tree building algorithm. Estimated truck trips are validated against truck counts on selected highway links.

CHAPTER 1. INTRODUCTION

In recent years there has been an increased interest in developing and using freight transportation planning models. This interest has been evident in the transportation literature generated since 1983. Numerous articles and special conferences have focused on freight transportation demand and planning modeling, or, more accurately, on the lack of freight modeling capabilities. Recent transportation policy also required the inclusion of freight in statewide transportation plans (6). Freight transportation is highly correlated with economic activity at national, regional, and local levels. Efficient freight transportation planning tools are essential for public agencies such as state departments of transportation and economic development agencies. Freight transportation planning models can aid in formulating effective transportation policies, and better allocation of limited funds for infrastructure maintenance. Better understanding of the freight transportation network will also serve to enhance efforts of state agencies that oversee economic improvement and development programs.

In contrast to urban transportation planning, the study of freight flows received less attention because of the inherent complexities of such problems (1, p. 25). Specifically, there is an evident shortage of practical models for predicting truck traffic flows and their distribution. As a result, accurate assessments of impacts of infrastructure or institutional changes can not be realized. The shortage of freight transportation planning models is due in part to: 1) the complexity of the demand for freight transportation, 2) the extensive data required to model freight transportation demand, and 3) the sparsity of relevant data. The complexity of freight transportation demand decisions has been further increased as a result of the growing level of interdependence among economic regions, increased competition for highway capacity among trucks and passenger cars, and increased competition between truck and other modes (2, p. 227).

The structure of the freight transportation industry experienced significant changes in the early 1980s. Several factors contributed to reshape its structure. The relaxation of regulations by the Motor Carrier Act of 1980 and the Staggers Act of 1980 had dramatic impacts on transportation services and rates. These acts affected the number and sizes of carriers; the transportation services offered and the availability of services; freight transportation rates and the freedom in setting rates; modal market shares, routing decisions, and vehicle sizes and configurations (3, pp. 31-42; 4). For those observing and examining the transportation industry, a major result of deregulation, however, was the decline in available freight transportation data. The freedoms granted to transportation carriers to provide flexible services, develop confidential contracts with shippers, and reduced reporting rules were among the causes for this decline.

1.1 Freight Planning Models

Freight planning models refer to the analytical methods of predicting the amount and distribution of freight generated within a geographical area. These models are used to assess the impact of changes in infrastructure, regulatory policy, and economic climate on freight traffic levels, modal shares, and routing decisions. The freight modeling process may include the following four elements: 1) freight traffic generation, 2) freight traffic distribution, 3) modal division, and 4) freight traffic assignment.

Freight generation involves the estimation of the quantity of products produced or demanded at a specific location. Freight generation is directly correlated with socioeconomic factors such as population and economic activity. The practice has been to aggregate micro-level production or demand in a geographical area to correspond to the freight generated at a single node. This node corresponds to a central location in the analysis zone or to the location of economic activity in that zone. The level of aggregation of production and attraction (shippers and receivers) will implicitly affect the level of accuracy (or approximation) used to capture the decisions of shippers and receivers in that area (3).

The distribution of freight traffic involves pairing production nodes with attraction nodes. This is accomplished by evaluating demand levels, production levels, and impedance on possible paths between origin-destination pairs. Impedance is expressed in terms of link costs, delays, or travel times. The results of traffic distribution analysis are flow matrices that define quantities of products shipped between producing nodes (origins) and attraction nodes (destinations).

The third element of a freight planning model is to divide estimated freight flows among competing modes. This element of the freight modeling process is complex and is an area where improvement is most needed. Contrary to passenger travel demand models, shipping decisions in freight transportation are difficult to capture. In addition to the numerous factors involved in shipping decisions, there is a wide range of freight transportation options available to shippers. Modal performances expressed in terms of shipping costs, delivery times, delays or variation in delivery times, are used in the modal division analysis. However, a more detailed consideration of the effect of transportation decisions on the overall logistics costs is required in most cases to accurately depict modal decisions, and thus increasing both of the data requirements and the required modeling capabilities. Many of the existing freight planning models focus on one mode, eliminating the need for modal analysis. Further, rail has been the freight transportation mode receiving the most extensive attention in freight transportation planning modeling literature.

The fourth step in freight planning models is the assignment of freight flows between origin-destination pairs to links and routes in the freight transportation network. The network may correspond to the existing physical infrastructure of one or more modes. The level of details in the network representation depends on the level of details desired in the analysis. Most existing freight models used the national rail or waterway network, while a few used the national highway network. Nodes in the network represent major cities or freight generation centers. Arcs or links in the network are assigned attributes such as distance, cost, or travel time. Each of these attributes can be used as a criterion for finding shortest paths between origin-destination pairs.

This research addresses the development of a practical procedure for freight truck traffic distribution at the state level and applies the model to the State of Iowa. The research approaches the issue at the macro-level analysis of traffic and infrastructure, rather than the detailed accounting of all truck traffic within the state. This research identifies the data required to conduct truck traffic planning at the state level based on different types of decision and planning issues. The technique developed utilizes existing relevant freight data sets available at the state and national levels.

1.2. Importance of Research

Truck transportation plays a major role in moving the nation's freight. In 1990, trucks accounted for approximately 25.6 percent of the total U.S. intercity revenue ton-miles (5). Trucks are used by haulers of premium services, particularly when moving time sensitive commodities. Furthermore, trucks share public roads with other traffic, raising two main issues: safety and user costs. There is continuous debate on the extent to which truckers pay their share of the costs of using public roads. These costs can be largely correlated with the extent of pavement damage attributed to trucks. Safety issues range from truck size and weight limitations to the transportation of hazardous materials. As a result of budget constraints and recent transportation policy, managing and optimizing the use of existing transportation facilities is receiving increasing attention.

In the freight transportation planning process, there is a dual role for governmental agencies as providers of roadway and regulators of some transportation operations. Because highway facilities are owned and maintained by the government, agencies are faced with important decisions including the range of services offered, the level and programming of road maintenance, taxing of road users, and regulation (economic, safety, environmental) (2, p. 228). These decisions have direct and significant impacts on the users of the transportation system and the economic competitiveness of the state. An increase in truck transportation costs due to inefficiencies in the transportation system are passed from carriers to shippers, and eventually to the delivered prices to final consumers. Effective truck planning tools at the state level are crucial if governmental agencies are to make sound economic and transportation policies that will maximize the efficient use of the transportation system..

States have been working to add freight transportation to their planning process, but state level freight planning procedures are limited, especially for the highway mode. Interviews with Iowa Department of Transportation personnel have revealed the need for practical tools to include freight transportation planning within the overall state intermodal plan. The intermodal planning concept has been advocated and required by recent transportation legislation. The 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) required states to develop and implement statewide transportation plans and other management systems that address freight transportation planning (6). However, there is an evident lack of tools and data sets to carry freight transportation planning functions at the state level.

Traditionally, economic models have been used to predict and distribute freight flows. However, these models had substantial simplifying assumptions regarding the behavior of carriers and shippers of various commodities, utilized national freight transportation network, with more attention to rail, and had extensive unmet data requirements. This research is intended for state level analysis and focuses on capturing transportation demand of major sectors. It utilizes available data to the fullest extent possible, and recommends improvements to data collection and coordination activities under state control.

1.3. Research Objectives

The research documented in this dissertation centers around two major domains in freight transportation planning: data requirements and state level applications. Subsequently, the objectives of this research can be summarized as follows:

1. Assess the data requirements for freight transportation planning, with more attention to truck transportation planning models at the state level. Identify available data sources at the state and national levels and their potential use in truck transportation planning modeling. Evaluate the data needs and availability to estimate unmet data requirements.

2. Develop a state-level truck commodity distribution and assignment model using available relevant transportation and socioeconomic data and state-of-the-art freight transportation planning modeling techniques. Demonstrate the model by a case study application to the major manufacturing sectors in the State of Iowa.

3. Identify the problems encountered in the modeling procedure due to inadequate freight data or modeling tools. Emphasize the deficiencies in the data having the greatest impacts on the accuracy of the truck commodity flow patterns estimated in the case study.

4. Recommend improvements to existing data sets at the state level to enable accurate estimation of truck commodity flows in the state. Identify missing data sets required for

efficient truck freight planning and possible collection schemes and estimate corresponding costs of data improvements.

1.4. Research Organization

The remaining chapters in this dissertation are organized as follows:

Chapter 2. Literature Review

This chapter is divided into two main parts. The first part is a review of general freight planning models and recent efforts in the area of multi-mode, multi-commodity models. The second part reviews efforts in assessing data requirements to conduct freight transportation planning, namely the National Cooperative Highway Research Program special reports 177 and 178 (7,8). Gaps in the current state-of-the-art are then identified and the research problem is introduced.

Chapter 3. Problem Statement

This chapter will consist of a detailed description of the research mission. It will identify the main parts of the research, and the variables and decisions involved in each part. The scope of the research is also defined in terms of geographical units, level of analysis, economic sector inclusion, and transportation network elements.

Chapter 4. Data Analysis

This chapter identifies the data required to conduct freight transportation planning using state-of-the-art tools appropriate for statewide analysis. It will also enumerate available data sources and provide a brief description of each source and its potential uses and limitations. This chapter is divided into three main parts: 1) data requirement, 2) available data sets, and 3) unmet data requirements.

Chapter 5. Methodology and Case study

This chapter begins with a general solution scheme, followed by a breakdown of solution elements into specific commodity flow analysis for the major commodities, network coding, freight generation, traffic distribution, determination of the truck traffic share and link assignment, and validation. The results of the procedure are evaluated to examine problem areas in the data used in the procedure.

Chapter 6. Conclusions

This chapter summarizes the results of this research. It uses the results from data assessment analysis and the case study application to propose changes to existing data sources and suggestions for collecting new freight data at the state level. It further suggests appropriate frameworks for applying methodologies for freight transportation planning.

CHAPTER 2. LITERATURE REVIEW

A review of the state-of-the-art in freight transportation planning revealed a clear shortage of practical statewide freight transportation models. The lack of adequate commodity flow data, cited as an obstacle in freight modeling, and the complexity of freight transportation demand are some causes for the shortage in effective planning tools. Nevertheless, there is extensive literature on freight transportation demand models and the development of tools for analyzing intercity freight. A major shortfall of these efforts, however, is the lack of applications as is evident at the state level. This chapter outlines relevant previous research efforts and identifies positive elements in these efforts that will be used in developing the methodology.

One factor that has been repeatedly identified in the literature is the lack of appropriate flow data to conduct freight planning (2,9,10). Inadequate flow data were also blamed for most problems encountered in modeling freight transportation demand (11). Another issue repeatedly discussed in the literature is the similarity, or more accurately the lack of similarity between modeling the passenger-oriented urban transportation demand and modeling freight transportation demand. Many early planning models approached freight transportation planning similarly to passenger urban transportation. Both of the travel demand characteristics and the types of decisions involved in planning urban transportation are different from their counter parts in freight transportation demand. While urban transportation models deal with moving people, in freight the movement of several commodities with distinct transportation requirements must be modeled. Further, urban transportation models focus on capacity improvements. In intercity freight transportation, however, there is little or no capacity constraints. Friesz and Morlok (10, p. 513), for example stated that:

> In dealing with questions about the intercity freight transportation system, . . . the typical approach has been to attempt to use network models which have been developed for passenger transportation . . . Yet there are fundamental differences between the urban automobile transportation systems for passengers and the intercity freight transportation systems. These differences have been largely unrecognized and they have led to great difficulty in realistically portraying the freight system.

Finally, most of earlier freight transportation planning models were conducted on a national level, while focusing on one economic sector (agriculture or energy) and a single freight transportation mode (rail or water). State-level freight transportation planning models are still at a rudimentary stage in many states. This shortage of state level applications became more critical as states are required to include freight transportation in their transportation plans.

This review will provide a brief description of the evolution of freight transportation models and delineate recent advances in this area. Of interest to this research are the transportation network representation ideas, efficient shortest-path calculation procedures, and modal split methodology useful for understanding commodity-mode relationships. The review is divided into two parts: 1) freight network models, and 2) statewide freight transportation models. The review is not exhaustive, but provides examples of major works categorized according to the following:

1. Purpose and method of analysis: network equilibrium models, spatial price equilibrium models, simulation models, or other.

2. Level of analysis: geographical area included in the model (national, regional, state, etc.), the number of modes (multimode or single mode), or the products considered (all or a subset of commodities).

3. Model output: traffic levels, routing decisions, or mode comparisons.

4. Data requirements.

2.1. Freight Transportation Planning Models

Methods used to model freight transportation demand can be categorized into two general types: spatial price equilibrium and network equilibrium. Spatial price equilibrium methods were used to model interregional freight flows. These models determine the flow between production and consumption regions by using demand and supply functions and, in addition, estimate commodity selling and buying prices (1, p. 25). Spatial price equilibrium models use a simplistic representation of the transportation network. They primarily use econometric methods to estimate supply and demand functions of the produced or consumed commodities. Previous applications of these models were mainly agricultural or energy related (1, p. 25). These models are not reviewed in this research since they are inappropriate for the research problem.

Network models, on the other hand, enable the prediction of flows on a multimodal network that closely represent the actual physical transportation network with little abstraction. The emphasis of network equilibrium models is on the representing the transportation network and modeling its operational characteristics. An important part of the solution is the computation of shortest paths connecting the nodes on the network (1, pp. 25-26). Since the demand for transportation is exogenous, these models use freight flow estimates from input-output models or actual observed flows. This class of models allows a level of detail that is appropriate for a nation or a large region.

2.1.1. Network Equilibrium Models

Transportation network models have been used since the early 1960s to analyze flow among origin-destination pairs connected by a finite network of transportation facilities. Most of these network applications were conducted to support urban transportation planning (11, p.

475). Early freight network models were developed in the late 1960s by Roberts and Kresge (12) for a developing country, Columbia.

Freight network models can be characterized according to purpose into service design models and predictive models (9, p. 191). Service design models are used to plan the supply of transportation services. These models focus on a specific agency which provides transportation services, e.g., a transportation carrier. They may address different planning horizons. In general, however, they address decisions related to allocation of investments, location of facilities, fleet sizing, routing decisions, and pricing policies (9, p. 196). These models are not reviewed since they are of no interest to this research. The analysis in the proposed research will deal with freight flows of the major commodities in the state rather than a particular carrier or shipper.

Predictive network equilibrium models estimate the distribution of freight flows by modeling decisions of carriers, shippers, and government and interactions among these actors. Predictive network models can be further classified according to their optimization strategies into user-optimizing and system-optimizing (9, p. 191). User optimizing models achieve a traffic equilibrium by estimating flows resulting from decisions of individual users trying to optimize their route choices. On the other hand, system-optimizing models assume that there exists a general system-wide goal that both users and providers of transportation services work to achieve, and estimate flow distributions accordingly. An example of a system-wide goal is to minimize total transportation cost (9, p. 191)

The theoretical basis for network equilibrium models was developed originally by Wardrop, and is stated in the following two principles (13, p. 162):

1. Each user seeks to minimize his transportation cost without consideration to other users or providers of transportation in the system, and thus resulting in a user-optimized equilibrium.

2. Users cooperate fully to minimize the total transportation cost in the system, or there exists a central authority which controls the system and enforce this goal. The resulting flow patterns will achieve a system-optimized equilibrium. Under this scheme, marginal total costs of transportation alternatives are equal.

Freight network models have, in general, satisfied Wardrop's second principle, thus leaving unclear the decisions of shippers and shipper-carrier interactions (13, p. 162). They use an objective function that reflects the total transportation costs summed for all movements or trips over the network. Such a formulation, however, neglects the efforts by shippers to minimize their individual costs, affected by their transportation decisions, such as inventory and order processing costs. Similarly, carrier efforts to minimize operating costs affected by routing decisions and types of vehicles used, are not reflected in these models. Furthermore, these models take on a global and aggregated view of the transportation system, focusing on a single outcome: the service flow distributions over the transportation network (9, p. 190).

2.1.1.1. Harvard-Brookings Model

The Harvard-Brookings model, considered the first freight network model, was developed by Roberts in 1966 and later modified by Roberts and Kresge in 1971 (13, p. 163). This model is explicitly multi-modal and multi-commodity and was applied to the transportation network of Columbia, a developing country. Links in the network correspond to possible transportation routes, while nodes represent cities and regions. The model has a macroeconomic driver to estimate commodity production and consumption quantities. Constant unit perceived shipping costs were used to calculate shortest paths over the network. These shortest paths were used to estimate commodity flows between origin-destination pairs and to assign these flows to links in the network. A standard gravity model was used to estimate flows of highly aggregated heterogeneous commodity groups, where each producer supplies every market. For disaggregate commodity groups, where producers supply only a few markets, a linear programming submodel is used to distribute these flows (12, pp 51-55). Backhaul trips were assumed to be rare for disaggregate commodity groups, such as coal, and were added after the assignment of aggregated commodity flows to the same links as the front-haul trips.

The Harvard-Brookings model represents the first comprehensive freight transportation model. The model explicitly related transportation decisions to economic and spatial factors. The theoretical component in the model presented an innovative method of estimating freight flows. However, the micro-level details in the model formulation and its extensive data requirements inhibit a practical application of the model.

The modal choice and routing analysis were conducted from a shipper standpoint. The model ignores the role of carriers and congestion effects on transportation links (9, p. 192). Commodity supply and demand relationships were estimated from a macroeconomic model at the regional level. However, these estimates were then disaggregated to the node-level in the transportation model using nodes commodity supply factors. This increased both the computational and data requirements of the model. Finally, the model was developed in Columbia's regulated transportation environment. In that system, a central authority controls the range and prices of transportation services offered.

Data Requirements

As mentioned earlier, the level of detail in the data required by this model is microscopic. The general data requirements can be summarized into the following elements:

- Economic-base data used in macroeconomic driver to estimate freight demand.
- Production, consumption, input-output coefficients, market locations, and commodity attributes.
- Network attributes: configuration, link time and cost parameters, link capacities, and modes.
- Commodity modal preferences represented by estimates of costs of transportation service attributes such as delay, delivery time, and delivery time variation.

2.1.1.2. CACI - Transportation Network Model

This model was developed by CACI, Inc., as a multi-commodity, multi-mode freight network model which was part of the 1980 National Energy Transportation Study. It was intended to predict and distribute freight flows, however, it fell short of estimating shipment origin-destination patterns (13, p. 163). Crainic concluded that the model had fixed demand, thus impairing the freight distribution patterns prediction (9, p. 192).

The model evolved from the Inland Navigational System Analysis developed by the Army Corps of Engineers in 1976. It underwent many changes in network representation and freight transportation modes considerations. The model was an application study of the movement of energy commodities through the transportation network (11, p. 480). Friesz and Harker; and Crainic identified two underlying assumptions in the model as follows (9, p. 164):

1. Freight routes are exclusively decided by shippers attempting to find minimum cost paths.
2. The cost on any path is a linear combination of transportation cost, time, and energy use.

Energy use was included in path costs to assess different energy-conservation scenarios (9, p. 192). The multi-modal network in the model used a node and link configuration. Nodes in the network corresponded to point-located transportation facilities having characteristics of location, mode, capacity, and time and cost parameters (11, p. 476). Links represented line-haul transportation facilities and were characterized by the end nodes, length, mode, capacity, and time and cost parameters (11).

Impedance on links and nodes was expressed by nonlinear functions that relate the cost on a link (or a node) to its traffic volume. These functions were evaluated in a table look-up procedure using piecewise linear approximation methods (11). The model identified the least perceived shipping cost paths for each commodity origin-destination pair. Path costs were the sums of shipment and delay costs. Delay costs were defined as the product of transit time, commodity value, and a factor representing holding costs (11). Commodities were assigned to shortest paths in the network using an "all-or-nothing" logic.

In the early version of the model, commodities were assigned to the network sequentially, thus disabling the multi-commodity attribute. The resulting commodity assignments were based on the loading sequence, rather than the commodity-implied transportation requirements. The most recent version of the model (1983) achieved traffic equilibrium but used aggregated cost functions (rather than per commodity), and therefore was reduced to a single-commodity model (13, p. 164). The model is not intended for a general freight application, but rather for a commodity group, mainly coal.

The difficulties in the model, the discrepancies in capturing the commodity-mode relationships, and shipper-carrier interactions were attributed to the lack of data. A detailed discussion of the evolution of this model was done by Bronzini, who was involved in the CACI project as a senior consultant (11). He cited the use of transportation costs rather than rates in modal analysis as a potentially serious source of error. He also recommended the use of vehicle flows in the network in addition to tonnage. Bronzini stated: "Despite progress made so far, there remains areas where significant improvements are required. The greatest need is for a comprehensive interregional commodity flow data base." (11, p. 483).

Data Requirements

The data elements required for the CACI Transportation Network Model can be summarized as follows:

- Commodity flow estimates, obtained from a separate model, commodity attributes.
- Network attributes: node and link configuration, links time and cost parameters, modes, capacity.

2.1.1.3. A Multimode Multiproduct Network Assignment Model for Strategic Planning of Freight Flows

This network model was developed for simulating freight flows on Brazil's transportation network. The basic assumption in the Multimode Multiproduct Assignment model was that freight is moved at a minimum total generalized cost. Shippers and carriers were not considered as independent entities, but aggregated by analysis zones (1, p. 26). The general methodology can be divided into three parts: network representation, a multiproduct costing model, and a shortest path algorithm. Parallel links are used to represent available modal freight transportation services in the network (i.e., more than one link is used to represent transportation services offered by different modes between the same origin-destination pair). This representation is similar to the network used by Roberts (12, p 46). Intermodal transfers were allowed at nodes where intermodal transfer facilities exist. These transfers were associated with appropriate costs and delays. The model considers multiple products by specifying a cost function for the flow of each product on a link or through a transfer that corresponds to one mode. The demand and modal choices for each product were obtained from a set of origin-destination matrices. Thus, freight generation, distribution, and mode choices were determined exogenously from the origin-destination matrices (1, p. 29).

Mathematically, the model consists of minimizing an objective function, the sum of all arc and transfer costs for all products, subject to flow conservation and non-negativity constraints. Flow conservation constraints stated that the sum of flow on all possible paths between an origin-destination pair is equal to the total flow between this pair. Cost functions were developed for arcs and transfer nodes to estimate path costs for the shortest path algorithm. The model calculated average costs as functions of flow vectors that could be separated by link in terms of delay and other link costs (1, p. 30).

Because of the multimode-multiproduct model formulation there was a problem of dimension that made linear approximation methods impractical. However, the model suggested a natural decomposition by commodities, and thus the overall objective function is the sum of individual product objective functions. A major part of the algorithm was to keep track of the origin and destination during path construction and calculations. This was accomplished by a link and node labeling procedure.

Although the model was intended to be flexible to various uses, it was applied in Brazil where a central authority provides and regulates freight transportation services. The size of the transportation network in Brazil is less extensive than in the United States, creating potential for coding difficulties if the model is applied to the United States. A major element of freight transportation modeling, estimating commodity flows, was not addressed in this model. The model relied on existing commodity flows that not only provided the quantity shipped between origins and destinations, but also the transportation mode used in the shipment. While these flow data were available in Brazil, they are not available in the United States. Furthermore, even when commodity flows exist, they are limited in level of details of geographical and commodity representations.

Data Requirements

The input data required by this model can be grouped into the following elements:

- Commodity flows between origin-destination pairs for eight major products;
- Modal choice and modal division data were obtained form existing mode choice studies and vehicle characteristics for each product; and
- Network attributes: node and link configuration, cost and travel time functions of nodes and links, and the modal services available between origin-destination pairs.

2.1.2. Statewide Freight Models

This section is devoted to a review of freight planning models that were explicitly designed for state level analysis. Statewide freight planning models have some characteristics that differ from national models. The differences are caused by the types of decisions investigated, the level of details required in the data sets, and the geographical delineation of study areas. The difficulty in conducting state level freight modeling lies not only in the microscopic data requirements, but also in the large role of external factors that affect the state freight system. States are not independent economic entities. The freight systems of an individual state might extend beyond the state's political boundaries. The data requirement issue emerges here again, due to the difficulty of obtaining accurate data on areas outside the state. State level freight modeling tools must address these issues and identify major corridors essential to moving the state's freight. Until recently there were few state level freight planning models. However, in the ISTEA (6) era, freight will be an important element in a state's intermodal transportation plans. The following summaries describe examples of state level freight planning models. These models generally focus on assessing freight shipment patterns and changes in these patterns on the transportation infrastructure.

2.1.2.1. Arizona Freight Network Evaluation Using Decision Support System (2)

The purpose of Rahman and Radwan's research was to develop a highway freight planning tool to enable the Arizona Department of Transportation to evaluate the performance of the highway network under different economic and regulatory scenarios. The criteria used for evaluating the impacts on the highway network relates estimated freight traffic levels to network utilization, number of accidents, and highway maintenance costs (2, p. 227). They stated that freight transportation planning tools were needed at the state level to ensure adequate performance of the state freight transportation system.

The authors pointed out that existing freight network models, such as the Harvard-Brookings Model, the Transportation Network Model (CACI), and the Freight Network Equilibrium Model (Pennsylvania-Argonne National Laboratory model) have solid theoretical frameworks, but they are difficult to implement. They referred to Sullivan's study which found these models to be not applicable to state level freight planning in California (14). Based on these observations, the Arizona Department of Transportation decided to use simulation techniques for highway freight evaluation. The modeling system consisted of four elements: a database, a data pre-processor, a simulation module, and a planning module (2, p. 230).

The data base information system included carrier information such as address, type of carriage (common, contract, or private), miles travelled in Arizona in 1985, and commodities carried. The database consisted of information on 2,000 motor carriers, 65 rail-freight intermodal carriers, 135 air carriers, 42 pipe line shippers, and 228 hazardous material carriers, all doing business in Arizona in 1985 (2, p. 229). Carrier information was obtained from the Arizona Motor Vehicle Division.

The data pre-processor module was used to estimate truck commodity flow patterns based on a sampling of truck shipments in the state. The types of data generated included origin and destination of shipment, the commodity shipped, and gross weight of the truck. This information was obtained from a survey of freight carriers in Arizona. Commodities were grouped in ten classes: agricultural, mining, construction, manufacturing (three groups), services, general freight, unknown, and empty truck. The survey asked respondents about the commodity shipped, tonnage, origin of shipment, destination of shipment, and Arizona route used (highway route).

The simulation module, a discrete event simulation, was based on probabilities computed from the commodity flow patterns on Arizona's road network. The network consisted of 102 one-way highway sections of primary and secondary highway systems and 81 nodes corresponding to cities. Inputs to this module were (2, p. 231):

1. Network configuration: the number of nodes, the number of links, and the number of possible links leading from and to each node.

2. Network parameters: link characteristics that corresponded to the highway segment represented by the link. These included the number of lanes, the length of the link, the

speed limit on the link, the surface condition of the highway link, and the traffic volume on the link measured in average daily truck traffic.

3. Origin-destination data: the percent distributions of shipments from an origin to potential destinations, and the probabilities of using highway links as part of a path from the origin node to every possible destination, and the probability of that shipment being made by a truck of a specific type and weight.

The simulation module assigned shipments to highway routes based on conditional branching distributions obtained from path probabilities as described in 3. above. Trips originating from a node were distributed to potential destinations based on the probability of terminating at each intermediate or destination node. Truck trips between this origin node and all other nodes were each assigned to appropriate paths in the network. The output of the module were estimated daily truck volumes on each link of the network, and confidence intervals for these estimates. Validation of the results obtained from the simulation system was achieved by comparing estimated results with those of the survey data. Only volumes estimated on interstate links, which totaled 56 links out of the total 102 links included in the network, were satisfactory (2, p. 232).

Finally, the planning module used estimated truck volumes on highway links to analyze traffic volumes, safety measured in number of accidents on links, and pavement maintenance cost implications of estimated link traffic volumes (2, p. 233). The module could evaluate future scenarios resulting of infrastructure and economic activity changes in the state. To obtain future traffic volumes, the affected nodes and links, and their attributes were modified using growth factors developed for each commodity group. These growth factors were developed from estimates of personal income and earnings from U.S. Department of Commerce data (2).

The methodology developed in this research is very promising. This modeling procedure focused on a statewide application and could assess impacts of system modifications on traffic levels and eventual maintenance and safety costs of these changes. The major underlying problem in this model is the commodity flow data. The sample covered 16 percent of freight carriers in Arizona, of which only 25 percent responded. Thus, transportation and routing decisions reflected in the commodity flows are solely based on probabilities obtained from this survey. The use of survey data to validate the estimated results from the simulation model rather than actual truck volume counts means that errors in the data are not detected and further extended to model validation. The survey was used as input and as a validation tool.

Data Requirements

The data requirements for this study can be summarized as:

- Commodity flow data, which were obtained from a three-stage mail survey of freight carriers operating in Arizona.
- Network attributes: link attributes such as: number of lanes, length, speed, surface condition, average daily truck traffic, and origin-destination for specific routes data.
- Other: economic growth factors to forecast growth, and accident cost parameters to estimate safety impacts.

2.1.2.2. Application of Statewide Freight Demand Forecasting Techniques (3)

This report was prepared in response to the need for the development and improvement of freight transportation planning techniques, on the state level. The technique was initially envisioned to be a highly structured step-by-step procedure. However, the variety of potential applications and the varying data sources to state agencies dictated the development of a framework instead of a procedure. The National Cooperative Highway Research Program Report

260, acts as a user manual, divided this technique into four main parts: problem definition, freight generation and distribution, modal division, and traffic assignment. Case studies and example applications are provided at the end of the report.

Freight traffic generation and distribution can be estimated using two approaches, depending on the availability of data. When commodity flow data are available, freight traffic generation and distribution are performed simultaneously. In the absence flow data, the volume of the generated freight traffic is estimated based on the freight volume produced and consumed by industries. Traffic distribution is performed in a separate step using a number of techniques, including trade models, gravity models, or linear programming.

If flow data are available, they are used to create base year commodity flow matrices. These data are generally census-type origin-destination data, where flows are expressed in vehicle equivalents or commodity tonnage. Unless the state has some type of data base of commodity flows, secondary type data are used to estimate freight flows. Some of these secondary data sources include (3, p. 20): Interstate Commerce Commission/Federal Railroad Administration one percent waybill sample; the Census of Transportation: Commodity Transportation Survey; the United States Department of Agriculture's Fresh Fruit and Vegetable Unload Reports; the Domestic and International Transportation United States Foreign Trade; and the National Motor Transport Data Base.

When flow data are not available, which is commonly the case, freight flows must be simulated. The freight traffic produced or consumed in a state is estimated from interactions among economic sectors using input-output analysis. When simulating freight traffic generation, it is assumed that industrial plants within the same sector have the same productivity, and that this productivity is directly correlated with employment rates. A productivity measure of tons of freight produced per employee is calculated for each industry. The size of industrial activity, measured by employment within a geographical area, and productivity measures are used to estimate freight tonnage. An input-output table of technical coefficients is used to estimate the amount of each industry's production used in other industries. However, input-output tables are usually prepared for the national level, where regional differences in factor prices are ignored. This may lead to inaccurate estimates of input requirements and output of local industrial plants (3, p. 25).

Three techniques were suggested for simulating freight traffic distributions. They include Trade Model, Gravity Model, and Linear Programming techniques (3). The report suggested conditions for deciding which of the three techniques is most appropriate for a particular situation. However, the general framework for distributing freight is similar in the three techniques. Freight traffic produced in an origin is distributed among competing destinations based on two variables. The first variable is the relative size of production at the origin to total consumption. The second variable is the impedance between the origin node and destination nodes.

Modal division is the process of assigning commodity shipments among origin-destination pairs to specific modes. Modal choice models are based on comparing modal performance measures and selecting the mode that has the best performance. The most used performance measures are transportation costs or rates, and total logistics costs (3, p. 43). Logistics costs are used to reflect service factors in the modal selection process. These costs include transportation costs, loss and damage costs, storage costs, pickup and delivery costs, and ordering costs, inventory carrying costs, and stockout costs. The main task in modal analysis then is to estimate the measures of performance used in the selection process, such as the unit cost or rates of competing modes. Unit costs are estimated using costing procedures for each mode. Some structured costing techniques were developed by public agencies for estimating rail costs, however, truck costing techniques are less available.

After determining modal traffic splits, traffic assignment is performed. Traffic assignment converts commodity flows into equivalent vehicle flows and assigns them to the modal transportation network. The report suggested use of computerized traffic assignment techniques developed for urban transportation, with little modification. The basis for selecting a route for a trip interchange is to minimize impedance (measured in travel cost or distance). To convert commodity flows into vehicle loads, it is necessary to determine the type of equipment and services most likely to be used for a shipment. The weight and/or the size of the shipment to be transported must also be estimated. Using information on equipment type, size of the shipment, and discussions with shippers and carriers it is decided whether the shipment is full or less than a vehicle load (truckload or less-than-truckload TL/LTL and carload or less-than-carload CL/LCL). Some factors that may be used are: shipment size and frequency; commodity value and other attributes; and the number of shippers involved in the movement (3, p. 74). Estimated vehicle flows are then assigned to the freight transportation network.

The transportation network is represented using nodes and links. Each link is assigned a speed, distance, and average daily traffic. Since most intercity truck freight is transported on rural highways, network links have no capacity constraints. This is based on the argument that most rural highways have traffic levels below their design capacities. Two techniques were suggested in the National Cooperative Highway Research Program report to assign freight traffic. They are PLANPAC/BACKPAC and UTPS, both of which are intended for urban transportation planning.

Although the technique developed by the National Cooperative Highway Research Program is very detailed and intended for general purpose applications, it is very difficult to apply. A number of alternatives were provided for approaching the different steps in the planning technique, but no clear methodology was explained for the users. Further, estimating freight traffic generated and attracted largely depends on relatively dated data (e.g., the 1977 Commodity Transportation Survey). The technique did not clarify the use of available rail and truck traffic flow data at the state level. An extensive list of assumptions undermined the estimation procedures used for freight distribution. Finally, it seems that the technique was a replica of the urban transportation planning process, and neglected the characteristics inherent in freight transportation. Much of the data required for conducting the modal division analysis for example are very hard to obtain in freight transportation, while such data are available for passenger transportation.

Data Requirements

The data required for the freight planning procedure presented in this report are summarized as follows:

- Commodity flow data: use available sources. If commodity flows are unavailable use: industry production and consumption, productivity, employment, input-output coefficients
- Modal performances: time and cost parameters related to commodity attributes
- Network attributes: network configuration, link parameters (speed, length, average daily truck traffic)

2.1.2.3. Kansas Transportation Planning Model (15)

The purpose of this study was to develop a procedure for estimating highway commodity flows and ESAL (equivalent single axle load) values in Kansas. The study focused on the highway mode and was limited to five agricultural commodities: wheat, corn, sorghum, soybeans, and boxed beef. The study relied on secondary commodity flow data from published sources in the State of Kansas. The original data were assembled from mail surveys, telephone interviews, and some site interviews. The data on grain movements provide percentages of truck shipments from origins within the state to in-state and out-of-state destinations. Truck shipments between origin and destination pairs were estimated using commodity production and the percentage of truck shipments for that commodity. Data on boxed beef distribution were based on a 1985 study at Kansas State University of shipment records of these commodities. The study found that boxed beef was transported exclusively by truck. About 12 percent of the total beef produced in Kansas was also consumed in the state, while the rest was shipped by truck to other states.

After adjusting the commodity data to the year 1989, estimated commodity flows between origin-destination pairs were converted to truck units. The study was intended to develop procedures for estimating vehicle equivalents based on commodity attributes and transportation requirements, but fell short of this objective. Arbitrary values of commodity weight and size units per vehicle were used to convert estimated shipments to equivalent truck trips (850 bushels per truck for grains, and 44,000 lb. of boxed beef per truck).

The study used a microcomputer-based urban transportation planning program developed by the Federal Highway Administration, Quick Response System II (QRS). The program was used to find the shortest time paths and to assign truck trips to these paths. The study used a statewide highway network developed by the Kansas Department of Transportation. The base network consisted of 202 transportation analysis zones and 2,200 links. The analysis zones represent 105 counties and 68 external stations where state highways cross state borders. Three networks schemes were used to represent the state highway system to eliminate the sensitivity of results to travel time.

The first network was based on a State Transportation Plan (STP) classification (A-E), (A) represents interstate routes, and B other primary routes. The second network was a toll facility. The third network was based on terrain, using "percent no passing" as a proxy for the terrain. These three networks were developed for the assignment of originating, terminating, and intrastate truck flows (a total of nine networks). Results of total truck traffic, were weighted from the three networks subjectively using 50 percent of state transportation plan network trips, 30 percent of toll network trips, and 20 percent of terrain network trips. The assigned truck volumes were plotted as bands on a map of state highway network. Band widths of these plots represented truck traffic density on the state highway network. The study did not validate estimated truck flows.

This study fell short of achieving its objectives. Vehicle equivalents were arbitrary selected not estimated from commodity attributes and transportation requirements, as was initially intended. When estimating the distribution of truck traffic external to the state, exit/entry points on state borders were used to represent production and attraction centers outside the state. However, impedances on paths between these nodes and internal nodes do not reflect actual impedances to the final origins and destinations outside the state. Thus, distribution results will be biased due to border nodes closer to the state's production and attraction zones. Another potential source of error in the procedure is the use of different networks based on incompatible criteria for assigning traffic. Results from these networks were given subjective weights to estimate the final traffic assignments.

Data Requirements

The study relied on existing data sources from the Kansas Department of Transportation, which assembled a commodity flow data base from a statewide survey. The transportation network was also developed by the Kansas Department of Transportation. The network file consisted of node and link, terrain, and travel times. The remaining major data element was commodity vehicle equivalents. To reiterate, the study used arbitrary values of vehicle equivalents.

2.2. Data Requirements

This section addresses the data requirements for freight transportation planning models identified from the literature review. The data requirements identified for each study reviewed in section 2.1. are summarized and aggregated into similar data groups. The first part of this section provides a review of the data requirements identified by a National Cooperative Highway Research Program study conducted in 1977. The second part of this section provides a general summary of freight transportation planning data requirements. It takes into consideration the changes in freight modeling capabilities and a level of analysis at the state level.

2.2.1. Freight Data Requirements for Statewide Transportation Systems Planning (7,8)

The purpose of this study was to identify the data essential for freight transportation planning. Five types of planning activities were considered. They included demand forecasting, modal choice, network analysis, economic evaluation, and impact assessment (7, p. 3). The criticality of the data elements was based on the availability of data and the frequency these data are required in statewide freight transportation planning. Most data deficiencies were found in the following areas:

- Commodity flows and traffic flow data. The information necessary to conduct freight transportation planning is more than traffic volumes. Commodity flows, in addition to volumes, identify the commodity shipped, the origin of the shipment, and the destination of the shipment. These data are still scarce, especially in the trucking sector.

- Routing data. These data provide information on the highway routes used by transportation carriers between given origin-destination pairs.

- Modal performance data: rates and tariffs; transport level of service; and unit costs. These data are essential to estimate the freight traffic share of competing freight transportation modes.

The approach to determine data needs was carried in the following manner (7, p. 5):

1. Identify the issues facing states in freight transportation planning. Five states were selected for site visits (California, Connecticut, Iowa, Maryland, Wisconsin) to identify issues and collect information on planning methods and data.

2. Inventory the planning methods through interviews with public and private agencies and a review of the literature.

3. Determine data needs based on the type and purpose of planning activities (outcome-oriented needs) and the data requirements for the planning methodologies (process-oriented needs).

4. Identify and list available data sources.

5. Propose strategies to improve data by comparing the data requirements to the available data.

The approach followed in this research represents a methodology to accurately assess freight transportation planning data needs. Since this research was conducted more than 15 years ago, however, it does not address some current issues in freight transportation planning. These changes are discussed in the following paragraphs before discussing the results of the National Cooperative Highway Research Program studies.

Many issues facing state departments of transportation when the study was conducted in the early seventies are no longer valid or have evolved into more complex and challenging issues. Sweeping changes in the transportation industry were caused, in part, by the regulatory reforms of 1980 and by the 1991 Intermodal Surface Transportation and Efficiency Act. These changes not only affected the structure of freight transportation, but also the role of government agencies at the federal and state or local levels. Modal relationships were one of the major changes during this period. The restructuring of the rail networks, especially in the northeastern and midwestern states, resulted in extensive line abandonments in many states. The states were faced with "service-preservation" issues, which led to states' involvement in rail financial assistance programs to alleviate impacts of rail line abandonment (3).

In the motor carrier industry, new distribution strategies such as Just-in-Time (JIT), in addition to rail line abandonments, increased reliance on trucking. The trucking industry, especially the Truck Load (TL) carriers, saw major changes in the number of carriers and the range of rates and services offered. States' roles in providing for and planning truck highway needs and enforcing safety regulations were further complicated. States are still divided on the extent of intrastate trucking regulations. There are also relatively new issues concerning truck size and weight limitations, and Long-Combination-Vehicles (LCVs), that constitute potential state involvements. The adoption of state-level LCV networks will not only affect modal traffic shares, but also, highway safety, design and maintenance of highways, and the economic competitiveness of the states.

In addition to changes in freight transportation planning issues, coupled with advancements in modeling capabilities have resulted in new freight transportation planning tools. These new methodologies have different data requirements from the data assessed in the National Cooperative Highway Research Program reports of 1977.

The most frequent issues facing state DOT's in the 1970s identified in the National Cooperative Highway Research Program reports were (7, P. 7):

1. Line-haul. These issues involved intercity movement of freight and included operational conditions and cost of the transportation facilities used in the movement.

2. Infrastructure issues, which involved capital and rehabilitation projects of facilities.

3. Impact assessment issues, which involved estimating the impacts of changes to the transportation system due to infrastructure, policy, or economic climate changes.

4. Competition. Competition includes carrier issues as market entry, routes, and services.

5. Terminal. Terminal issues involve freight handling at origin or destination.

6. Intermodal. Finally, intermodal involves transfers between modes and modal competition. It should be noted here that the intermodal issue has a higher priority now after the enactment of the recent transportation policy.

Major classes of data to address the above issues were identified, according to the urgency of the need, into essential data and optional needs. The requirements were categorized by mode, however, they can be summarized into five main elements as follows, in order of importance to the freight planning process (7, P. 37):

1. Traffic Flow Data
   These data include commodity production and consumption; commodity flows between origins and destinations; traffic flows by mode; import-export shipments; and the transportation routes used.

2. Carrier Data
   These data include carriers' financial and operating statistics.

3. Shipper Data

   The data on shippers include plant location and production; location of markets and supplies; and the transportation and handling requirements of the product.

4. Physical and Operating Data

   Network data include an inventory of link and node transportation facilities; the conditions of these facilities; the operating characteristics and limitations; volume-capacity ratios of these facilities; and the costs of operating these facilities.

5. Impact Data

   These data are required to estimate the impacts of transportation decisions. They include performance measures to estimate environmental impacts; economic impacts; energy related impacts (relative use of fuel); and safety impacts.

It can be noted from these five points, that commodity flow data had the highest priority and urgency among the data required to advance freight transportation planning. Impact data, which were listed last on the list, has, however, been receiving more attention recently. One challenge caused by the 1991 Intermodal Surface Transportation Efficiency Act is to develop performance measures for system monitoring. Statewide transportation plans not only consider the intermodal elements of the transportation system, but must develop performance measures to assess how this system is performing over a long-term period. Performance measures will be used to justify transportation projects funded with federal or state monies.

2.2.2. Summary of Data Requirements (state-of-the-art)

As states approach freight transportation planning in a formal framework, essential data elements crucial for the success of their planning efforts must be identified. Although data requirements vary with the type and level of analysis, adequate commodity flow data are essential for transportation planning at all levels. This is where improvement is most needed, as it is particularly evident in the trucking sector. Truck traffic data in most states, for example, include axle counts, with little coverage of commodities carried and the origin and destination of shipments. As a result, it is difficult, if not possible, to adequately model truck traffic flows at the state level.

Since truck traffic flow data are scarce, indirect measures for estimating these flows must be substituted for the primary data. These estimates can be made using economic base data, the relatively reliable rail data, and shipper and carrier surveys. States can develop a survey data base covering the commodities shipped in the state and the freight transportation mode of carriage. Information on physical road conditions is relatively available since most states have adopted pavement maintenance management systems.

At the state level, there is, minimally, a need to know what products are important to the state economy, the locations of the production and consumption of these products, the transportation modes most likely used to move these products, and the transportation facilities used for these movements. At the microscopic level--corridor-level analysis-- detailed information about the state's economic base is required. The type, number, and size of industrial plants must be identified. Further, the analysis must provide for a detailed assessment of the transportation infrastructure at the corridor-level. Detailed network information such as physical and operational parameters of highway links must be included in the analysis.

The end result of the planning process is to estimate impacts under future scenarios. There are readily available methodologies to predict the number of extra auto trips caused by new land development, but no such assessment techniques are readily available to forecast freight transportation. To assess the impacts of changes in the freight transportation system, planning agencies must have knowledge of the economic base in their states and distribution and logistics factors pertaining to major economic sectors. These data are examined further in chapter 4 and are compared with available data sources.

2.3. Conclusions

A review of the literature revealed that the lack of appropriate commodity flow data is a critical issue in freight transportation planning. This problem is further compounded in the forecasting of truck traffic where a clear shortage in commodity flow data exists. Since network models consider freight transportation demand and distribution to be exogenous, they assume that distribution factors are represented in commodity flow matrices. Inadequacy of these flow matrices will affect the quality of the results generated from these models. There is also a shortage of practical planning tools to study truck commodity flows. Applying network or spatial price equilibrium models to predict truck traffic distribution requires extensive modal performance data. Such applications, however, may be too theorétical and data intensive for state needs. Applications of existing freight models have been, at best, general. Results were not properly validated or utilized in an intermodal freight transportation plan.

Many of the weaknesses in modeling capabilities in freight transportation planning are attributable to data availability. The methodological tools developed for freight planning are fairly easy to apply when appropriate data are available. The difficulty, however, lies in tailoring these methodologies to a specific planning problem given limited data.

Furthermore, many complexities in modeling freight transportation demand can be reduced by the modeling approach. Previous studies incorporated the transportation demands of several commodities and assumed these commodities to compete for capacity on transportation links. This approach is appropriate for the passenger-oriented urban transportation planning.

However, as shown in the case study, most state's economies are made of few sectors. In addition, capacity is not a major issue when studying intercity freight. The analysis of freight flows can then be broken down by individual commodities.

CHAPTER 3. PROBLEM STATEMENT

The research problem addressed in this dissertation is the development and application of truck freight planning models at the state level. The tasks in this research can be categorized in three main areas: 1) assessment of the data requirements to conduct freight transportation modeling; 2) development of a truck planning procedure based on state-of-the-art freight transportation modeling tools; and 3) application of the procedure to a case study consisting of a selected subset of commodity groups in the State of Iowa. This chapter is divided into three sections: 1) a general description of the research mission, 2) data assessment, and 3) case study development.

3.1. General

The approach followed in this research was one responding to a growing need in the area of state level freight transportation modeling techniques. There is an evident shortage of practical planning tools for predicting truck commodity flows. Furthermore, a literature review of state-of-the-art freight planning modeling techniques has revealed a clear lack of state level applications of developed methodologies. The theoretical premises upon which most of these model were based, combined with acute freight data deficiencies inhibited efficient application of freight planning models. For this research to add a valuable contribution to truck flow modeling, it must demonstrate its practical value. That is, given the available data sets at the state level, develop a macro level truck commodity distribution and assignment technique. The technique is not developed in isolation from the freight data predicament. It is also responsive to the transportation planning decisions at the state level. An example of assessing the impacts of changes to the transportation system is included in the methodology.

At a minimum, the state should be able to identify and quantify the major truck commodity flows in the state. A comprehensive inventory of the economic sectors in the state that have significant freight production potential is a first and important step in the planning process. The results of the inventory analysis are locations of freight producing industries within the state, the commodities produced and/or consumed within these sectors, and an understanding of the distribution patterns of these commodities (i.e., market and supply locations).

As major commodity shipments are identified, potential infrastructure impacts can be investigated. Commodities that are likely to use the trucking mode are the ones that will most likely have the greatest impact on the highway infrastructure in the state. Similarly, changes of transportation level of service on a highway link will affect transportation options of commodities that use this link in their shipments. In the absence of adequate modal performance data and modal decision models, the research uses available rail commodity flows to estimate potential truck traffic. The process is not absolute, but if carried over a number of years to obtain representative shipment samples may produce reasonable commodity modal split estimates. The analysis is supplemented by secondary data sources including the census data and the Iowa truck weight survey.

In conclusion, this research investigates and considers the inherent characteristics of freight transportation planning problems. The literature review clearly shows that traditional urban transportation planning concepts are inappropriate for freight transportation planning. Two concepts are utilized in order to simplify the model, unconstrained highway capacities on intercity links and the decomposition of commodities. The analysis can be broken down to one commodity at a time, and considers major commodities.

3.2. Freight Data Assessment

The approach to assessing freight transportation planning needs is based on the data requirements of applying available freight transportation planning models to state level analysis. An inventory of available relevant data sets identifies potential uses and the shortcomings of these data sets. Unmet data needs are estimated by comparing freight planning data requirements with available relevant data sources.

The freight data element with the greatest deficit is commodity flow data. Commodity flows correspond to information on commodity shipments between origin-destination pairs in a transportation network. The data may be in the form of commodity tons shipments without identifying transportation modes used for the shipment. Commodity vehicle flows on the other hand, provide the origin and destination of the shipment, the mode used, and the number of vehicles used in the shipment. Commodity vehicle flows are available for shipments by rail in the waybill sample. By contrast, there is no national or state level data set of truck commodity flows.

In the absence of available truck commodity flow data, these data must be estimated using economic data and distribution modeling tools. Distribution models use commodity production and consumption estimates at nodes in a network and estimate a commodity shipment between each pair of nodes. These shipments are inversely realted to impedance on the links connecting these nodes. The three major tasks in these models are to: 1) estimate the amount of production and consumption at each node, 2) select an appropriate measure of link impedance, and 3) develop a function that estimates the quantity shipped between two nodes relative to the impedance between them. The data requirements for these analysis are economic data to estimate commodity production and consumption, and network data to estimate impedance.

The primary economic data that will be examined are input-output coefficients. These data define and quantify the interactions among sectors of the economy. These coefficients form the basis for estimating commodity requirements for industrial plants and personal consumption that add up to total commodity tonnage attracted to an analysis zone. The major element in network data is a measure of link impedances. Impedance may be measured using link distance, link travel time, or link transportation cost. Transportation cost is most appropriate for multimodal freight planning models to measure cost performance of competing nodes. For highway networks, however, travel time may be used to measure link impedance.

3.3. Case Study Development

The development of the case study must: 1) demonstrate a state level truck commodity distribution technique using available modeling tools and given available freight data sources, 2) identify and document the deficiencies in the data sets used and their impact on the accuracy of truck commodity flows estimated by the technique, and 3) serve as a macro level tool for analyzing truck commodity flows in the State of Iowa. The model must also, at a minimum, identify major commodity groups generated in the state, estimate the distribution of major commodity flows among internal and external locations, and identify the major highway routes that carry these flows.

3.3.1. Scope

The scope of the case study is defined in order to serve the objectives set forth in this section. The case study is delineated by geographical representation, commodities included in the analysis, and the transportation infrastructure elements included in the network.

3.3.1.1. Study Area

The study area is the State of Iowa. The truck planning procedure will estimate the distribution of the truck traffic originating or terminating in major freight generation locations in the state. The resulting traffic patterns will identify major truck traffic corridors of the state's major commodities. External locations that have substantial trade with Iowa are also included in the analysis. These external zones are represented with less detail than the locations within the State of Iowa. The combination of internal and external nodes make up the analysis zones that are represented by nodes in the transportation network

3.3.1.2. Transportation Infrastructure

The focus of this research is on a single mode, truck transportation, and hence only the highway infrastructure is considered. The highway segments connecting the nodes in the transportation network are represented by links. These links correspond to the primary highway network in the state. This network is comprised of interstate highways, United States highways, and major state highways. All possible direct highway links leading from an origin to a destination are evaluated to select the link with minimum travel time (shortest link). The shortest link is added to the network, while the rest of the links between that origin-destination pair are eliminated (i.e. only one link is used to connect any two nodes, when such a connection exists).

3.3.1.3. Shippers and Receivers

The set of shippers and receivers included in the analysis is delineated by major industrial sectors in the state. The analysis in this research is at the macro level. Commodities important to the state economy are selected based on employment data and observed commodity flows. Activity centers where these commodities are produced or consumed are identified. Inputs to produce the major commodities in the state are determined from input-output tables. These input commodities are also included in the analysis.

Since the case study serves as a vehicle to demonstrate the impact of using available data and modeling capabilities, only a subset of the state's major commodities is used. The two commodity groups selected are the 'food and kindred products' and 'machinery products'. These two sectors accounted for the largest employment in manufacturing plants in Iowa. The limited resources in time and personnel inhibit the inclusion of all freight producing sectors in the state. The procedure developed in the case study is, however, expandable to incorporate more industries and commodity groups.

3.3.2. Specific Tasks

The specific tasks followed in developing the truck distribution technique for the case study may be summarized as follows:

1. Obtain, arrange, and analyze available data. Through an ongoing research project for the Midwest Transportation Center, at Iowa State University, some data analysis had been performed for rail and truck traffic. This research will use and build on these data as required by the type of analysis to be performed.

2. Determine prevailing economic activity in the state by identifying industry sectors with substantial freight traffic generation or consumption potential that have the largest employment. Identify the commodities produced and used by these sectors.

3. Using the county as the analysis zone in the State of Iowa, locate activity centers for the major commodities identified in step 2, based on county employment levels in the State of Iowa.

4. Estimate the freight tonnage generated in all activity centers by industry for the major commodity groups. The freight produced is calculated using production rates of tons of freight per employee that are estimated from census data. The freight attracted to an area is estimated from consumption and industry input requirements. These requirements are determined from input-output analysis.

5. Perform simple input-output analysis to estimate: 1) input requirements for the state industries, and 2) the distribution of the state's production among other industries in the state, personal consumption, and the remaining as export to other states. Personal consumption is allocated to counties based on population. The commodity groups included in the analysis are expanded to include the inputs that are used in producing the major commodities.

6. Estimate the portion of commodities shipped by truck. The truck share of the total traffic originating in a zone is estimated as the zone's total freight tonnage produced minus the rail tonnage shipped from that zone. Similarly, the truck traffic share from the freight shipped to a zone is estimated as the its total freight tonnage attracted minus the rail tonnage shipped to that zone.

7. Identify market locations for commodities shipped to and from the state. Internal locations are represented by internal nodes corresponding to counties in the State of Iowa. External markets are represented by the states which have substantial freight shipments with Iowa. The results of these analysis are origin-destination matrices for each of the commodities included in the study.

8. Using the output from step (7) above, conduct traffic distribution analysis. The amount of freight tonnage produced in an origin is distributed among competing destinations with known impedance values. The impedance between an origin and a destination measured in travel time is estimated from average running speed on links and link distances. A gravity model is used to find the freight traffic distribution among origin-destination pairs.

9. Convert the estimated truck freight tonnage between origin-destination pairs into vehicle equivalents. The type of vehicle configuration used is determined from observed truck configurations in the available commodity flow and census data.

10. Develop a network of nodes and links to represent interacting zones and transportation links connecting them. Nodes in the network correspond to activity centers of counties within the state of Iowa, or the largest activity center located in states other than Iowa that are included in the analysis. Links in the network represent highway segments directly connecting origin and destination pairs of nodes. Links are directional to allow using different travel times in both directions of travel.

11. Assign the estimated truck traffic to the highway network based on the least travel time. Input to this step are the travel times on the transportation links. The total truck volume assigned to a link is calculated from the sum of individual commodity flows assigned to that link.

12. Validate assigned traffic with observed truck traffic at selected locations. The Iowa Truck Weight Survey and truck volumes from traffic counts will be used for the validation. The computed truck shares in the commodity shipments analyzed are compared to truck shares observed in the 1989 truck weight survey and extended to the 1991 survey.

13. Document research findings and conclusions. Identify problem areas in this research and future recommendations for improving the freight planning process at the state level, especially in the area of commodity flow data.

CHAPTER 4. DATA ANALYSIS

The purpose of this chapter is to assess the data requirements for conducting freight transportation planning. The chapter is divided in four main sections: 1) summary of data requirements; 2) summary of available data sources and potential uses; 3) unmet data requirements and recommendations for data improvements; and 4) a detailed description of available data sources used in the methodology.

4.1. Data Requirements

The data requirements summarized in this section are based on the review of the state-of-the-art freight planning tools and the proposed methodology for the case study. Some general data requirements can be established for the freight planning process, but various issues, levels of analysis, and analysis tools impose varying requirements. The discussion will focus on statewide truck freight planning issues and the data requirements.

4.1.1 Economic Base Data

A majority of network equilibrium models developed for freight transportation planning assumes that the distribution patterns of freight flows are available in the form of commodity origin-destination matrices. Some of the models reviewed, however, have economic sub-models to estimate production and demand based on some measure of the economy, e.g. the GNP. A correlation between freight generated with national economic indicators (GNP or GDP) will disregard specific trends in a region or a state. Therefore, a more detailed consideration of the economy is required. Economic analysis should identify the major economic sectors in the state, the products produced or demanded by these sectors, and the locations and sizes of industrial plants.

The economic data requirements can be summarized as follows:

1. Commodity production and consumption
    Economic sectors delineated by industry classification (SIC codes)
    Plant location and size for each sector by county
    Measure of productivity per unit size of establishment (e.g. tons produced as function of employment)
    Products (commodities) produced and consumed by sectors (input-output model)
    Input-output coefficients in proper units (tons)
    Product classification: raw material, product of manufacturing, or for consumption
    Population by county and consumption per capita by commodity
    Economic growth and future fluctuations in demand and supply

2. Commodity attributes and market factors
    Commodity value (Dollar per unit size or weight)
    Market locations for supply
    Market locations for demand

4.1.2. Transportation Network Data

The transportation network in freight transportation planning refers to the modal freight transportation infrastructure and services. There are five freight transportation modes: rail, truck, waterways, pipeline, and air. There is, however, a wide range of services and subgroups within each mode. This research focuses only on trucking. The highway infrastructure used by trucks is owned and operated by public agencies and is shared with other transportation users as contrasted with the private ownership of the rail infrastructure. The transportation network concept uses a node-and-link configuration in which nodes correspond to point location of transportation facilities or shipping activity. Each node may correspond to the center of an analysis zone dictated by the level of the planning procedure, economic and population densities and locations, and available data. Links in the network correspond to line-haul transportation facilities that include physical and service factors. Both of the nodes and links in the transportation network have important attributes that are used in the modeling process. Typical attributes include physical condition, geometry, distance, and congestion. A network coding scheme is also necessary to represent link and node attributes. The network data requirements can be summarized as follows:

1. Physical characteristics
   Spatial distribution (connectivity)
   Geometry: lanes, limitations on size and weight
   Link attributes: length
   Condition of pavement

2. Operational characteristics
   Link attributes: speed, traffic volumes, congestion, safety.

4.1.3. Traffic Flow Data

Ideally, the level of commodity shipments among regions using different freight transportation modes would be available. However, a commodity flows data base does not exist. The lack of commodity flow data sets is more acute for trucking than other modes. As a result, truck flows are estimated using modal performance measures, if available, or using other methods, such as survey data. Even when truck commodity tonnage between origins and destinations are available to be used in the planning process, they must be converted into vehicle flows. The two main tasks to estimating truck flows are to obtain truck traffic share from total commodity tonnage and convert this truck share into appropriate vehicle flows. The data required for this process are:

1. Commodity flows
2. Commodity-mode relationships
3. Modal performance data: costs or rates, and service
4. Vehicle equivalents by commodity weight

4.1.4. Other Data

Additional information relevant to freight planning may be required in some instances. These requirements are largely implied by the planning issues undertaken. Examples of such requirements are state transportation policies, specific carrier information and their operations, and variables to assess indirect impacts of future transportation scenarios.

4.2. Available Freight Data

A detailed description of the data sources used in the case study are found in section 4.4 of this chapter. This section provides a brief summary in order to assess shortages in freight data.

4.2.1. Economic Base

There is an extensive list of available economic data, however, there are problems of fragmentation, level of aggregation, and coverage. Largely, economic base data are obtained from different census reports commonly published by the Department of Commerce. Local or state level data are less available and are not as well structured and reliable as national data sets. Available relevant economic data can be grouped as follows:

1. Economic indicators: GNP and more recently the GDP[1]
2. Industry statistics: income, expenditures, assets, productivity indices
3. Industry interactions: input-output coefficients represent the amount of interactions between economic sectors based on national expenditures. There is a lack of input-output coefficients at the state and local levels.
4. Labor statistics: national (Census of Manufacturers) and state
5. Population and income: national and state

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[1] GDP excludes incomes by U.S. companies and individuals earned abroad.

4.2.2. Transportation Network

Most of the elements of the freight transportation network data are available. However, there no unified model to represent the highway network, whereas such models exist for rail and waterways. Some states have developed their own network models, but not necessarily for freight transportation planning purposes. In Iowa, for example, there is no network model readily available for the state's highway network. It should be noted, however, there are some national highway networks developed by the private sector, e.g. TransCAD (32). In addition, state Pavement Management Systems include some highway network. These networks, however, are too detailed for statewide applications. While attributes of links and nodes can be easily obtained, building a state highway system network requires an extensive coding effort.

4.2.3. Traffic Flows

1. Commodity flows
   - Currently not available. Latest Commodity Transportation Survey was in 1977
2. Vehicle flows
   - Rail: available (waybill sample) at both of the national and state levels
   - Truck: only truck counts and truck weight surveys
3. Vehicle classification
   - Limited survey data (Truck Inventory and Use Survey)

4.3. Unmet Data Needs and Recommendations for Improvements

The most critical element in unmet data is the commodity flow data. When commodity flows are not available, they have to be simulated using economic models. This will in turn increase the data requirements for freight transportation planning. If employment data are used to estimate commodity production, there must be a reliable measure of tons produced per employee. This can be achieved by using shipper surveys or sample studies of representative industrial plants in each sector. To achieve acceptable accuracy, the grouping of industries must be studied carefully. Although for national freight studies a 2-digit Standard Industry Code (SIC) might be appropriate, state level studies require a more detailed grouping to at least the 3-digit SIC codes. For example, the productivity of workers in meat packing plants (SIC 201) is different than that of workers in grain mills (SIC 204), even though both sectors are in the same group of food and kindred products (SIC 20).

Demand estimates are more critical since they capture the interaction among the different sectors in the economy. There are three major problems with existing input-output coefficients: 1) the level of details in sector representation and eventually aggregation of coefficients; 2) the use of national level data sets to construct input-output tables ignores regional differences; and 3) the coefficients may not reflect current production technologies. The latest available input-output coefficients for the national economy date back to 1977. Extending these national level coefficients to state and local levels will ignore regional differences. In addition, these coefficients represent values of inputs and outputs, making it difficult to accurately estimate the actual tonnage of these requirements.

The other area where lack of data is evident is modal analysis. There is a need for practical modal performance models, mainly costing models. Existing costing models have extensive data requirements and do not reflect variations in carrier operations that affect the total cost or rate. A more useful tool is to develop commodity-mode relationships, which will estimate the mode of transport used by a particular commodity as a function of length of haul.

Breakpoints in length of haul could be established where a commodity might favor one mode over the other. The modal analysis data are less urgent when traffic flows are available.

In conclusion, standards are needed to upgrade the freight planning process to comparable reliability and practicality levels of urban transportation planning. This will enable transportation planners to fully utilize freight transportation planning tools to assess impacts and estimate future needs and trends. Standardization should begin at the state level. A discouraging factor in embarking on freight planning is the high cost of collecting freight data. Data costs may be minimized by good organization, accurate assessment of data needs based on planning issues and purpose, and utilization of available data sets to the fullest.

One major area for improvement identified by this research is the Iowa truck weight survey. With little additional cost, the survey can be improved to secure better coverage of truck freight movements. The location of survey stations is very important in determining its coverage of truck traffic in the state. In order to obtain a representative sample of the state's truck traffic, these locations must be positioned along major highway routes. Major portal points, locations of the intersections of major highways with state borders, are ideal to survey truck traffic trends. Only a few internal stations are needed. Sampling in the 1989 weight survey was performed, primarily, on minor highways near urban areas within the state.

Another improvement in the truck weight survey is to further the use of this survey by designing standard forms for collecting and entering the data into a DOT database. These data can be validated and expanded using truck counts at the same locations of the survey. Furthermore, the timing for the survey should be changed to capture seasonal trends in truck traffic in the state.

In terms of economic base data, the state has a good number of published periodical data sources on agricultural sectors. However, the manufacturing sector is not included in these data sets. One practice used in other states that can benefit Iowa is to conduct a one-time shipper survey. The survey can obtain information on the types of commodities produced or demanded, shippers marketing policies, and transportation options and needs. The information obtained from the survey can also assist the state in economic development efforts. Deficiencies in the transportation system that have the greatest impact on shippers can be identified and given higher priority in order to preserve existing businesses and attract new activities.

Knowing the high financial and personnel burden of collecting new data, available data sources must be utilized to the fullest. There are numerous sources of data that can be used in freight transportation planning. These data sets are fragmented. Different agencies are responsible for collecting economic and transportation data. The resulting data sets covering different sectors, are compiled over different time periods, using different geographical units for reporting purposes and thus have different levels of aggregation. Innovative approaches are necessary to develop guidelines for making these data homogeneous, and for transforming national data to regional and state levels.

As a result of the 1991 Intermodal Surface Transportation Efficiency Act, states are including freight transportation planning as a basic part of their plans . The first step in these efforts must be to set realistic goals and objectives for the planning process, which must be designed to enhance the way critical decisions are outlined in state goals. The next step would be to identify the data requirements. Finally, data assessment (comparing needed data to available data) is conducted. It may be a good practice to designate a "data coordinator" to ensure intraagency coordination and to contact state and private agencies for potential data sources. The private sector (shippers and carriers) maintains extensive data on its operations. If these private parties are involved in the freight planning process they may provide valuable data.

4.4. Description of Available Data Sources

4.4.1. Rail Commodity Data

Data on rail movements in the State of Iowa were obtained from the 1989 confidential waybill sample. The waybill is a one percent sample of all railroad movements within the United States. It is prepared by the Interstate Commerce Commission and is expanded to reflect rail traffic trends during the year. The waybill sample is a comprehensive source of information on rail commodity shipments. Some of the information provided in the sample includes: 1) the type of commodity shipped, 2) the origin and destination of the shipment, 3) the weight of the shipment, 4) the type of shipment (railcar or intermodal, 5) the carrier (railroad), 6) and interlining railroads. The confidential version of the waybill sample provides additional information that might have been otherwise withheld to protect shippers' identity at the county level. Portions of the 1989 confidential waybill sample containing rail traffic originating from, terminating in, or passing through the State of Iowa were obtained from the Interstate Commerce Commission on a computer tape.

4.4.2. 1989 Iowa Truck Weight Survey

The survey was conducted by the Iowa Department of Transportation biannually at various truck weigh stations in the state. In 1989, sampling was performed at 17 locations, as shown in Figure 1. Although these locations are not ideal for a representative sample of truck traffic, they cover most of the interstate highways within the state. Although truck weight is the

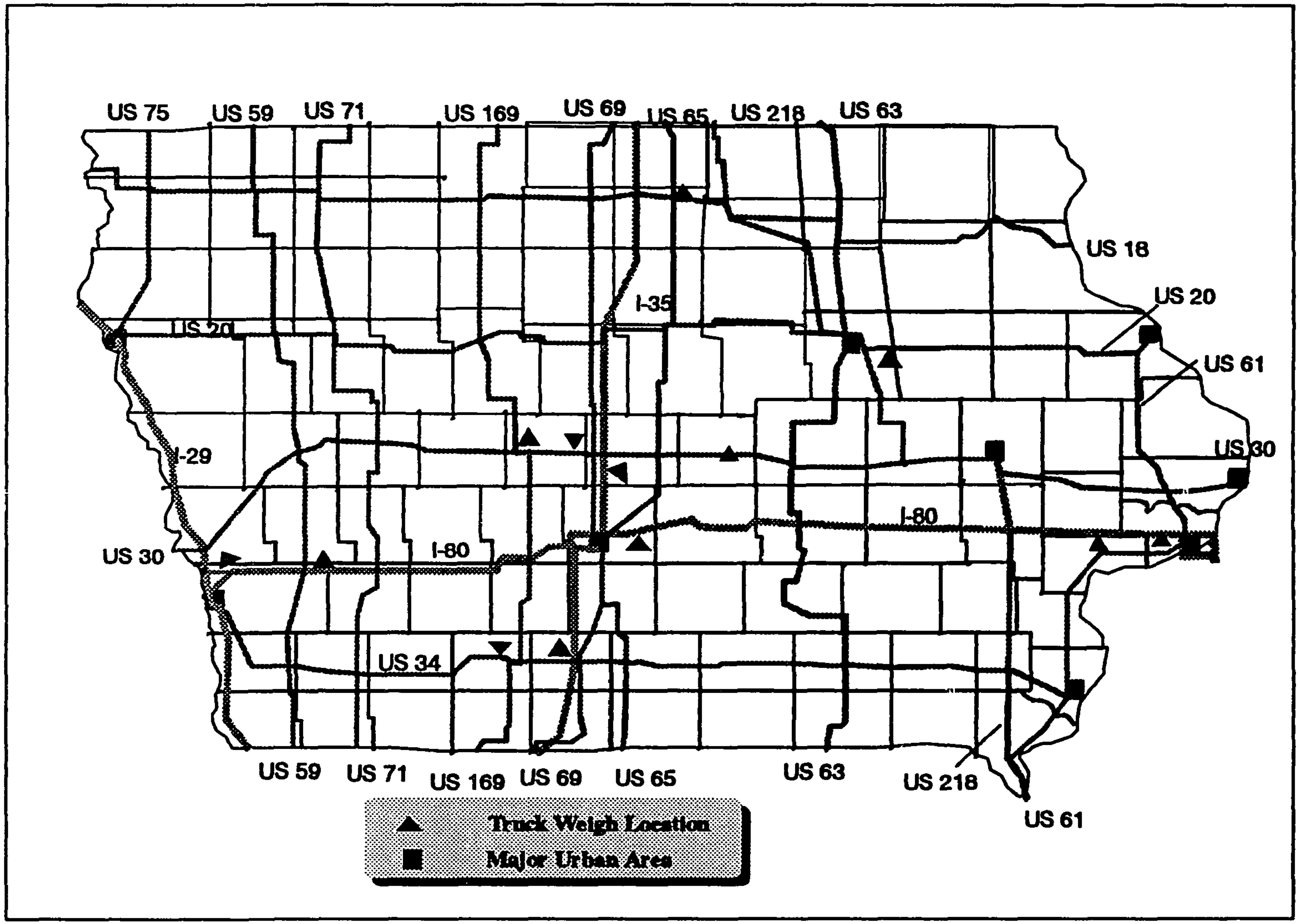

Figure 1 Iowa Major Highways and Locations of Truck Weight Survey

focus of this survey, additional information on the shipment is recorded manually on standard field forms corresponding to each truck. The information includes the commodity carried and the origin and the destination of the shipment. The weight data, which include the vehicle classification (identified by vehicle type and the number and configuration of its axles) and the commodity codes are kept in a computerized format. The origin and destination information of truck shipments were coded and added to the vehicle records in computerized relational data base (PARADOX). The primary limitation of the data from the truck weight survey that is conducted only during the summer months (May through July) (16). The Iowa DOT does not use these data for any truck traffic analysis.

4.4.3. Economic Factors

Employment Data Confidential employment levels prepared by Job Service of Iowa were obtained from the Rural Data Project in the Department of Economics at Iowa State University. These data provide the number of workers employed by establishments as classified by a four-digit SIC code in each of Iowa's counties. These employment numbers are used to estimate freight traffic productions by industry group and county.

Agricultural Data The Iowa Department of Agriculture publishes reports on crops and livestock productions by county. The 1989 Iowa Crop County Estimates (17) provide information on the area of farms by crop type, the yield per acre, and the total county production in bushels or tons for each of the 99 counties in the state. The state is divided into nine districts for the purpose of reporting agricultural statistics. The 1989 Iowa Livestock County Estimates (18) similarly provide information on inventory and marketings of hogs, cattle (beef and milk), and sheep in the state by county.

4.4.4. Census of Transportation- Truck Inventory and Use Survey (19)

This survey provides data on the physical and operational characteristics of trucks by state of operation. The data in the survey are based on a sample of private and commercial trucks licensed in each state. The survey provides the following relevant information:

- Major use and product carried
- Body type (single unit, tractor trailer combinations)
- Range of operation (local, short range: 50-200 mi, long range: > 200 miles)
- Vehicle size

4.4.5. Census of Transportation: Commodity Transportation Survey (20)

The Commodity Transportation Survey was prepared every five years by the Bureau of the Census at the Department of Commerce. It was discontinued because of a decrease in data reporting, particularly in the motor carrier industry (the last edition was in 1977). The survey, nonetheless, provided a comprehensive data base on freight traffic movements within the United States. Many of the recent studies dealing with freight transportation planning use data from the Commodity Transportation Survey for base year freight traffic distribution (see, for example, National Cooperative Highway Research Program Special Report # 260, 3). However, this may result in a misrepresentation of the changes in the freight traffic distribution patterns brought about by deregulation.

CHAPTER 5. METHODOLOGY AND CASE STUDY

The purpose of this chapter is to describe the proposed methodology and demonstrate the methodology using the Iowa case study. The impact of data availability on the methodology used to estimate truck traffic distribution will result in some modeling variations among specific states. As a result, the first part of this chapter outlines a general framework of the procedure for truck traffic distribution and assignment. The method recognizes and considers the available data sources at the state and national levels and demonstrates how changes to the transportation network will affect truck traffic levels. The remainder of this chapter covers the application of the truck planning procedure to Iowa.

This chapter consists of seven main sections. Section 5.1 describes the layout of the methodology and the general elements of the truck commodity distribution and assignment technique. Section 5.2 provides a brief summary of major economic sectors and their commodity shipments in the state. Section 5.3 describes the delineation of analysis zones and the representation of the transportation network. It also includes a description of the shortest path algorithm. Section 5.4 covers the calculation of freight tonnage produced and attracted in each analysis zone. Section 5.5 describes the distribution of freight tonnage by estimating truck commodity tons shipped among nodes in the network. Section 5.6 describes the assignment of truck traffic to highway links. This section also includes an example on conducting sensitivity analyses, by changing travel time on some network links and estimating resulting truck flows. Finally, section 5.7 discusses the validation of the truck distribution and assignment results. Estimated truck volumes on network links are compared to actual truck counts on comparable locations on the state highway network.

5.1. General Layout of Methodology

This section briefly describes the technique developed for the prediction, distribution, and assignment of truck commodity flows. The main steps in the technique can be summarized as follows: 1) identify production and attraction zones and develop a simplistic network of nodes to represent analysis zones and links to represent highway links connecting them; 2) calculate the commodity tonnage produced or attracted at each node; 3) estimate the portion of nodes' commodity production and attraction carried by truck; 4) estimate the commodity tonnage shipped between nodes in the network (traffic distribution); and 5) convert truck commodity tons into equivalent number of trucks and assign these trucks to highway links. These steps are shown in Figure 2. It should be noted, however, that the first step in developing freight planning models is to conduct an inventory of relevant economic and transportation data in the state. The methodology must take into consideration available data sets and their limitations.

While there is an evident shortage in truck commodity flows, the waybill sample provides a reliable data base on rail commodity flows. Relevant socioeconomic data that can be used in freight transportation planning are also relatively ample at both of the national and state levels. For example, labor and population statistics are generally available at the county level. These data can be used to estimate the amount of freight generated in a geographical area and subsequently predict commodity flows. A major effort in using these data sets is to combine fragmented data sources intended for different purposes, and hence, follow different formats.

This leads to an alternate approach to estimating truck commodity flows. The technique developed in this research uses available socioeconomic data to estimate the freight tonnage generated in an area. The portion of freight tonnage carried by truck is estimated as the total

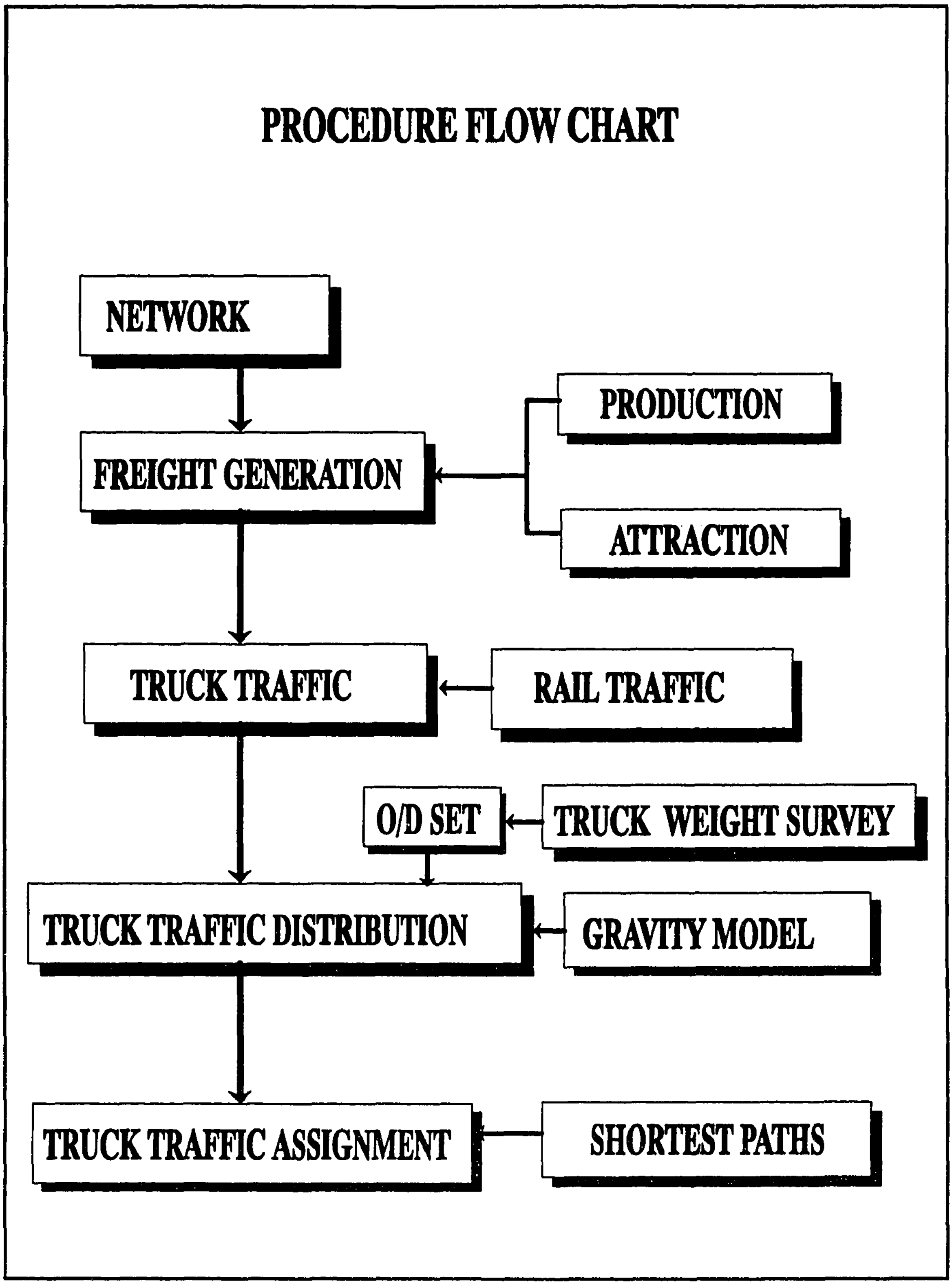

Figure 2 Procedure Flow Chart

freight tonnage generated, less the rail tonnage originating or terminating in an area. Contrary to structured (formal) modal analysis methods, this approach uses available data, has minimal data requirements, and may yield comparable results, especially in the absence of reliable modal performance data. Although this method is approximate it should capture average modal shares in the major commodity groups in the state. Furthermore, the level of analysis addressed in this research is at the macro level. It is intended to predict truck commodity flows that make up a significant portion of the total state truck traffic, rather than account for all truck shipments in the state. This concept of capturing major shipments is further explained in the following sections.

The first element of the truck planning procedure is an inventory of the economic sectors in the state that have substantial freight generation. Major commodities used or produced by main economic sectors are identified as those commodities which account for 80 to 90 percent of the state's total freight generation. The scope of the planning problem is narrowed down to include the major commodities that account for most of the tonnage shipped within the state. The commodity flow analysis showed a clear concentration (80 to 90 percent of the state total freight tonnage) in a few commodities (e.g., the top five). By examining the flow patterns of these commodities, it is possible to identify highway links essential for these flows. This information about the use of highway links will enhance the evaluation of alternative transportation projects. The following sections briefly describe elements in the truck transportation planning technique.

5.1.1. Transportation Network

The first step in the modeling process is to delineate the transportation network to represent freight generation zones and the transportation routes connecting them. The sizes of the analysis zones depend on the level of details needed in the analysis and available in the data.

For state level commodity flow analysis, the county is a logical starting analysis zone. County level data can then be aggregated to larger zones if necessary without loss of representation. External locations (areas outside the state boundaries) are represented with less detail. Some of the freight planning models reviewed aggregated all locations outside a state to one external zone.

Locations outside the state may be aggregated to a state level. A state is then represented by one or more nodes corresponding to major production, distribution, or consumption areas. Since the planning domain at the state level focuses on highway segments under state jurisdiction, the level of details in representing external highway segments is reduced. External locations are connected by paths leading from portal points on Iowa's borders to the centers of these external zones. These paths need not represent actual physical facilities. Instead, they are represented by paths with average impedance values that correspond to travel times.

Nodes in the network have attributes corresponding to the freight tonnage generated (production and attraction) in the zone represented by each node. Links have attributes of length, speed, travel time, and traffic volume (that can be used as a proxi for congestion if needed). The travel time on links is used to measure impedance, which can also be expressed using travel distance or transport cost on network links. Each link is identified by a beginning node and an end node. Links are directional, and therefore, two links represent both directions of travel on the same highway segment.

Part of the network analysis is to find the shortest paths connecting nodes in the network. The travel times on the shortest paths are used in the traffic distribution analysis. The links comprising these paths are used in the traffic assignment analysis. Finding the shortest paths in a network can be modeled as a network flow problem and solved using Linear Programming or

Dynamic Programming. However, the shortest path problem has a special structure, where the flow in the network is equal to one unit. Several available methods exist that take advantage of the special structure of the shortest path problem, and are readily available for network applications. Two of these methods are a tree algorithm (21, p. 251) and Dijkstra's algorithm (30, p. 46). These methods mainly involve a labeling system to keep track of the nodes and links added to a path, and a spanning method that, for a specified origin, determines the sequence of links to a specified destination.

5.1.2. Freight Traffic Generation

The freight tonnage generated in a particular area is the amount of freight produced and/or attracted in that area. The freight produced is generally made of products of manufacturing, natural resources (mining), and agricultural (crops and livestock). The freight tonnage attracted to an area is used as input to industrial plants, farm use (fertilizers, feed, and farm machinery), or for personal consumption. Input requirements refer to the commodities used in manufacturing to produce other products (output).

The amount of freight produced is correlated with plant size measured by employment levels in manufacturing sectors. The attracted freight tonnage for input requirements is similarly determined by using input-output analysis given the final output levels. The portion of the freight attracted for consumption is a function of population levels. Personal consumption expenditures are given in input-output tables for the commodities consumed. These expenditures are converted to commodity tonnage per capita using commodity values and population statistics for the bench mark year of the input-output table used. This process is carried out for all the major commodities included in the analysis.

Productivity data are needed to estimate freight tonnage from employment rates. If the state has conducted a shipper survey, such information can be directly obtained by establishing average production rates for different commodity groups. When productivity data are not available, estimates of productivity can be calculated from census sources, the Commodity Transportation Survey (20) and the Census of Manufacturers (22). The total freight tonnage shipped from a state is obtained for manufacturing sectors from the Commodity Transportation Survey. Corresponding employment levels for the same sectors are obtained from the state statistics in the Census of Manufacturers. If the state has historical employment data they can be used in place of the Census of Manufacturers data. An estimate of a sector's productivity is the tons shipped divided by the number of employees in that sector.

Initial productivity rates are computed for each industry group (3-digit SIC code). These rates are then modified to reflect recent changes in productivity and production technology by using published Department of Labor information (23). The most recent productivity index was based on 1987 statistics. The report provides productivity indices only for selected industries and does not cover all the products included in the state freight transportation plan. Average annual rates of change in productivity are computed from the productivity indices and projected to the analysis year. The modified production rates are then multiplied by corresponding sector employment levels in each analysis zone to determine the produced freight tonnage.

Freight attraction is the freight tonnage shipped to a zone, and will either be consumed directly, or used as input to an industry in that zone. Commodities shipped to the state must be allocated to these two categories. Traditionally, input-output analysis has been used to allocate freight tonnage to the economic sectors in a region. Input-output tables were developed to determine the interaction of various economic sectors at the national level. Sectors interactions are estimated from total expenditures of economic sectors in the national economy (24). These tables provide technical coefficients that represent the value of input industry required to produce a one dollar value of output industry. To use these tables, the values of commodities of the producing and consuming industries must be converted to tonnage. The total requirement for an industry sector will be the amount (tonnage) of its final output as estimated in an earlier step using that sector's employment levels. Personal consumption is allocated based on the zone's population and consumption rates in commodity tons per capita.

5.1.3. Estimating Truck Freight Tonnage

The total freight tonnage produced and attracted in each sector are tabulated for all of the zones. Next, the rail commodity flows compiled from the waybill sample are summarized into originating and terminating tonnage for these zones. The originating tonnage is the amount of freight (in tons) shipped by rail from a certain zone. Similarly, the terminating tonnage refers to the amount of freight shipped to that zone using rail. An estimate of truck tonnage is obtained by subtracting the observed rail tonnage from the total freight generated in an area. This approach was used because of the lack of modal performance data. In the case when modal division data for commodity groups are available, the total freight tonnage is allocated to competing modes accordingly.

The use of rail commodity flow data to estimate the truck freight tonnage is easy to apply if adequate rail commodity flow data exist. The confidential waybill sample may be required for state level analysis, since origin and destinations are expressed at the county level. The truck tonnage originating in one zone is roughly equal to that zone's freight production less the observed rail tonnage originating in that zone. The truck tonnage terminating in a zone is estimated similarly using freight attraction and terminating rail tonnage. In the case of Iowa, only two modes are involved to moving freight to final and intermediate destinations. Freight shipped by barge along the Mississippi has to be initially transported from counties to river ports using rail or truck.

It should be noted that modal analyses are performed before distributing the generated traffic in this research. They succeed freight distribution in the planning process as suggested by the National Cooperative Highway Research Program report 260 (3). This modification may improve the quality of the traffic distribution results since rail services may be an irrelevant option for some commodities and between some origins and destinations. For example, Russell et al., found that no boxed meat is carried by rail (15).

5.1.4. Truck Commodity Flows Distribution

The purpose of this part of the procedure is to determine the origin-destination sets for the state's major commodities and identify the major corridors over which these commodities are transported. The results of traffic distribution are directed flows of commodity tons from origin nodes to their destinations. There are three main elements to finding freight traffic distribution:

1. Identify a set of origin and destination nodes for each of the major commodities included in the analysis and the transportation links connecting them. Find the shortest paths between all origin and destination pairs and sum the travel times on these links in the path to arrive at a total path travel time.

2. Estimate the freight tonnage produced and attracted at these nodes. The attracted freight is the sum of freight for consumption and freight for input requirements.

3. Apply a gravity model to estimate the freight tonnage shipped between each pair of nodes.

The theoretical basis for the gravity model simply states that trips from an origin node will be distributed among competing destinations based on the attraction factors at these destinations and the impedance on the paths connecting this origin node to its destinations (25, pp. 116-118). The attraction factor of a destination (sink) node is a measure of that node's demand relative to the total demand of all nodes in the network and its relative proximity to the origin. The impedance factor is a measure that inversely relates the amount of traffic shipped between two nodes to a measure of impedance on the path connecting them. The path impedance is the sum of impedances on each of the links making up that path.

Impedance on a link can be expressed in terms of its length (distance), it's travel time, it's travel cost, or a combination of these variables. The impedance factor is the inverse of the impedance raised to an appropriate power, usually a power of one. For instance, if impedance is assumed to be a function of travel time and (t_{ij}) corresponds to travel time on a link connecting nodes i and j, the impedance factor for this link could be written as ($1/t_{ij}$).

An important assumption in distribution models, however, is that the demand and supply summed over the entire network are equal. These procedures were developed mainly for urban transportation planning dealing with moving a single commodity, passengers. In contrast, freight transportation planning involves a number of commodities with varying supply-demand patterns and transportation requirements. The balancing of supply and demand in freight planning problems should then be carried out for each commodity then summed up over the network. The difference between supply and demand for a certain commodity is the amount of export to or import from external regions. When dealing with partial networks, i.e. a state or a region, equilibrium is hard to achieve. This is more evident in this statewide planning problem. Only a few commodities and a subset of external zones are considered in the analysis. If adequate data are available, a larger set of external zones may be included in the analysis to account for the majority of external freight production and attraction.

5.1.5. Truck Traffic Assignment

The traffic assignment process estimates the number of trucks moving between origin-destination pairs and allocate these truck-trips to specific highway links. The results of the commodity flow distribution are a set of origin-destination matrices showing the commodity tonnage shipped between origins and destination. Although paths were used to compute impedance in the distribution process, the specific highway links that make up these paths were not identified. Further more, commodity flows have been, up to this stage, expressed in tons. These commodity flows have to be converted to appropriate vehicle flows.

Vehicle equivalents are needed in order to convert the estimated commodity tonnage to truck trips. These vehicle equivalents are obtained or estimated from available data sources, such as the Truck Inventory and Use Survey (19) and the Iowa Truck weight Survey. A vehicle equivalent corresponds to a particular class and size of truck and the weight (tonnage) for a certain commodity to make one truck load. Vehicle equivalents are commodity dependent and are functions of a commodity's density and its transportation and handling requirements. The information on vehicle equivalents, if not available through a state study, may be obtained from census data. The department of commerce publishes a Truck Use and Inventory Survey as part of the Census of Transportation (19). The survey data provide information on trucks used and commodities carried in individual states. Since commodity flows were computed on an annual basis, the calculated equivalent trucks are estimates of annual truck trips. The purpose of the freight transportation planning study will dictate whether annual or daily trips are appropriate traffic units. Planning issues dealing with long-term highway impact assessment might use annual trips. Whereas, proposed highway improvements and design projects will require truck daily trips.

There are two possible approaches to estimating daily truck trips from the estimated annual trips. The first simple approach is to divide annual trips by days of the year to obtain daily trips. The commodity flows that can be dealt with in this manner must have stable production and consumption year round. For commodities with seasonal volume levels the periods of highest flow levels should be identified and allocated the greatest portion of the annual trips. Daily average truck trips may be used for flows during off-peak seasons.

The estimated truck trips between an origin and destination are assigned to the highway links of shortest travel time. The shortest path algorithm finds the shortest paths connecting all origin-destination pairs. This algorithm may be developed using the methods described earlier in the transportation network section. If the state has a network model, shortest paths can be obtained from the model. The criteria for shortest path calculations is travel time that is based on a weighed link speed. The value of the speed can be generally related to link parameters such as: the facility type (interstate or other), speed limit on the link, traffic levels, geometry (terrain and number of lanes), and number of stops or delays. For the Iowa case study, congestion effects are dropped from the speed estimation since most highway routes in the state are rural and operate below their capacity.

The shortest path algorithm derives the optimal sequence of links and nodes used for a shipment between the origin and destination. The assignment routine keeps track of the amount of truck trips assigned to each link from the different commodity groups. The total link volume is then found by summing all its commodity volumes. The results of the traffic assignment may be tabulated or better represented on a state highway map.

5.2. Economic Base

5.2.1. Topography of the State's Economy (Major Sectors)

This section provides an inventory of Iowa's economic sectors. The purpose of this analysis is to identify the major sectors in the state that have substantial commodity production and attraction potential. Manufacturing sectors are identified by the Standard Industrial Code (SIC). The data in this section are used in following sections to estimate the tonnage of the major commodities that are produced or consumed in the state. The sectors included in the case study were selected based on their employment relative to the total employment in manufacturing in the state.

5.2.1.1. Manufacturing

Employment statistics by industry sector at the county level were obtained from the Rural Data Project, Department of Economics, Iowa State University. The data were compiled from confidential Department of Employment Services files for the year 1989. The total state employment in all sectors, including services, was estimated at over 1.1 million employees. The commodity producing sectors' employment accounted for about 20 percent of the state's total employment. Table 1 lists these sectors, which are mainly manufacturing related, arranged in descending order of the number of employees. Each of these industries represents an industry group, as indicated by the 2-digit Standard Industry Code (SIC). The percentages in the table are based on the sum of employment in the listed sectors, and not the total employment in all

Table 1 1989 State Employment by 2-digit Industry Group

SIC[1]	Industry Group	Employees	%[2]	Cum %[3]
20	Food and kindred products	44843	19.2	19.2
35	Machinery and computer equipment	44798	19.2	38.4
27	Printing, publishing	20793	8.9	47.3
34	Fabricated metal products	17949	7.7	55
36	Electronics, except computer equipment	15056	6.5	61.5
30	Rubber and plastic products	12434	5.3	66.8
38	Instruments	12070	5.2	72
37	Transportation equipment	11906	5.1	77.1
33	Primary metal industries	7406	3.2	80.2
24	Lumber and wood products, except furniture	6519	2.8	83
25	Furniture and fixtures	6025	2.6	85.6
32	Stone, clay, glass, and concrete products	5595	2.4	88
28	Chemicals and allied products	5438	2.3	90.3
23	Apparel	5120	2.2	92.5
39	Misc. manufactured products	5082	2.2	94.7
26	Paper and allied products	4754	2	96.8
1	Ag production- crops	2017	0.9	97.6
2	Ag production- livestock and animal specialties	1915	0.8	98.4
14	Mining	1840	0.8	99.2
31	Leather and leather products	908	0.4	99.6
22	Textile mill products	608	0.3	99.9
29	Petroleum refining and related industries	180	0.1	100
12	Coal mining	100	0	100
Total		233356		

1 Standard Industry Code
2 Percentage
3 Cumulative percentage

sectors in the state. The major manufacturing sectors in the state were found to be food and kindred products (SIC 20), machinery (SIC 35), printing and publishing (SIC 27), fabricated metal products (SIC 24), electrical machinery (SIC 36), rubber and plastic products (SIC 30), instruments (SIC 38) and transportation equipment (SIC 37). These industry groups together accounted for 77.1 percent of Iowa's employment in non-service sectors.

The largest two manufacturing sectors in the state, in terms of employment, are food and kindred products and machinery products. These two sectors are selected for the case study application. They each employ about 45,000 employees each, making up close to 40 percent of the total manufacturing employment. These industries are further analyzed to examine their sub-industries (three-digit SIC codes) relative employment size and their locations by county.

Food and kindred products industries have a wide array of products which include: meat; dairy products; canned and preserved fruits, vegetables, and sea foods; grain mill products (flour, cereal, corn starch, etc.); and bakery products. Employment levels for these sectors are listed in Table 2. Meat products has the largest employment among the food industries in Iowa, and accounted for about 53 percent of the employment in this sector, or 23,640 employees. The second largest food industry in Iowa was grain mill products, which employs 9,488 workers, or 21 percent of the food industry employment in the state. Dairy and bakery products accounted for 6.9 percent and 5.7 percent, respectively. Machinery production which had the second largest employment in Iowa includes the following industries (listed in order of employment): farm and garden machinery (36.6 percent), construction related machinery (23.6 percent), miscellaneous machinery (11.4 percent), refrigeration and service machinery (6.5 percent), and special industry machinery (6.5 percent), as shown in Table 3.

Table 2 1989 Employment in Food Industries in Iowa

SIC	Food Industry	Employees	%	Cum %
201	Meat Products	23640	52.7	52.7
204	Grain Mill Products	9488	21.2	73.9
202	Dairy Products	3093	6.9	80.8
205	Bakery Products	2554	5.7	86.5
203	Preserved Fruits and Vegetables	2108	4.7	91.2
207	Fats and Oils	1448	3.2	94.4
208	Beverages	1406	3.1	97.5
209	Misc.	775	1.7	99.3
206	Sugar, Confectionery	331	0.7	100
	Total	44843		

Table 3 1989 Employment in Machinery Industries in Iowa

SIC	Machinery Industry	Employees	%	Cum %
352	Farm and Garden Machinery	16,390	36.6	36.6
353	Construction related	10,561	23.6	60.2
359	Misc. except electric	5,108	11.4	71.6
358	Refrigeration and service	2,934	6.5	78.1
355	Special Industry	2,919	6.5	84.6
354	Metalworking	2,779	6.2	90.8
356	General Industrial	2,376	5.3	96.1
357	Office and Computing	1,461	3.3	99.4
351	Engines and Turbines	270	0.6	100.0
	Total	44,798		

5.2.2.1. Census of Transportation Commodity Flows

The Commodity Transportation Survey was the only source of comprehensive data on freight traffic flows. This section will briefly examine the state's traffic trend in 1977, the most recent year the survey was published. The purpose of including this analysis is to develop an understanding of the state's commodity-mode relationships and commodity origin-destination patterns (i.e., the state's trade partners). Table 4 lists the tonnage of all commodities originating in Iowa by mode and destination. A total of about 43.7 million tons of freight originated in the state. About half of these shipments, 46 percent, also terminated in the state, i.e. intrastate shipments. Other significant shipments were made to Illinois, Minnesota, California, Nebraska, and Wisconsin.

As can be noted from Table 4, more than 90 percent of Iowa's intrastate traffic was shipped by truck, which is logical for such short-haul shipments. About 40 percent of shipments to Illinois were by rail, while the remaining 60 percent were by truck. Shipments to California were about equally distributed between rail and truck. However, almost all of the shipments from Iowa to Nebraska were made by Truck. After examining the patterns of the freight traffic terminating in Iowa, it was found that, excluding intrastate shipments, the majority of this traffic originated in the following states: Kansas, Indiana, Illinois, Missouri, Oklahoma, Wyoming, and Minnesota.

Finally, some commodity-mode relationships were examined using the reported tonnage of commodity shipments from Iowa by mode of transportation. About 73 percent the food products originating from Iowa were shipped by truck. However, meat products, dairy products, and bakery products were almost exclusively shipped by truck. Machinery products were shipped by truck 81 percent of the time. Rail rail shipments of machniery products accounted for about 13.4 percent of the movements of these products. Shipments of chemicals and allied products were distributed as 47.2 percent truck and 33.3 percent rail, while other modes accounted for the remaining 19.5 percent.

Table 4 Tonnage Originating in Iowa by Destination and Mode (1977 CTS)

(All values are in 1000 Tons)

Dest	Rail	Rail (%)	Truck	Truck (%)	Total	State (%)
IA	1787	8.9	18140	90.2	20104	46
IL	1702	40.2	2529	59.7	4235	9.7
MN	455	16	2376	83.8	2836	6.5
CA	1024	50.6	988	48.8	2023	4.6
NE	32	2.3	1382	97.6	1416	3.2
WI	468	34.1	899	65.6	1371	3.1
OH	481	51.1	454	48.2	942	2.2
SD	164	18.5	721	81.3	887	2
MI	311	44.2	384	54.5	704	1.6
TX	308	44.4	378	54.5	694	1.6
KS	65	9.7	602	90.1	668	1.5
NY	229	34.6	424	64	662	1.5
MO	110	17.1	530	82.3	644	1.5
TN	294	56	227	43.2	525	1.2
IN	104	22.3	357	76.4	467	1.1
ND	47	10.2	411	89.3	460	1.1
LA	209	48.7	70	16.3	429	1
Total (listed destinations)					39067	89.5
Total (all destinations)					43682	

5.2.2.2. Rail Traffic Trends

Data on rail commodity movements were obtained from the 1989 railroad waybill sample prepared by the Interstate Commerce Commission. In summarizing rail commodity flows, frequency analysis of commodities shipped were cross tabulated by origin and destination. Commodities were ranked in order of tonnage shipped for railcar traffic and they are tabulated in that order. The summaries include commodities shipped, weight of shipment, and the percentage of the commodity tonnage to the total tonnage and are included in the appendix. The analysis will focus on railcar traffic. Intermodal traffic originating in or terminating in the state carried a small portion of the commodities included in the analysis. This traffic could be classified as freight all kind, and some high value electrical and transportation equipment. In contrast, Iowa's bridge intermodal traffic is very substantial.

Originating Traffic Railcar shipments originating in Iowa amounted to 24.3 million tons (excluding intrastate) 1989. Table A-1 lists commodities accounting for the largest tonnage. Field crops (grain) accounted for 53 percent of the total traffic originating in Iowa. Food and kindred products came in second, accounting for 34.9 percent, followed by chemicals and allied products accounting for less than five percent. More than 42 percent of the shipments originating in Iowa in 1989 terminated in Illinois, while intrastate shipments amounted to about 29 percent. Other significant destinations included Missouri, Louisiana, California, Minnesota, and Texas. These six states accounted for 82.1 percent of the total commodities originating in Iowa. Table A-2 lists terminating states accounting for at least one percent of Iowa's originating tonnage.

Terminating Traffic The commodities most frequently shipped to Iowa in 1989 are shown in Table A-3. The total tonnage terminating in the state equaled about 21.8 million tons (excluding intrastate tonnage). Coal accounted for the largest tonnage terminating in Iowa, more than 13 million tons, or about 61 percent of the state terminating tonnage. Chemicals and allied products was the second largest tonnage, at 12.1 percent, followed by farm products shipments of about 9.5 percent of the total tonnage terminating in Iowa. Nonmetallic minerals and pulp and paper products each accounted for 4.7 percent and 3.1 percent of the terminating tonnage respectively. The top five commodities terminating in the state accounted for more than 90 percent of the terminating tonnage. About 57 percent of the coal shipped to Iowa originated in Wyoming. Table A-4 shows states with significant shipments to Iowa. Among the states with significant shipments to Iowa were Minnesota, Illinois, South Dakota, Texas, and Nebraska.

Intrastate Railcar Traffic There were more than 9.8 million tons of intrastate railcar shipments in Iowa in 1989. The majority of these shipments were intrastate farm products (grain) movements, which made up more than 76 percent of the total intrastate tonnage, as shown in Table A-5. Other significant intrastate shipments were food and kindred products (especially, grain mill products), nonmetallic minerals, and chemicals and allied products.

5.2.2.3. Truck Traffic

Truck commodity flows were obtained from the 1989 Iowa Truck Weight Survey. The final number of trucks sampled in the survey in 1989, after removing incomplete records, was about 10,000 trucks. The traffic summaries in the following sections are based on truck shipments included in the data base.

Originating Truck Traffic The total observed originating truck tonnage at truck weight locations in 1989 was about 47,000 tons, excluding intrastate tonnage which totaled more than 49,000 tons. Table 5 lists major commodities originating in Iowa. Food and kindred products

Table 5 1989 Truck Tonnage Originating in Iowa by Commodity

STCC	Commodity	Tons	%	Cum %
20	Food and Kindred Products	17302	36.8	36.8
1	Farm Products	5094	10.8	47.6
41	Miscellaneous shipments	4460	9.5	57.0
32	Stone, Clay, and Glass	3053	6.5	63.5
35	Machinery, except electrical	2250	4.8	68.3
26	Pulp, Paper, and Allied Products	1978	4.2	72.5
33	Primary Metal Products	1955	4.2	76.7
24	Lumber and Wood Products	1372	2.9	79.6
34	Fabricated Metal Products	1082	2.3	81.9
91	hazmat	1003	2.1	84.0
37	Transportation Equipment	935	2.0	86.0
30	Rubber and Misc. Plastic Products	907	1.9	87.9
28	Chemicals and Allied Products	849	1.8	89.7
14	Nonmetallic Minerals	790	1.7	91.4
36	Electrical Machinery	642	1.4	92.8
25	Furniture and Fixtures	584	1.2	94.0
47	Small Packaged Freight	495	1.1	95.0
Total (All commodities)		44,761		

accounted for the largest portion of the total originating tonnage, about 37 percent; followed by farm products, about 11 percent; and miscellaneous mixed shipments, 9.5 percent. The majority of the truck tonnage originating in Iowa terminated in neighboring states. States that received significant truck tonnage from Iowa are Nebraska 16.1 percent, Missouri 13.5 percent, Illinois 13.1 percent, Minnesota 11.8 percent, and Kansas about eight percent of the total originating tonnage. Table 6 lists the major destinations in terms of tonnage received from Iowa.

Table 6 1989 Truck Tonnage Originating in Iowa by Destination

Destination	Tons	%	Cum %
Nebraska	7582	16.1	16.1
Missouri	6356	13.5	29.6
Illinois	6169	13.1	42.7
Minnesota	5552	11.8	54.5
Kansas	3742	7.9	62.4
Texas	2521	5.4	67.8
South Dakota	1584	3.4	71.2
California	1235	2.6	73.8
Wisconsin	1210	2.6	76.4
Michigan	1198	2.5	78.9
Ohio	893	1.9	80.8
Indiana	772	1.6	82.4
Arkansas	679	1.4	83.9
Florida	660	1.4	85.3
Oklahoma	601	1.3	86.6
New York	575	1.2	87.8
Pennsylvania	480	1	88.8
Georgia	434	0.9	89.7
Idaho	430	0.9	90.6
Sum (listed states)	42673		
Total (all States)	47080		

Terminating Truck Traffic About 47,000 tons were observed as terminating traffic in Iowa in 1989, excluding intrastate shipments. Food and kindred products accounted for the largest tonnage, about 23 percent. Miscellaneous shipments accounted for close to 12 percent, and farm products 10 percent of the total tonnage terminating in Iowa. Table 7 lists the major commodities terminating in the state in 1989. The majority of shipments terminating in Iowa originated in the following states: Nebraska 17.9 percent, Kansas 15.4 percent, Illinois 11.6 percent, Missouri 10.9 percent, and Minnesota 9.3 percent of the total tonnage terminating in the state, as shown in Table 8.

Table 7 1989 Truck Tonnage Terminating in Iowa by Commodity

STCC	Commodity	Tons	%	Cum%
20	Food and kindred products	10858	23.1	23.1
41	Miscellaneous shipments	5585	11.9	35
1	Farm products	4574	9.7	44.8
26	Pulp, paper, and allied products	3227	6.9	51.6
33	Primary metal products	3210	6.8	58.5
28	Chemicals and allied products	3100	6.6	65.1
24	Lumber and wood products	2533	5.4	70.5
37	Transportation equipment	2381	5.1	75.5
32	Stone, clay, and glass	1972	4.2	79.7
35	Machinery, except electrical	1589	3.4	83.1
91	hazmat	1286	2.7	85.9
14	Nonmetallic minerals	1016	2.2	88
34	Fabricated metal products	793	1.7	89.7
25	Furniture and fixtures	680	1.4	91.2
29	Petroleum and coal products	561	1.2	92.4
36	Electrical machinery	482	1	93.4
Sum (listed commodities)		43847		
Total (all commodities)		46952		

Table 8 1989 Truck Tonnage Terminating in Iowa by Origin

Origin	Tons	%	Cum %
Nebraska	8,435	17.9	17.9
Kansas	7,242	15.4	33.3
Illinois	5,449	11.6	44.9
Missouri	5,124	10.9	55.8
Minnesota	4,396	9.3	65.2
Texas	2,246	4.8	70.0
South Dakota	1,631	3.5	73.4
California	1,519	3.2	76.7
Wisconsin	1,417	3.0	79.7
Arkansas	1,319	2.8	82.5
Oklahoma	1,052	2.2	84.7
Ohio	1,005	2.1	86.9
Indiana	806	1.7	88.6
Michigan	775	1.6	90.2
Indiana	468	1.0	91.2
Sum (listed states)	42,885		
Total (all origins)	47,018		

Intrastate Truck Traffic The total observed intrastate truck tonnage in Iowa was 49,304 tons in 1989. Table 9 lists the major intrastate tonnage by commodity. Similar to railcar traffic, food and kindred products and farm products were the two main intrastate commodities. Intrastate shipments of food products amounted to 22.5 percent of the state intrastate tonnage, while farm products accounted for 18 percent. Other commodities with significant tonnage were miscellaneous freight shipments, nonmetallic ores, and hazardous materials.

Bridge Truck Traffic The commodities most frequently shipped by truck through Iowa are listed in Table 10. More than 25 percent of Iowa's bridge truck traffic is made up of food and kindred products. Farm products, which include grain and fresh fruits and vegetables; and miscellaneous freight shipments accounted for about 11 percent, each. Primary metal products and paper products accounted for more than seven percent, each.

Table 9 1989 Iowa Intrastate Truck Tonnage by Commodity

STCC	Commodity	Tons	%	Cum %
20	Food and kindred products	11087	22.5	22.5
1	Farm products	8885	18	40.5
41	Misc. freight shipments	4435	9	49.5
14	Nonmetallic ores	3846	7.8	57.3
91	hazmat	2972	6	63.3
35	Machinery, except electrical	2586	5.2	68.6
32	Stone, clay and glass products	2500	5.1	73.6
33	Primary metal products	1583	3.2	76.9
47	Mail and express	1427	2.9	79.8
24	Lumber and wood products	1273	2.6	82.3
37	Transportation equipment	1179	2.4	84.7
34	Fabricated metal products	1061	2.2	86.9
26	Pulp, paper and allied products	892	1.8	88.7
29	Petroleum or coal products	785	1.6	90.3
28	Chemicals and allied products	749	1.5	91.8
40	Waste and scrap materials	676	1.4	93.2
11	Coal	674	1.4	94.5
Total		46610		

More than 60 percent of Iowa's bridge truck tonnage originated in bordering states: Minnesota, Nebraska, Kansas, Missourl, Illinois, and Wisconsin, as shown from Table 11. California and Texas were major origins for truck shipments through Iowa. However, truck traffic through the state is scattered from around the region, which is expected from typical truck shipments of shorter halls. Tables 10, 11 and 12 summarize Iowa's truck bridge traffic. The commodity tonnage observed in Iowa bridge traffic are shown in Table 10. Table 11 list origin states Iowa's bridge truck traffic. Similarly, Table 12 lists destination states for this traffic.

Table 10 Bridge Truck Tonnage Through Iowa by Commodity

STCC	Commodity	Tons	%	Cum %
20	Food and kindred products	30674	26.2	26.2
1	Farm products	12770	10.9	37.2
41	Misc. freight shipments	12665	10.8	48.0
33	Primary metal products	8930	7.6	55.6
26	Pulp, paper and allied products	8456	7.2	62.9
28	Chemicals and allied products	6885	5.9	68.8
24	Lumber and wood products	5075	4.3	73.1
35	Machinery except electrical	4345	3.7	76.8
32	Stone, clay and glass	3942	3.4	80.2
37	Transportation equipment	3547	3.0	83.2
34	Fabricated metal	2404	2.1	85.3
25	Furniture and fixtures	2010	1.7	87.0
36	Electrical machinery	1954	1.7	88.7
29	Petroleum or coal products	1902	1.6	90.3
		116892		

Table 11 Bridge Truck Tonnage by Origin State

Origin	Tons	%	Cum %
Minnesota	17,875	15.3	15.3
New Hampshire	16,545	14.2	29.5
Illinois	10,109	8.7	38.1
Kansas	9,747	8.3	46.4
California	9,058	7.8	54.2
Wisconsin	8,284	7.1	61.3
Missouri	7,184	6.1	67.4
South Dakota	6,175	5.3	72.7
Texas	4,807	4.1	76.8
Colorado	2,599	2.2	79.1
Michigan	2,327	2.0	81.1
Arkansas	1,916	1.6	82.7
Oklahoma	1,723	1.5	84.2
Ohio	1,697	1.5	85.6
Idaho	1,609	1.4	87.0
Indiana	1,548	1.3	88.3
Canada	1,281	1.1	89.4
Pennsylvania	1,174	1.0	90.4
Oregon	1,070	0.9	91.3
North Dakota	1,066	0.9	92.2
Sum	107,794		
Total	116,854		

Table 12 Bridge Truck Tonnage by Destination

Destination	Tons	%	Cum %
Minnesota	21453	18.4	18.4
Illinois	13277	11.4	29.7
Nebraska	11638	10	39.7
Missouri	10490	9	48.7
Kansas	7331	6.3	54.9
Wisconsin	6530	5.6	60.5
South Dakota	6279	5.4	65.9
Texas	5612	4.8	70.7
California	4702	4	74.7
Michigan	3260	2.8	77.5
Ohio	2820	2.4	79.9
Colorado	2118	1.8	81.7
Canada	2082	1.8	83.5
New York	2011	1.7	85.2
North Dakota	1991	1.7	86.9
Indiana	1798	1.5	88.5
Oklahoma	1482	1.3	89.7
Pennsylvania	1156	1	90.7
Total	116854		

5.2.3. Location of Economic Activity

The purpose of this section is to examine the distribution of the economic sectors within the state. Counties of high economic activity will have more employment and hence will generate more freight. Summaries of economic factors are used to estimate zonal freight generation as will be shown in section 5.4. Employment levels for the 3-digit SIC (Standard Industrial Code) are tabulated for counties with substantial employment levels in the state. The following is a summary of employment trends for the two sectors selected for the case study: SIC 20 food and kindred products and SIC 35 machinery products.

Geographically, food industries are located in a large number of counties. County level employment in meat packing industries (SIC 201) in Iowa showed no substantial concentration. Counties that account for about 65 percent of the state's employment in this sector are: Woodbury, Dubuque, Buena Vista, Linn, Polk, Crawford, Scott, Louisa, Muscatine, and Marshall. Grain mill products county employment patterns show some concentration in a fewer number of counties. Linn county, with a center of activity in Cedar Rapids, is a major hub for food processing industries, and contains about 32 percent of state employment in grain mill products. Muscatine county has the second highest concentration of grain mill industries employees, followed by Clinton, Lee, Scott, Webster, and Polk counties and accounted for and additional 44 percent of the state employment in that industry.

Employment in the machinery manufacturing sector is mainly in the manufacturing of farm and garden machinery. Further more, the farm and garden machinery employment is concentrated in few counties. About half of this employment is located in Black Hawk county. Polk county had 12 percent of this sector's employment, while Wapello county accounted for 7.7 percent.

5.3. Transportation Network

The basic concepts introduced in section 5.1 are applied to the network development. The purpose of the network is to represent freight generation zones and the transportation routes connecting them. The coding scheme for representing nodes and links is influenced by data availability and the level of detail sought in the analysis. Counties are represented by a single node, each, corresponding to the economic activity center in that county. The center of a county is some what identified subjectively based on the location of employment and population, the spatial location in the county, and proximity to transportation services. There are 99 potential nodes, corresponding to counties in the State of Iowa.

Since the case study considers only a subset of products in the state, the number of these internal nodes is reduced to only those counties with substantial employment, at least one percent of the total state employment in the included sectors. The sum of the food and machinery tonnage produced are shown in Table A-6. Twenty three counties accounted for 90 percent of the total tonnage of food and machinery products produced in the state. The nodes representing these zones make up the internal set of nodes in the state as shown in Table A-7. Furthermore, this set of internal nodes will capture the high density and concentrated movements of input and outputs in the two sectors. The counties represented by these nodes account for more than 55 percent of the total population of the state and include major population concentrations. The internal network of nodes and highway links are shown in Figure 3, which also displays the main highways in Iowa.

External locations to the state are aggregated to the state level. These zones are identified by examining the commodity flow analysis performed in section 5.2. A set of external destinations is identified from the analysis of commodities originating in Iowa. Similarly, external origins are identified by examining commodity shipments terminating in Iowa. However, the commodities included in the terminating traffic analysis are the two sectors of food products and machinery in addition to the input requirements to produce these commodities. The inputs are

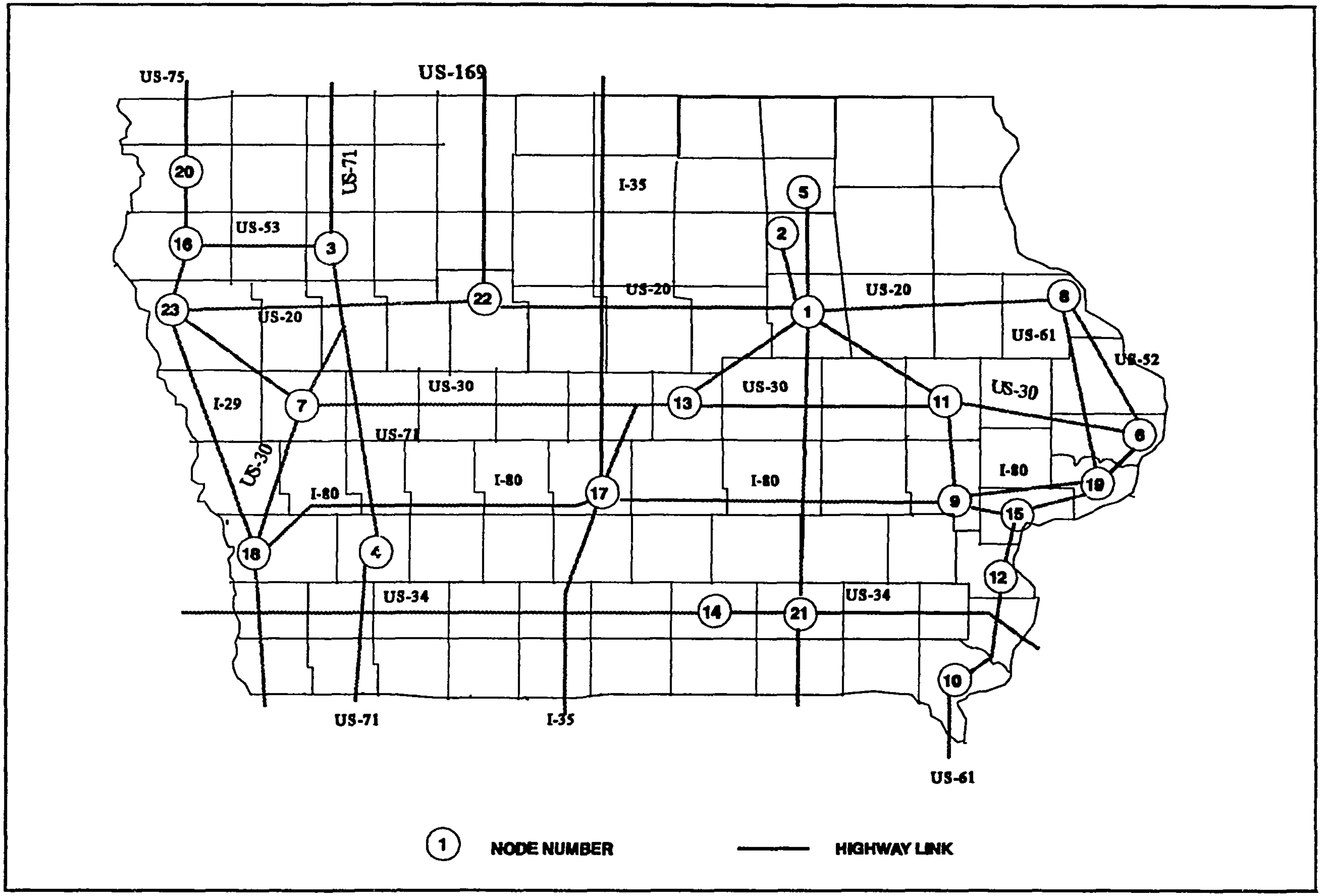

Figure 3 Internal Zones and Connecting Highway Links

identified from input-output analysis. Additional commodities, identified as major inputs for the food products and machinery industries are: chemical products, petroleum, primary metal, lumber and wood products, and stone, glass, and clay.

The traffic distribution of Iowa's commodities, food products and machinery, in each of the major destination states is examined to identify traffic concentration. External states are each represented by a node corresponding to where the traffic was concentrated. There are a number of reasons for aggregating external zones to the state level. The analyses in statewide planning are limited to areas within state boundaries. Highways outside these boundaries are beyond state jurisdiction. Another reason for aggregating shipments to external states is the lack of employment data in these zones. Any breakdown of external states into several zones requires obtaining detailed employment and population for these zones. Since such data were not readily available, all external states are represented by one node each, representing the largest concentration of freight shipments to or from Iowa.

Table A-8 shows the distribution of Iowa's originating tonnage in the food and kindred products sector (STCC 20) and the machinery products sector (STCC 35). The majority of the traffic originating in Iowa terminated in bordering states. Similarly, Table A-9 shows the origins of the shipments of food products, machinery, and their input tonnage terminating in Iowa. The set of external zones to be included in the transportation network is the combined listings of tables A-8 and A-9. External zones and the corresponding nodes are summarized in Table A-10.

To achieve connectivity between external nodes and internal nodes, a set of intermediate nodes are defined. Intermediate nodes represent the intersections of major highways and the points where primary highways cross Iowa borders. Some of these crossings have already being represented by internal nodes. The set of intermediate nodes, the internal nodes directly connected to them, and the highway links connecting them are shown in Table A-11. The collection of internal, intermediate, and external nodes are shown in Figure 4.

The network shown in Figure 4 contains 64 nodes corresponding to 23 internal nodes, 18 intermediate nodes, and 13 external nodes. A total of 254 undirected links connect these nodes. There are 83 (two way) links that connect internal nodes to other internal nodes or intermediate nodes represent actual highway links between these nodes. Links that lead to and from external nodes do not necessarily correspond to a single highway route. They represent 43 (two-way) least travel times links that connect external nodes to other links in the network.

The impedance on the network links is measured in travel time. Travel times on individual highway links between origin and destination pairs were estimated using AUTOMAP (27). AUTOMAP is a digitalized road atlas that covers most of the road system in the United States. Paths can be constructed using this program to minimize travel time, travel distance, or both. The lower speeds for local arterial streets. The impedance on the paths connecting Iowa with other states is computed based on the distance from the origin and ending at the center for that state. The travel time for shipments within a zone represented by an internal node is set to 30 minutes, while travel time within an external zone is set to 60 minutes.

A tree-building algorithm is used to find shortest paths between all possible origin-destination nodes in the network. This algorithm is based on a formulation suggested by Smith, Hinton and Lewis (21, p. 251). A FORTRAN routine was written to apply the algorithm on all possible origin-destination pairs in the network. The algorithm uses travel times measured in minutes between nodes connected by direct links. A direct link exists if an actual highway link

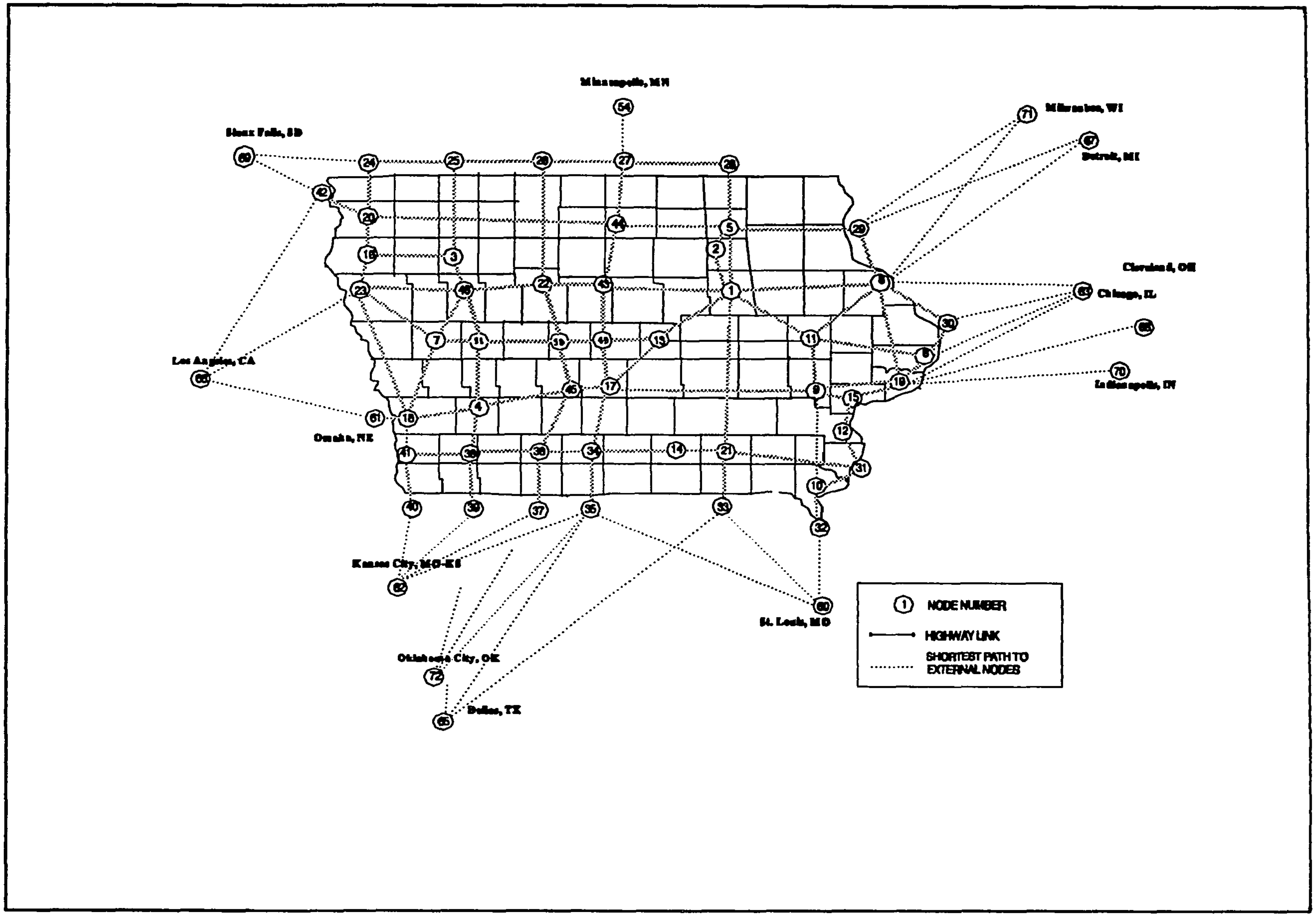

Figure 4 Network Representation of Nodes and Links

connects a pair of nodes without passing through another node in the network. Travel times between nodes not directly connected are set to zero. The routine finds the sequence of nodes and links from a specified origin to all other nodes in the network and can be described as follows:

1. Variable definition.
   C(i,j) = Travel time on the shortest direct link from node (i) to node (j)
   COPT(j) = the sum of travel time form an origin node up to node (j)
   NUS(j) = node downstream from node (j)
   T(i,j) = Travel time on the shortest path between node (i) and node (j)
   NA = origin node
   NB = destination node

2. Read input data.
   Read number of nodes (N) and number of links (L)
   Matrix of travel times C(i,j), for all i and j.
   Read an origin node (NA) and destination node (NB)

3. Initialize variables NUS and COPT as follows. The tree has no links at this point.
   NUS(i) = 0, for all i = 1,2,...,N
   COPT(j) = 0, for origin node (j = NA)
   = ∞, for all other nodes (j $\neq$NA)
   Current node is origin (NA)

3. Extend the tree by adding a branch (link) from current node
   Examine all links leading from current node.
   Select the link with least travel time and add it to the tree.
   Update the values of the variables NUS and COPT.
   Let (j) be the end node for this link, then

   COPT(j) = COPT(j) + C(i,j)

4. Examine the end node (j).
   If the destination is reached, return the calculated travel time to the main program.
   if j = NB, then
   T_{ij} = $COPT_j$.

   if j $\neq$NB, then
   continue to step 5.

5. Reset values and prepare for next move. The selected link is marked by setting its travel time to (-1.0), thus removing it from further consideration.
   C(i,j) = -1.0
   The tree is extended from the end node (j).
   Go to step 3.

6. If all links are evaluated, stop and return to main program.

5.4. Freight Traffic Generation

The purpose of this section is to determine the amount of freight generated at the freight producing nodes. The freight generated at a node is a function of the economic activity in the zone (the county or state) represented by this node. The economic data presented in section 5.2. are used to predict the freight generated. Freight generation can be classified in two ways: 1) freight production in a zone which is a function of industrial activity (manufacturing) in the zone, and 2) freight attracted to a zone, which can be broken down to input requirements for industrial plants and final demand or personal consumption. The freight tonnage attracted to a zone is then a function of population (consumption) and production (input requirements).

5.4.1. Input-output analysis

Input-output analyses are used to examine the interactions among the sectors of an economy and provide a tool to quantify these interactions. This research will refer to a summary of the 1977 input-output tables, published in the Survey of Current Business in 1984 (24). There are a number of input-output tables that provide information on: 1) the output of commodities by industries (dollars), 2) the use of commodities by industries (dollars), 3) the commodity requirements by industry to produce one dollar of that industry's output, 4) commodity-by-commodity requirements in dollars of input per dollar of output, and 5) the industry-by-commodity requirements per dollar output. The commodity-by-commodity requirements are used to predict commodity requirements.

The first step in estimating input requirements is to identify the industry sectors included in the analysis and their subindustries. Eighty commodities were listed in input-output tables. The classification of these commodities is different from other standard classifications such as the STCC (Standard Transportation Commodity Code) or the SIC (Standard Industrial Code). An examination of this table shows that all of the food and kindred products were classified in one group. The inputs for specific food industries can not be estimated from these tables. In addition, it is necessary to aggregate the employment figures for that sector to a 2-digit SIC level. This clearly shows how the data availability will dictate the level of details that can be realized in the analysis. The machinery industries could be classified in four groups in the same table corresponding to general machinery products, farm and garden machinery, construction related machinery, and miscellaneous machinery.

The data in the input-output table represent the dollar value of inputs required to produce one dollar of output, and are referred to as technical coefficients. Many of these coefficients have very small values, denoting insignificant interaction between the output sector and the corresponding input sectors. The coefficients are ranked in descending order in a table for each industry included in the analysis. Sectors that have no physical output (mainly service industries) are eliminated, since the interest of this analysis is in estimating freight tonnage. Next, the values of input requirements are converted to tonnage requirements per ton of output. Figure 5 shows a sample calculation for the food industries. A summary of the food products inputs are shown in Table A-12. Machinery industries inputs are summarized in Tables A-13, A-14, and A-15.

Sample Input-Output Analysis for Food Industries

(1)	(2)	(3)	(4)	(5)
Input Commodity	Value ($)	Value ($/ton)	Tons per Ton STCC 20	Total Tons
Food and kindred products	1.29676	456.0	1.30	31,953,534
Livestock and livestock products	0.30272	1,300.00	0.11	2,616,507
Other Agricultural products	0.19922	456.0	0.20	4,908,991
Chemicals and allied products	0.05758	267.0	0.10	2,423,174

Column (1) shows the input commodity required in manufacturing food products.

Column (2) is obtained form the input-output table. It represents the value of the input industry listed in that row that is used to produce a one dollar value of food and kindred products.

Column (3) values were obtained from 1977 commodity attribute data summarized in Appendix B of the National Cooperative Highway Research Program report 260 (3). These values represent the 1977 dollar value per ton of commodity.

Column (4) values are calculated by finding the fraction of the value of the input commodity of the value of one ton of food products then dividing by the value of the input to find its weight. Mathematically, this can be expressed as
$[(2) \div (3)] \times$ (value of output per ton = $456 for food products)

Finally, column (5) shows the total requirements to produce the 24.641 million tons of food products in Iowa in 1989

Figure 5 Sample Input-output Analysis for Food Products

The input tonnage requirements are used to estimate the freight tonnage attracted as input to industry in analysis zones. Furthermore, the flow patterns of the input commodities are examined to identify major origin states, as was mentioned in section 5.2. The per ton input requirements listed in tables A-12 through A-15, represent the tonnage required from the listed inputs to produce one ton of output in the food and machinery industries. The per ton requirements are multiplied by the total tons produced in each analysis zone to estimate the freight attracted for industrial inputs.

The major inputs that were found significant for both of the food and machinery industries are: food and kindred products (STCC 20); lumber and wood products (STCC 24); chemicals and allied products (STCC 28); stone, clay, and glass products (STCC 32); primary metal products (STCC 33); machinery products (STCC 35; except 352, 353, and 359); farm and garden machinery (STCC 352); construction machinery (STCC 353), and miscellaneous machinery (STCC 359). Note that the two significant input commodities, petroleum refinery products and agricultural products, were not included in the list. The reason for not including petroleum products was the difficulty in estimating actual production using available employment data. Further more, a substantial portion of these shipment was carried through pipelines. As for agricultural products, the difficulty as mentioned earlier, is in determining specific input requirements from available input-output tables. Estimating the production in this sector also requires extensive historical data on farm acreage production and fluctuation in productions.

Personal Consumption requirements, represent the amount of commodities used for personal consumption, are estimated in a different manner. Input-output tables show the amount of personal consumption expenditures for purchasing commodities. These expenditures are converted to commodity tonnage using commodity value in dollar per ton. An estimate of per capita tonnage consumption is obtained from dividing total tonnage requirements by the total United States population in that year (both of the input-output tables and the population statistics were obtained for 1977). The calculations of the per capita requirements are shown in Table A-16.

5.4.2. Produced Freight

Productivity rates of tons per employee were estimated for the nine commodity groups included in the analysis as described earlier in section 5.1. Figure 6 shows sample calculations to estimate production rates. The commodities for which productivity rates can be estimated are those included in the Commodity Transportation Survey and their employment reported in the Census of Manufacturers for the same year. Both surveys cover only manufacturing sectors. Productivity rates are aggregated to the industry classification level reported in these surveys.

The commodity productivity rates estimated for 1977 are modified using productivity indices, as shown in Figure 6. These indices were identified for some of the commodities included in the analysis. Average annual rates of change are established for these commodities. The calculated 1977 rates were then modified by the average annual rates for a 12 year period (1977 to 1989). The resulting values represent estimates of the number of tons produced by one employee in a specific industry in the year 1989.

The quantity of freight produced at each zone is estimated by multiplying that zone's employment by the estimated productivity rates. This is carried out for the nine commodities included in the analysis at the internal and external nodes. Employment levels in Iowa counties were obtained from the Rural Data Project data base at the Department of Economics, Iowa State

Production Rates for Food Products Census					
(1)	(2)	(3)	(4)	(5)	(6)
	Tons	Employees	1977	Annual	1989
STCC	(1000)	(1000)	Tons/Empl	% Increase	Ton/Empl.
20	21,879	46.3	900.4		
201	4,929	24.3	202.8	2.9	273.4
202	1,545	3.6	429.2	4.4	655.8
203	390	2.0	195.0	4.7	305.0
204	8,998	10.0	899.8	6.5	1601.6
207	4,975	1.3	3826.9		3826.9
208	655	1.3	503.8	6	866.6
209	102	1.2	85.0		85.0
		43.7			

Column (1) contains the standard commodity classification codes for the food industries.

Column (2) is the total weight of shipments of food products originating in Iowa. These tonnage were obtained from the Commodity Transportation Survey (20).

Column (3) lists the number of employees in the food production industries in Iowa in 1977.

Column (4) values are obtained by dividing values in (2) by values in (3) to obtain estimates of production in tons per employee in 1977..

Column (5) lists average rates of change in productivity of industrial plants. These rates were obtained from Department of Labor statistics (23).

Column (6) values are the modified production rates. These values are computed by applying productivity change rates over a 12 year time period on the 1977 production rates. These values of tons per employee are used in the freight production calculations.

Figure 6 Sample Calculations of Commodity Production Rates

University. Employment for external zones were obtained for 1989 from the Annual Survey of Manufacturers (28). The results of these calculations are gross commodity tonnage produced in 1989 at each node. Rail commodity flows are used in section 5.5 to estimate what portion of the commodity gross production is potential truck traffic.

5.4.3. Freight Attracted

The freight tonnage attracted at analysis zones is made up of input tonnage used in production and freight tonnage for personal consumption. The first part of this section describes the estimation of freight tonnage for input requirements using industry production data. The second part discusses the estimation of freight tonnage for personal consumption using population data for internal and external zones. Both of these sections use the input-output analysis described in section 5.4.1.

5.4.3.1. Input requirements

The freight tonnage attracted to a zone for use in industrial production is based on the input requirements estimated in section 5.4.1 and represent the tons of input commodities used to produce one ton of output commodity. Total input requirements for the food and machinery sectors are calculated using the production quantities estimated in section 5.4.2. Mathematically, the total input tonnage required from a commodity (k1) at node (i) can be stated as:

$$INP_{ik1} = \sum_{k=1,nk} P_{ik} \, INC_{kk1}$$

Where,

INP_{ik1} = Total tonnage of commodity (k1) required as input at node (i)
P_{ik} = Production of commodity (k) at node (i)
INC_{kk1} = Tons of commodity (k1) required to produce one ton of (k)
nk = 9, number of commodities included in the analysis

The above calculations are carried out for all the commodities included in the analysis and the set of external and internal zones. The results of these calculations are summarized in a matrix of zone commodity requirements. Entries in this matrix correspond to the input tonnage required at internal and external nodes from the commodities included in the analysis.

5.4.3.2. Consumption requirements

The commodity tonnage required for personal consumption is estimated using per capita requirements (from section 5.4.1.) and population levels at internal and external nodes. Population data were obtained from the Statistical Abstracts (29). Food products had the most significant tonnage used for personal consumption. The estimated consumption requirements are added to the input requirements to determine the total commodity tonnage attracted to internal and external nodes.

5.5. Truck Tonnage Estimation

The purpose of this section is to estimate the freight tonnage shipped to or from Iowa by means of trucks. The truck freight tonnage produced within a zone is the total commodity tonnage produced within the zone less the rail tonnage originating in that zone. Similarly, the attracted truck freight tonnage is equal to the attracted commodity tonnage less than the terminating rail tonnage. Rail commodity flows are obtained from the 1989 waybill sample.

The process of estimating truck tonnage is straight forward and involves minimal calculations. The commodity tonnage produced at the analysis zones are tabulated for the nine commodities included in the analysis. Corresponding rail commodity flows originating in these zones are subtracted from total production tonnage. A sample of estimated originating truck tonnage is shown in Table A-17. Similarly, the truck tonnage attracted to a zone is estimated by subtracting the terminating rail tonnage from the total attracted freight tonnage at that zone. The attracted freight tonnage includes personal consumption and input freight requirements. As can be seen from Table 17, rail accounts for only a small portion of the shipments of manufactured commodities in the state. The products of the two major sectors selected for the case study are predominantly shipped by truck. The only significant rail shipments in these sectors are in the grain mill products manufacturing and some chemical products. The truck commodity tonnage estimated in this section are used as input to the gravity model in the traffic distribution analysis.

5.6. Truck Commodity Flows Distribution

The purpose of this part of the procedure is to determine the commodity tonnage shipped between producing and consuming nodes in the network. The analysis finds the commodity flows between pairs of nodes and identifies the major commodity movement corridors.

5.6.1. Estimating commodity flows

The traffic distribution analysis is based on the gravity model described in section 5.1. The model is based on the premise that commodities are distributed in patterns that minimize travel time on the network. That is, shippers select destinations closer to their production, and select routes that have least travel times. The gravity model uses the following Input:

1. shortest time paths obtained form the tree building algorithm explained in section 5.3.
2. Production and attraction tonnage of each of the commodities included in the analysis at each of the internal and external node (note that intermediate nodes have zero production and attraction)

Mathematically, the gravity model can be illustrated as follows (3, pp. 29):

$$X_{ijk} = \frac{P_{ik}\, C_{jk}\, F_{ij}}{\sum_{j=1,N} C_{jk}\, F_{ij}}$$

Where,

X_{ijk} = Shipment of commodity (k) from node (i) to node (j)
P_{ik} = Production of commodity (k) at node (i)
A_{jk} = Attraction of commodity (k) at node (j)
F_{ij} = $1/T_{ij}$, Impedance factor for traveling from node (i) to node (j)
T_{ij} = travel time between node (i) and node (j)

The model can be rearranged for efficient computer coding and restated as follows:,

$$X_{ijk} = R_{ik}\, C_{jk}\, F_{ij}$$

Where,

$$R_{ik} = \frac{P_{ik}}{\sum_{j=1,N} C_{jk}\, F_{ij}}$$

A FORTRAN routine was developed for the gravity model to distribute truck commodity tonnage. The routine uses the results from the shortest path algorithm described earlier. Both of these routines are included in one main computer program to conduct the analysis. A major part in the computer program is to manage the data files. Several input data files are used to store the network data, nodes production, and nodes input and consumption requirements. Another important factor in running the program was the computer storage requirements. Three dimensional variables, such as the flow variable, increase memory requirements rapidly. An increase in the number of commodities in the flow variable for instance, will substantially increase memory and computation time requirements.

The main elements of the computer program can be described as follows:

1. Variable definitions and file locations.
   X_{ijk} = Flow of commodity (k) from node (i) to node (j)
   Y_{ijk} = Flow of commodity (k) on link between node (i) and node (j)

2. Read network data

   N, number of nodes
   L, number of links
   NK, number of commodities
   C(i,j), travel times on direct links between all nodes in the network.
   i,j = 1, N

   Production data

   P(i,k) = production of commodity (k) at node (i)
   CON(j,k), consumption of commodity (k) at node (j)
   INP(j,k), input tonnage of commodity (k) at node (j)

3. For an origin node (i) find shortest paths to all other nodes (j = 1, N) and calculate the travel time on these paths, T(i,j). Calculate impedance factor F(i,j) as 1/T(i,j).

4. Calculate the attractiveness factor R(i,k) for all commodities (k=1, NK)

5. Find the tonnage of commodity (k) shipped from node (i) to all other nodes in the network (i.e., calculate X(i,j,k); i , j = 1,N and k = 1, NK)

7. Is i = N ?
   No, i = 1+1, go to step 3.   Yes, go to step 6.

6. Calibrate estimated commodity flows. Calculate the sum of commodity tonnage originating in and terminating in each node in the network. Compare these values with the total commodity production and attraction at this node. Repeat for all commodities included in the analyses.

The results from the gravity analysis are K flow matrices of [N x N] elements, where N is the number of nodes and K is the number of commodities. The flow from each node in the network can also be represented by a matrix of [N x K] elements. The program also checks the total amount of commodity tonnage assigned to each node (origin and destination) to verify these assignments do not exceed the commodity production and attraction at that node.

5.6.2. Traffic Distribution Results

The purpose of the traffic distribution analysis is to identify how major commodities in the states are shipped. As discussed in earlier chapters, the results of traffic distribution are approximated shippers decisions. However, these results when based on reliable data, can be used to identify major patterns of commodity shipments in the state. Some observations on using the gravity model to a state level study are made before discussing the results.

The level of details in describing commodities and network analysis zones has a critical impact on the results. The commodity grouping influences how the model considers production and attraction patterns. Even when commodities are classified by the three-digit STCC code, the gravity model could not distinguish between "parts" and the "finished products".

An example is the manufacturing of farm tractors. The tractors are classified as "farm and garden machinery" and designated as STCC 352, which is a subset of machinery product (STCC 35). As found in the input-output analysis, the major inputs to manufacturing farm tractors are STCC 352 and STCC 33. STCC 33 refers to primary metal products, where STCC 352 refers to "farm and garden machinery" products. Most probably these products are parts or components that are used in the manufacturing of the tractor. Since no such distinction could be made, the model will assign most, if not all, of the production of STCC 352 in a node to the same node.

To avoid this problem requires an examination of the commodity types and their production process and forcing the model to use external sources for input requirements. A penalty of high impedance can be imposed on local shipments for nodes representing counties. An other way to distinguish between products and parts is to make several runs of the gravity model while setting the production at affected nodes to zero to force the model to use non-local production. For the same example above, the production of STCC 352 in node 1 was set to zero. The gravity model assigned flows to node 1 mainly from Illinois and the Kansas City area.

The major commodity groups and the locations for producing and consuming counties in the state have been identified in section 5.2. Nine commodities, in total, were included in the traffic distribution analysis. These commodities correspond to the food and kindred products sector, the machinery products sector, and the input commodities for these two sectors. The discussion in the following sections focuses on how these commodities are distributed from or to major generators in the state.

5.6.2.1 Distribution patterns of food and kindred products

Food products make up the bulk of the shipments originating in the state. The largest potential truck tonnage of food products in the state is located in Cedar Rapids, and to a lesser extent, in Muscatine, Davenport, and Des Moines. More than 52 percent of the food products estimated flows had an origin in these four counties. The largest shipments of food products to external zones from Cedar Rapids were to Illinois, followed by Wisconsin, Texas, and Minnesota. Food products shipped from Muscatine terminated in Illinois, Milwaukee, and Texas among the external nodes; Cedar Rapids and Davenport among internal nodes.

5.6.2.2 Distribution patterns of machinery products

The production of machinery products as was discussed earlier is largely made of farm and garden machinery. The majority of farm equipments made in Iowa is used in the state in farming, or shipped to neighboring midwestern states. Shipments to Illinois and Wisconsin were the largest, followed by Minnesota and Ohio. Inputs distribution patterns of commodities classified under the same group were obtained by setting the production at node 1 (represents

Black Hawk county) to zero. The shipments of these inputs to Waterloo originated in Illinois, Wisconsin, Kansas City area, and the Omaha, Nebraska area.

5.6.2.3 Distribution patterns of input commodities

This section provides a brief summary of the distribution patterns of the input commodities attracted to Iowa for use in manufacturing food and machinery products. The first of these inputs, lumber products, originated in Indiana (15 percent), Wisconsin (14 percent), Minnesota, California and Ohio (11 percent, each).

The distribution of chemical and allied products flows is more scattered. The quantity shipped to the state in truck in reality is underestimated in the model because of the agricultural sector is not included in the analysis. The use of chemicals in farms is not accounted for. The distribution patterns of these products in the state however, can be described by consolidated shipments to few distribution centers. Shipments to specific farms are made from these centers.

The products classified under STCC 32 include stone, clay, glass, and concrete. These products are largely produced and used locally or in surrounding regions. Except for regions located at state borders, these shipments are largely intrastate. In Iowa, about 24 percent of these shipments originate in the Fort Dodge area. Other areas with significant shipments are Des Moines (19 percent), Davenport (15 percent), and Cedar Rapids area (10 percent).

Primary metal products are among the largest commodities attracted to Iowa. The largest shipments of primary metal products were attracted to Waterloo, followed by Cedar Rapids, Dubuque, and Des Moines. An analysis of primary metal shipments to Waterloo reveals that the majority of these shipments originated in Illinois, Minnesota, and the Kansas City area. Shipments of these commodities to Des Moines are very similar, except that Kansas City top origin.

5.7. Truck Traffic Assignment

The purpose of this section is to summarize the process of assigning estimated commodity flows to highway links in the network. Traffic assignment involves two tasks: convert estimated commodity flows (from commodity flow distribution analysis) into vehicle equivalents and assign calculated truck flows to the highway links making up the shortest paths between origin-destination pairs. These two tasks are explained in section 5.7.1 and 5.7.2, respectively. The results of the assignment analysis are summarized in section 5.7.3. Finally, section 5.7.4 demonstrates an example of sensitivity type analysis by examining the impact of changes in the transportation network on truck traffic volumes. The transportation network is modified to include a recently planned highway, the Avenue of the Saints that will connect Minneapolis/St. Paul with St. Louis.

5.7.1. Truck Equivalents

Truck commodity flows have been, up to this step, expressed in tons shipped between origin-destination pairs. Commodity tons are converted to an equivalent number of trucks by using a vehicle equivalent for each commodity group. A commodity vehicle equivalent is the typical truck type, weight and configuration (axle arrangement), used to transport a commodity. Knowing the typical truck weight, commodity flow tonnages are converted to truck flows.

The weight of vehicle equivalents for the commodities included in the analysis are estimated from the truck weight survey. A vehicle equivalent weight for a specific commodity is taken as the average weight of all trucks observed in the survey carrying that commodity group. The equivalent truck weights for the nine commodities included in the analysis are shown in Table A-18. Vehicle equivalent weights are 31.6 tons of food products per truck, 28.8 tons of lumber and wood products per truck, 29.5 tons of chemicals and allied products per truck, 30.5 tons of stone, glass, and clay products per truck, and 31.8 tons of primary metal products per truck. Vehicle equivalent weights for the machinery products were calculated for the general and sub-commodity groups as: 21.9 tons of machinery products per truck, 24.8 tons of farm and garden machinery per truck, 20 tons of construction machinery per truck, and 17.4 tons of miscellaneous machinery products per truck.

Another approach to estimate equivalent vehicle weights is to find typical truck combination used for each commodity. Average weights can be established for these truck types knowing their maximum capacity. A sampling of the truck configuration used in carrying different commodities showed these trucks to be mainly tractor-trailer combinations. The portions of commodities carried by tractor-trailer, shown in Table 19, are about 97 percent of the food products; 95.5 percent of the lumber and wood products; 96.6 percent of the chemical products; 97.4 of the stone, glass, and clay products; 97.6 percent of the primary metal products; and 88.4 percent of the machinery products. The observed vehicle types can be used to find a typical vehicle weight based on truck capacity. The use of observed truck weight may yield a better estimate of the commodity vehicle equivalents since the truck weight survey provides a sampling of actual truck weights carrying specific commodities.

5.7.2. Highway Truck Flows

The final step in the truck planning procedure is to assign the estimated truck commodity volumes to the highway network. The output of this step can be tallied truck volumes by commodity type or a total link volume summed for all commodities. The assignment of truck traffic to the highway links connecting nodes in the network is relatively easy. After the commodity flows are converted to numbers of trucks, the routing of these truck trips is estimated.

The selection of a specific route is based on the same principle used in the traffic distribution. Highway routes used for truck shipments are those with least travel times. Highway links located on a shortest time path between an origin and destination node are all assigned the flow estimated between these nodes. The link volume is summed for all origin-destination pairs using that link.. Traffic assignment uses the results from that truck commodity flow distribution and shortest path calculations.

A FORTRAN routine is included in the main program that perform the analysis to find link assignments. The routine uses the shortest path calculations to mark links on shortest paths. The link volume is updated each time it is used by a path by adding the flow between the nodes on the path to the previous link volume. A total of 254 links are included in the network developed for the case study. These links are directional, and hence, truck flows assigned to highway links represent one way truck volumes. The total (two-way) link truck volumes are estimated in the FORTRAN routine as follows:

1. Variable definitions

   X(NA,NB,K) = flow of commodity k from origin node NA to destination NB

   Y(i,j,k) = total truck volume of commodity k on the link between nodes i and j. The value of Y is increased each time this link is traversed by a shortest path, by the equivalent number of trucks of the commodity tonnage shipped between the origin and destination of this path.

   nl = number of links on shortest paths

   WT(k) = equivalent vehicle weight (tons) for commodity (k)

2. Initialize variables

   Y(i,j,k) = 0, for all i, j, and k

3. For each possible origin-destination pair (NA, NB = 1,N), identify links between NA and NB. Links are identified from the shortest path calculations. The link truck volume is calculated for each commodity as

$$Y(i,j,k) = Y(i,j,k) + X(NA,NB,K)/WT(K)$$

3. Are there more origin-destination pairs in the network ?
   if yes, go to step 2

   if no, stop.

The link flow variable (Y) is the sum of truck commodity flows on a link in the network. Initially, all link volumes are set to zero. Each time a link is part of a shortest path, the link's flow is increased by the equivalent number of trucks of the flow estimated between the origin node and the destination node for this path. A commodity flow is divided by the average truck weight for that commodity to obtain the equivalent number of trucks. After all possible origin-destination pairs are processed, the calculated link volumes represent the total annual truck volumes for each commodity using these links. Truck volumes are summed for both directions average of travel on each highway link and divided by 365 (days per year) to estimate daily truck traffic.

5.7.3. Traffic Assignment Results

The final results of the truck planning procedure are estimated truck commodity flows on highway links in the state. Link truck traffic may be used to evaluate the performance of the transportation network. Estimates of truck traffic levels can also be used to assess impacts due to changes in economic activity in the state, the transportation network, or transportation policy. The type of transportation issue considered in the analysis will dictate the format for presenting the results. While annual truck traffic may be appropriate for measuring system-wide impacts, daily truck volumes may be needed for single highway link evaluation.

Estimated truck volumes represent part of the total truck traffic on state highways. A partial set of commodities and nodes were included in the case study. The estimated link truck volumes cannot be directly compared to truck traffic counts. However, these results can be used to identify common highway corridors used to ship commodities to and from the state.

The results of traffic assignment can be used for a number of analyses. Estimated truck flows on highway links have the advantage, compared to truck counts, of identifying the commodity shipped and the origin and destination of truck shipment. The mix of commodities using the highway network can be identified at any link in the network. A possible scenario for analysis is to examine the transportation patterns of a single or group of commodities in the state. Another scenario is to study freight traffic generators in the state. Further more, the proportion of the highway truck traffic that has an origin or destination in the state vs. bridge truck traffic can be identified. Such information will aid in understanding the demand placed by truck traffic on the highway network and enhance the allocation and programming of transportation projects.

As this research focuses on state level analysis, only internal highway links are covered in the discussion of results. Other reasons for excluding external links lie in the modeling of the transportation network and include: 1) external highway links beyond state borders were aggregated to few shortest travel time routes, and 2) external freight traffic analysis zones were aggregated to state level, eliminating the detailed layout of the highway network in these states.

There are 89 one-way highway links in the internal transportation network. The highway routes represented by these links include interstate highways I-29 and I-35 in the north-south direction, and I-80 in the east-west direction. Other United States highways included in the north-south direction are: US-75, US-71, US-169, US-63, and US-61. In the east-west direction, the network includes US-18, US-20, US-30, US-34, and US-52.

The map in Figure 7 shows the estimated truck volumes on highway links in Iowa. Truck traffic density measured by average daily truck traffic (ADTT) is represented by the thickness of the lines representing links in Figure 7. Four ranges of ADTT values are used: less than 500, 500-999, 1000-2500, and greater than 2500 trucks per day. Most of the state highways in the state fall in the light truck traffic category, averaging less than 1,000 trucks per day. However, almost all interstate highway links in the state fall in the highest two ranges. There is a clear increase of truck traffic on highway links crossing state borders as these links collect state truck traffic headed to external locations. The average daily truck traffic on these links approaches or exceeds 4000 trucks per day.

The heaviest truck movements across state borders occur near the eastern Iowa borders with Illinois on I-80 and to some extent on US-30 and US-20. Other high truck traffic density locations are along the Minnesota borders, over 4,200 trucks per day, as Iowa acts as a bridge for truck flows northbound to Minnesota or southbound from Minnesota. The Omaha-Council Bluffs area also has large concentration of truck traffic, over 4,000 trucks per day.

The mix of commodities using highway links is examined at selected cross-sections along highway links near state borders. Three cross-sections are shown in Figure 7 to show how commodities can be identified at any link in the transportation network. About 30 percent of the trucks on interstate highway I-80 carries food products, 54 percent carry stone, clay, or glass products, while the remaining 16 percent of these trucks carry other products. This trend is similar in the other two cross-sections on I-35 near the Minnesota borders in the north and the

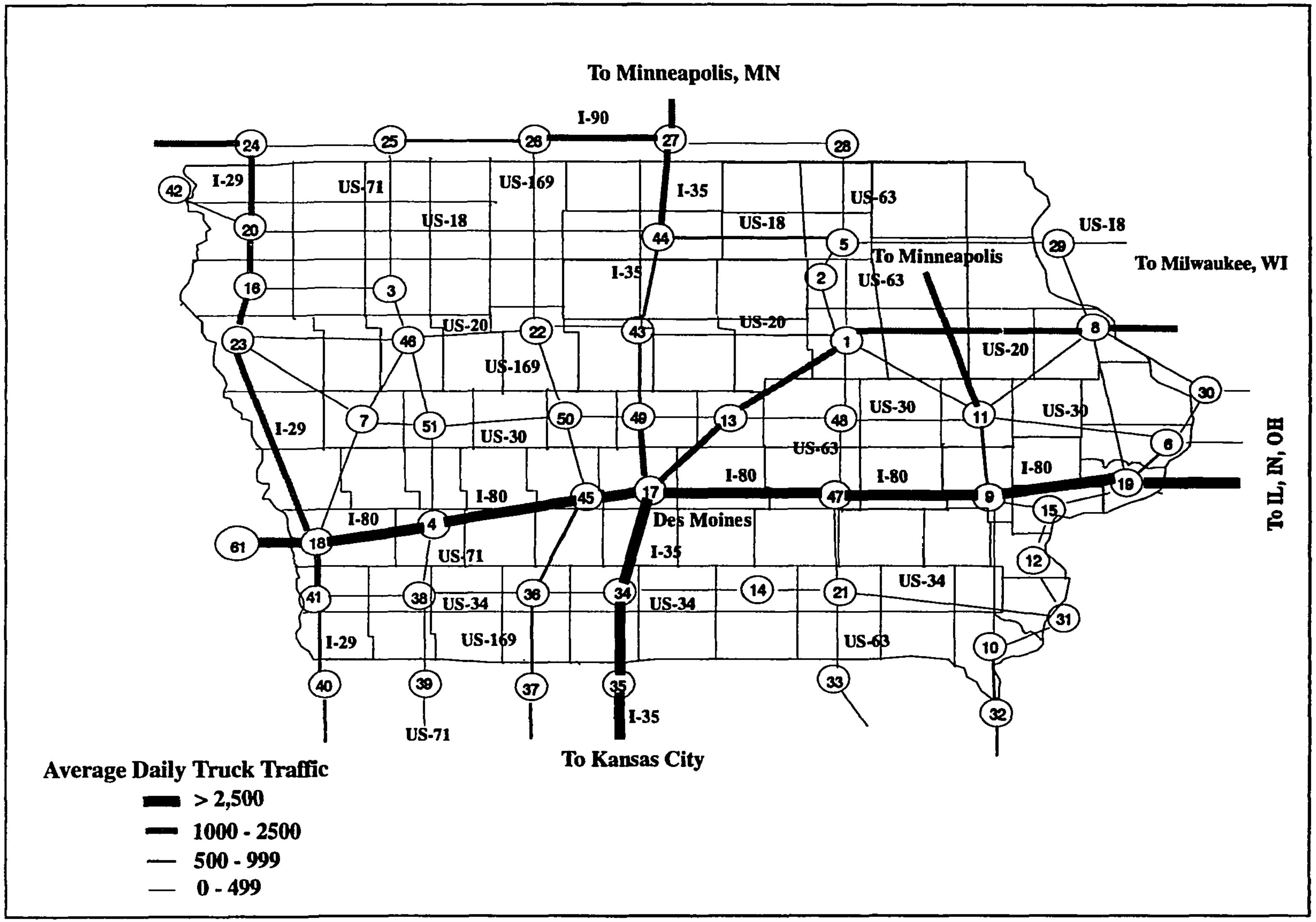

Figure 7 Estimated Truck Traffic Density on Internal Highway Links

Missouri borders in the south. The proportions of the products carried by trucks in the state can be established for selected locations along the state highways. These proportions can be applied at actual truck traffic counts to investigate the type of products carried by truck.

5.7.4. Sensitivity Analysis

One of the advantages to developing freight transportation planning models is to assess the impacts of changes in the transportation system on traffic flows. The changes can be in the activity system or they can be changes to the transportation network. To demonstrate how the developed procedure can be responsive to addressing impact analyses, the transportation network is modified by adding a direct, interstate highway link, between Minneapolis and Cedar Rapids. This link can be part of the proposed Avenue of the Saints, which will connect Minneapolis/St. Paul, Minnesota with St. Louis, Missouri.

The impact of adding a link to the highway network will change the travel time in the network, and as a result, the distribution patterns for some commodities. As commodity distribution patterns change, the truck volumes on some highway links will also change. The information obtained from these analyses can be used in: 1) calculating the benefits of proposed changes by identifying traffic levels that will utilize the proposed link, 2) assessing traffic levels on other links in the network if the objective was to reduce these levels, and 3) trace benefits (or costs) to individual shippers or producers (i.e., user costs).

In this scenario, an interstate highway link was added to the network to directly connect Cedar Rapids with Minneapolis/St. Paul. The link has a direct distance of 215 miles. Based on an average speed of 65 miles per hour, this link's travel time is approximately 200 minutes. The direct impact of adding this link to the network was an increase in shipments of food products from Cedar Rapids to Minneapolis by more than 50 percent. Also, shipments of chemical and allied products from Minneapolis to Cedar Rapids increased by more than 90 percent. Other significant traffic shifts were noted between Minneapolis, Milwaukee and Chicago. The reduction in travel time between Chicago and Minneapolis resulted in an increase, about 25 percent, in shipments between the two. At the same time, shipments between Milwaukee and Minneapolis declined by similar amounts.

The changes in traffic volumes of affected highway links are shown in Figure 8. As can be seen from the figure, estimated truck volumes on highway links originally used for shipments between Minneapolis and Cedar Rapids have mostly declined, and shifted to the new shortest time route. However, other major links, such as I-35, did not see substantial decrease of traffic. That is true because adding the new link increased traffic shipped between Minneapolis and Cedar Rapids due to reduced travel time. The increase in these shipments came as additional traffic.

5.8. Validation

The results obtained using the developed truck planning technique are validated against existing data sets. The two main outputs of the technique are: 1) estimates of commodity flows from the gravity model in the distribution analysis and 2) estimates of link truck volumes from the assignment process. Two validation methods may be used depending on data availability: 1) comparisons of estimated truck flows with actual truck traffic data and 2) trend extension.

5.8.1. Validation of Distribution Results

Currently there is no data set of actual commodity flows shipped to or from Iowa. The only data set that has commodity flow data is the commodity transportation survey. The survey is outdated and lacks the appropriate details in commodity classification and representation of

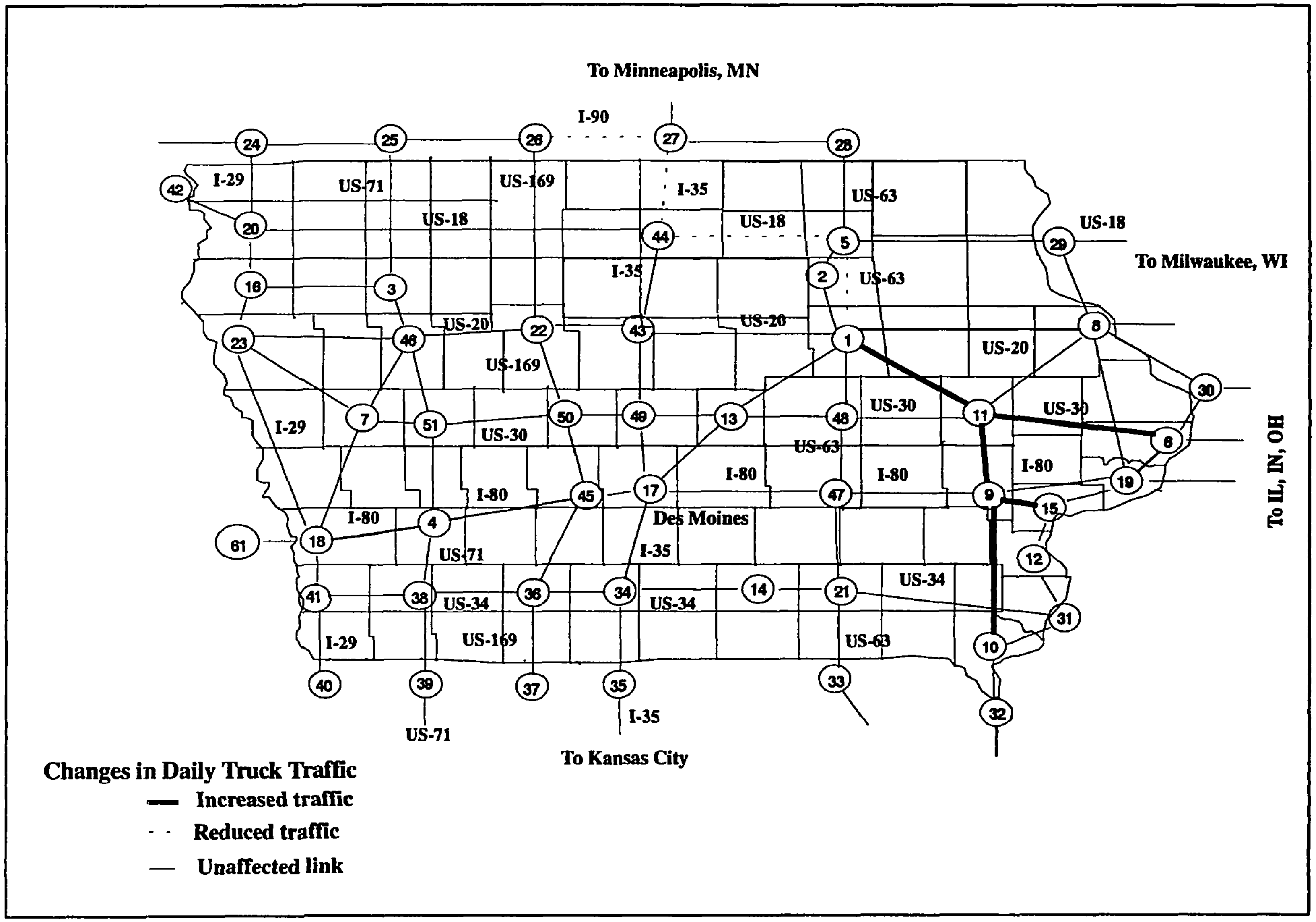

Figure 8 Changes in Estimated Truck Traffic Density on Internal Highway Links

geographical areas. Although the survey cannot be used directly to validate results, some comparisons of the general trends of freight shipments originated in Iowa can still be valuable. The survey can be used to identify: 1) states that exhibit significant shipments to or from Iowa, 2) commodities most frequently shipped to or from the state, and 3) the modal splits of these commodities using rail or truck.

An investigation of the Commodity Transportation Survey showed that about half of all the freight shipments originating in Iowa were intrastate shipments. Significant interstate shipments originating in Iowa terminated in the same set of states identified in the 1989 analysis. The top fifteen states in order of freight tonnage received from Iowa are: Illinois, Minnesota, California, Nebraska, Wisconsin, Ohio, South Dakota, Michigan, Texas, Kansas, New York, Missouri, Tennessee, Indiana, and North Dakota. The set of external locations used in the development of the transportation network in this research included all but three of these destinations (New York, Tennessee, and North Dakota).

The commodities observed to be most frequently shipped from the state in the Commodity Transportation Survey were stone, clay, and glass products (STCC 32); food and kindred products (STCC 20), chemical and allied products (STCC 28); lumber and wood products (STCC 24); and primary metal products (STCC 33). Similarly, these commodities were identified in the model to account for more than 75 percent of the truck shipments within the state, and were included in the case study.

5.8.2. Validation of Assignment Results

The estimated truck volumes on highway links may be compared to actual truck traffic counts collected periodically at selected locations in the state. These truck counts are based on

24-hours, 365-days counts of the number of axles crossing a section of the highway. The timing between axle crossings is used to determine vehicle type. The truck traffic counts on Iowa highways are expected to be greater than corresponding estimated truck volumes due to the partial set of commodities and nodes included in the case study.

Bridge truck traffic between pairs of states not part of the set of external zones transported through Iowa is not accounted for. Furthermore, the partial set of commodities included in the state will result in an underestimation of truck flows. A substantial segment of truck traffic, and containerized traffic for that matter, is classified as mixed shipments or "freight-all-kind". These shipments are hard to predict using the traffic generation analysis. An alternate approach would be to locate generators of these shipments, such as distribution and consolidation centers, and contact their traffic managers for information on their operations.

Truck traffic counts can still serve as upper-bounds on the estimated truck volumes. In addition, the relative truck traffic density on major highway routes in the state produced by the model should be similar to actual traffic densities. Truck traffic counts at selected highway sections are shown in Table A-20. Shown in the same table are corresponding estimated truck volumes. As expected, the estimated truck volumes at these arbitrary locations were less than actual truck counts. The differences between estimated truck volumes and actual truck counts can be attributed to counter location. The truck counts represent the number of truck crossing a point on a highway segment, while link truck volumes are constant for the length of that link. Since only two sectors were included in the analysis, truck traffic generated by other sectors is not reflected in estimated truck volumes. In addition, the only bridge truck traffic accounted for will be freight movements of the two sectors among the set of states included in the model.

5.8.3. Trend Extension

Results of the truck planning procedures can be validated using trend extension. This method of validation can be very useful in absence of comparable actual data. In this case, general truck traffic trends estimated in 1989 may be extended to future years. The 1991 truck weight survey data are used to examine these trends. One area that can be investigated is the set of origins and destination included in the model based on 1989 data compared to that in the 1991 truck weight survey. The destinations that received most of the freight truck tonnage shipped from Iowa in 1991 were Nebraska, Illinois, Missouri, Minnesota, Kansas, Texas, California, South Dakota, Indiana, Wisconsin, and Ohio accounting for more than 80 percent. Shipments to these states in 1989 were very similar, and accounted for more than 81 percent of the freight tonnage originating in Iowa.

The most frequent commodities shipped from Iowa in 1991 were also similar to those in 1989. Food products shipments from Iowa increased from 23 percent in 1989 to 38 percent of the total tonnage originating in Iowa in 1991. However, the set of top ten commodities accounted for the same portion of the total tonnage, about 84 percent. These trends are also similar in the truck traffic terminating in Iowa.

It is concluded that the set of external zones included in the case study does capture most of the origin-destination patterns for Iowa's commodities. The commodities included in the analysis were frequently shipped by truck in both years of the truck weight survey. These trends should be augmented by continually updating data from the truck weight survey. The time and effort involved in coding data from the survey are so little compared to the potential uses of a reliable truck data set. The survey is conducted every two years. If included in a freight related data base, the survey can provide valuable information on the products carried by trucks, the weights of these trucks, and the origin-destination patterns of truck shipments in the state.

CHAPTER 6. CONCLUSIONS

The purpose of this chapter is to summarize the research findings. The mission of this research was to investigate the data requirements for conducting freight transportation planning and to develop a truck planning technique for application at the state level. The assessment of relevant freight data revealed that the greatest deficiency was in commodity flow data sets. These data are either inadequate or do not exist. Ironically, commodity flow data are essential for the development of freight planning models.

The research identified potential freight data sources at the state level. These data sources and the state-of-the-art freight modeling capabilities were used to develop a state-level truck planning technique. This technique was adapted to a case-study application in Iowa using a subset of products and analysis zones. The procedure yielded two main outputs: 1) estimates of truck commodity flows between origin and destination zones in the network and 2) estimates of truck volumes on highway links represented in the transportation network. Results from the developed technique were validated using relevant available data sets.

This chapter is divided into three sections: freight transportation planning requirements, the truck planning technique, and suggestions for future research.

6.1. Freight Transportation Planning Requirements

A review of relevant literature on freight transportation planning revealed a shortage in planning tools, especially at the state level. Existing freight transportation models were developed without a realistic consideration of available data sources. In addition, these models were mainly applied in rail transportation, which has reliable data sources. Multimodal freight transportation models were developed and applied in developing countries, where the decisions of shippers and carriers are restricted by a central authority. These models cannot be easily adapted to the transportation system of the United States.

The complexities of freight transportation planning can be attributed to three factors: the shortage of reliable data, the large number of variables involved among various players (shippers, carriers, and government agencies) in moving products, and the various transportation requirements of several commodities. Although some of these complexities are inherent to freight transportation, the freight transportation planning process can be simplified without great loss in value.

The complexity of freight transportation modeling can be reduced significantly by modifying the scope of the analysis to focus on the major freight shipments rather than including all shipments. Existing freight transportation planning models attempt to model heterogeneous and conflicting micro decisions of shippers and carrier based on economic factors. However, the shipper-carrier interaction poses a complicated and dynamic process that is hard, if at all possible, to capture. These decisions, however, can be "averaged out" over the system to establish general trends that can be used for particular commodities.

The aspect of freight transportation planning dealing with multiple commodities has been overstated in some freight transportation planning models. These models assumed that different commodities compete over limited transportation supply, in terms of available modes and transportation link capacities. In reality, however, there is excess capacity in most transportation links. Further more, the choice of a transportation mode is not considered each time a shipment is made. The transportation system in the United States had reached its basic service stage, i.e., mode-commodity relationships have been long established for most commodities, especially after the regulatory reform of 1980. Only major changes in transportation services and/or rates will cause major modal shifts.

For a state level application, a planning model needs to consider a relatively small number of commodities. Except states with diverse and intense economic activity (e.g., California), the bulk of the economic activity in a state can be captured in a few sectors (less than five). The products used or produced by these sectors can then be investigated to determine their transportation requirements implied not only by the products but also the locations for supplies and consumption of these products. This analysis will also help planners select transportation links to include in the analysis. The consideration of all existing transportation links will result in modeling complexities and inaccuracies in model output. Transportation routes most frequently used should make up the transportation network so the model can capture actual transportation trends.

Reducing the level of details in freight transportation models will also reduce data requirements. Freight data have been cited repeatedly in the literature as a major impediment to efficient planning tools. However, data collection put a burden on states and private sector budgets. The fragmented state of freight transportation services and players complicates the process of selecting what freight data to measure. Many of the available freight data sets are collected and reported by different agencies and thus lack consistency. Carriers, shippers, departments of transportation, departments of commerce, departments of agriculture, agricultural groups, state police and highway patrol are only some sources for freight transportation data.

The availability and quality of freight data should improve greatly in the near future because of new transportation policy. The 1991 Intermodal Surface Transportation Efficiency

Act resulted in two main changes: freight is included in the transportation planning process at the state level, and the development of management systems that will rely on adequate data to measure the performance of the transportation system. The new planning requirements and the revival of the national commodity transportation survey should improve freight related data.

6.2. Development of Truck Planning Technique

The research developed a technique for planning truck transportation in the state and applied the methodology to the State of Iowa. The developed technique predicts commodity tonnage produced and attracted to the state, the distribution of truck commodity flows among origin-destination pairs, and the truck volumes on highway links in the state. Three factors were considered in developing the methodology: applicability to state level analysis, freight data availability, and practical value. State level freight transportation planning requires greater details in describing commodities and analysis zones in the state. Freight produced or attracted in a state is shipped to or from external locations. A subset of external locations may be used that captures most of the shipments in the state. In contrast, in national level models, freight traffic generation and distribution can be aggregated to larger units, but considers all commodity production and attraction zones.

The availability of freight data was considered in the design of the truck planning technique. A model that requires data that are not available would have little practical value. The approach followed in this research was to determine what end results must be reached and, given what data are available, select appropriate tools. The desired output of the technique was estimates of truck volumes on highway links identified by commodity groups and origin destination of shipments. To estimate truck volumes, commodity flow distributions were required. These distributions in turn, were calculated based on commodity production and attraction and a criteria for route selection. Travel time was selected as the basis for traffic distribution.

Commodity productions and attractions are aggregated to nodes that represent analysis zones. Analysis zones within the state correspond to counties, while external analysis zones correspond to states. Available employment and population data are used to estimate freight generation in analysis zones. The highway link with minimum travel time is selected to represent all links connecting each pair of nodes in the network, if one exists. The collection of nodes and links makes up the transportation network in the methodology.

The practicality feature in this methodology is directly implied from its design around the case study application. Although, Iowa was used as a vehicle for the development of the methodology, the technique can be applied with little modifications to other states. Similar freight data sets are available to all states. Only the nodes and products in the model need to be fitted to particular state needs. The general framework for obtaining and assigning truck commodity flows can be directly used in other states.

The results of the model can be used for various analysis. One potential use of the estimated truck traffic is to determine how highway links are used by different commodities or sectors. The transportation patterns of commodities that are important to the state's economy or an area in the state are identified. Commodity transportation needs can be compared to the transportation system to identify problem areas that may cause inefficiencies to shippers and movers of these commodities. Deficiencies in the transportation system that have critical impacts on the efficient movements of the state commodities can be given higher priorities in future transportation programs.

Knowing the combination of commodities using a highway route can aid in the programming of maintenance activities on this route. Factors that can be used in the planning process are: time sensitivity of commodities using the highway route, seasonal fluctuations in commodity flows, peak commodity flows, and alternate routes that can be substituted if this route is removed. Truck commodity flows can aid in these and other transportation planning decisions.

Truck data currently available at the state level are truck traffic data and some truck weight classification samples. These data sets do not identify the commodity shipped in these trucks, nor the origin or destination of these truck shipments. State DOT officials might have an idea on major truck traffic generators in the state, but these views cannot be quantified without efficient truck transportation planning models. Origin and destination data will identify what portion of truck traffic on the state highway system is local or bridge traffic. The growing applications of the IVHS (Intelligent Vehicle Highway Systems) focus on easing the movement of truck traffic across state lines. The accurate assessment of affected truck volumes is paramount to justify and assess impacts of possible IVHS projects.

6.3. Recommendations

Given the importance of freight transportation to the economy and the major role of trucks in moving freight, efficient freight transportation planning must be established as a basic part of the states' overall planning process. States tended to focus on movements of passengers in automobiles, not on freight movements of several commodities and transportation modes. The transportation system must be viewed as multimodal and multicommodity. The emerging concept of intermodalism poses great challenges for state planners and requires changes in not only the planning concepts but also the organizational structure of planning agencies. Until recently, many state departments of transportation were called highway departments. Highway expenditures absorb the majority of state transportation funds. However, states must oversee a total and comprehensive transportation system that consists of all transportation modes and must recognize significant interactions, or interface, between these modes.

To understand the transportation system in the state requires complete understanding of each component in the system. The trucking sector, although paramount to moving freight, has received less attention in freight transportation planning. Also, trucks share public highways, and therefore, are responsible for a share of the cost of keeping and operating these highways. States must develop efficient tools to be able to quantify the impacts of truck shipments.

Given limited resources, this research included a subset of commodities, used a simplified highway network, and subset of freight generators. Analysis dealing with specific issues may not be appropriately performed using this model. The major effort of developing freight transportation models lies in assembling a reliable data base of freight data. Once that step is performed, it is easy to design the model. However, two areas where more work is required are freight generation modeling and modal analysis.

The development of standard commodity production rates is the first area for improvement and easiest to accomplish. These rates should be standardized, similar to trips production rates used in the passenger trips for urban transportation planning. The next area of improvement is input-output relationships. Existing input-output data are inconsistent with other data sets in their sector classifications and lack coverage of agricultural sectors. However, agricultural sector makes up the greatest portion of the rural state economy and produce significant truck freight.

Finally, more research is required in the area of modal analysis. This process must be simplified in terms of the detailed data requirements and the difficulty of applications. Many commodities can be classified as captured for one mode. For example, coal shipments are almost entirely carried by rail, while meat products are mostly carried by trucks. Instead of building modal cost functions for all commodities, more effort is needed for those commodities with transportation needs that enable them to use more than one mode.

The future of freight transportation planning looks very promising. Great advances in computer technology, especially in data management and graphical representation systems will enhance and encourage the development of freight transportation models. In addition, the recent changes in transportation policy will help freight transportation to receive significant attention from state DOTs. The new management systems developed by states enable the retrieval and display of complex transportation data, too. As these systems are developed it is essential to understand and validate the underlying modeling concepts before these systems are implemented.

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APPENDIX

Table A-1 1989 Railcar Tonnage Originating in Iowa by Commodity				
STCC	**Commodity**	**Tonnage**	**%**	**Cum %**
1	Farm Products	12,903,313	53.0	53
20	Food and Kindred Products	8,494,076	34.9	88
28	Chemicals	1,067,612	4.4	92.4
32	Stone, Clay, and Glass Products	740,942	3.0	95.4
40	Waste and Scrap Materials	578,274	2.4	97.8
29	Petroleum and Coal Products	146,960	0.6	98.4
14	Nonmetallic Minerals	128,846	0.5	98.9
37	Transportation Equipment	86,817	0.4	99.3
33	Primary metal products	50,160	0.2	99.5
24	Lumber and wood products	43,320	0.2	99.7
35	Machinery, except electrical	34,260	0.1	99.8
26	Pulp, paper and allied products	17,200	0.1	99.9
Sum of listed commodities		24,291,780		
Total (all commodities)		24,323,556		

Table A-2 1989 Railcar Tonnage Originating in Iowa by Destination
(excluding intrastate traffic)

Destination	Tonnage	%	Cum %
Illinois	10,298,943	42.3	42.3
Missouri	2,845,714	11.7	54.0
Louisiana	2,127,245	8.7	62.8
California	1,405,985	5.8	68.6
Minnesota	1,173,021	4.8	73.4
Texas	1,134,507	4.7	78.1
Washington	994,368	4.1	82.1
Wisconsin	476,556	2.0	84.1
Nebraska	409,102	1.7	85.8
Kansas	318,228	1.3	87.1
Tennessee	310,215	1.3	88.4
Sum listed states	21,493,884		
Total	24,323,556		

Table A-3 1989 Railcar Tonnage Terminating in Iowa by Commodity

STCC	Commodity	Tonnage	%	Cum %
11	Coal	13,292,397	60.9	60.9
28	Chemicals	2,648,206	12.1	73.0
1	Farm Product	2,077,793	9.5	82.6
14	Nonmetallic minerals, except fuels	1,024,089	4.7	87.2
26	Pulp, paper and allied products	668,860	3.1	90.3
33	Primary metal products	430,932	2.0	92.3
24	Lumber and wood products, except furniture	414,580	1.9	94.2
20	Food	381,280	1.7	95.9
29	Petroleum and coal products	295,572	1.4	97.3
40	Waste and scrap materials	235,316	1.1	98.4
Sum (listed commodities)		21,469,025		
Total (all commodities)		21,825,805		

Table A-4 1989 Railcar Tonnage Terminating in Iowa by Origin
(Excluding intrastate traffic)

Origin	Tonnage	%	Cum %
Wyoming	12,432,773	57.0	57.0
Minnesota	2,116,759	9.7	66.7
Illinois	1,128,351	5.2	71.8
South Dakota	869,488	4.0	75.8
Texas	489,484	2.2	78.1
Nebraska	449,279	2.1	80.1
Indiana	431,637	2.0	82.1
Canada	391,944	1.8	83.9
Florida	303,694	1.4	85.3
Missouri	295,020	1.4	86.6
Louisiana	287,664	1.3	88.0
Wisconsin	271,660	1.2	89.2
Kansas	222,212	1.0	90.2
	21,825,805		

Table A-5 1989 Iowa Intrastate Railcar Tonnage by Commodity

STCC	Commodity	Tons	%	Cum %
1	Farm products	7,516,085	76.1	76.1
20	Food and kindred products	802,604	8.1	84.2
14	Nonmetallic minerals	604,577	6.1	90.3
28	Chemicals and allied products	528,040	5.3	95.6
32	Stone, clay, and glass products	128,660	1.3	96.9
40	Waste, scrap	114,620	1.2	98.1
11	Coal	89,608	0.9	99
24	Lumber and wood products	49,500	0.5	99.5
37	Transportation Equipment	35,822	0.4	99.9
29	Petroleum or coal products	12,244	0.1	100
Total		9,881,760		

Table A-6 Major Production Counties in Iowa

COUNTY	TONS	%	CUM %
LINN	5,417,351	23.3	23.3
MUSCATINE	2,370,593	10.2	33.5
POLK	1,657,209	7.1	40.6
SCOTT	1,508,069	6.5	47.1
CLINTON	1,317,940	5.7	52.7
LEE	1,149,536	4.9	57.7
WOODBURY	916,763	3.9	61.6
DUBUQUE	777,321	3.3	64.9
WEBSTER	776,776	3.3	68.3
PLYMOUTH	517,507	2.2	70.5
JOHNSON	502,607	2.2	72.7
BUENA VISTA	446,143	1.9	74.6
POTTAWATTAMIE	389,585	1.7	76.2
BLACK HAWK	385,153	1.7	77.9
MONROE	375,179	1.6	79.5
CRAWFORD	375,105	1.6	81.1
CHICKASAW	369,423	1.6	82.7
LOUISA	349,405	1.5	84.2
MARSHALL	304,664	1.3	85.5
WAPELLO	290,589	1.2	86.8
SIOUX	288,598	1.2	88.0
CASS	246,646	1.1	89.1
BREMER	244,080	1.0	90.1
Sum of listed	20,976,242		
All counties	23,275,286		

Table A-7 Internal Zones: Selected Iowa Counties and their Centers

NODE	COUNTY	CENTER
1	Black Hawk	Waterloo
2	Bremer	Weverly
3	Buena Vista	Storm Lake
4	Cass	Atlantic
5	Chickasaw	New Hampton
6	Clinton	Clinton
7	Crawford	Denison
8	Dubuque	Dubuque
9	Johnson	Iowa City
10	Lee	Fort Madison
11	Linn	Cedar Rapids
12	Louisa	Wapello
13	Marshall	Marshall Town
14	Monroe	Albia
15	Muscatine	Muscatine
16	Plymouth	Le Mars
17	Polk	Des Moines
18	Pottawattamie	Council Bluffs
19	Scott	Davenport
20	Sioux	Sioux Center
21	Wapello	Ottumwa
22	Webster	Fort Dodge
23	Woodbury	Sioux City

Table A-8 Distribution of Originating Truck Traffic: Major Destinations

	STCC 20	STCC35	SUM		
DESTINATION	TONS	TONS	TONS	%	CUM %
Missouri	2,573	269	0.00	0.00	0.00
Nebraska	2,455	323	0.00	0.00	0.00
Illinois	2,064	213	0.00	0.00	0.00
Kansas	2,042	166	0.00	0.00	0.00
Minnesota	1,503	75	0.00	0.00	0.00
Texas	1,172	246	0.00	0.00	0.00
California	404	183	0.00	0.00	0.00
Michigan	484	87	0.00	0.00	0.00
Ohio	441	69	0.00	0.00	0.00
South Dakota	395	113	0.00	0.00	0.00
Indiana	353	41	0.00	0.00	0.00
Wisconsin	330	41	0.00	0.00	0.00
Oklahoma	148	90	0.00	0.00	0.00
Canada	77	84	0.00	0.00	0.00
Listed destinations			16,442		
All destinations			0.00		

Table A-9 Terminating Traffic Tonnage STCC 20 , 35 and their Inputs

Major Origin States						
	STCC 20	STCC 35	INPUTS	SUM		
ORIGIN	TONS	TONS	TONS	TONS	%	CUM %
Kansas	2,121	293	2,423	4,837	20.2	20.2
Nebraska	2,758	291	1,568	4,617	19.3	39.5
Missouri	945	109	1,516	2,570	10.8	50.3
Illinois	838	180	1,536	2,554	10.7	61.0
Minnesota	1,185	82	755	2,022	8.5	69.5
Texas	568	145	888	1,601	6.7	76.2
Wisconsin	334	8	378	720	3.0	79.2
South Dakota	270	74	259	603	2.5	81.7
Ohio	200	72	241	513	2.2	83.9
Oklahoma			454	454	1.9	85.8
California			248	248	1.0	86.8
Listed origins				20,491		
All origins				23,869.0		

Table A-10 External Zones and their Centers

Node	Zone	Area Included	Center
60	Missouri	20% of total freight generated in Missouri	St Louis
61	Nebraska		Omaha
62	Kansas	Total Freight generated in Kansas, and 80% of freight generated in Missouri	Kansas City
63	Illinois		Chicago
64	Minnesota		Minneapolis
65	Texas		Dallas
66	California		Los Angeles
67	Michigan		Detroit
68	Ohio		Cleveland
69	South Dakota		Sioux Falls
70	Indiana		Indianapolis
71	Wisconsin		Milwaukee
72	Oklahoma		Oklahoma City

Table A-11 Intermediate Nodes and their Connectivity

		Connecting Nodes			
Intermediate Nodes		Internal and Intermediate		External	
Node	No.	NU	Nodes	NE	Nodes
Luverne, MN	24	2	2520	1	69
Jackson, MN	25	3	24263	0	
Blue Earth, MN	26	3	252722	0	
Albert Lea, MN	27	3	262844	1	64
Chester, IA	28	2	275	0	
Prairie du Chian, WI	29	2	58	5	7167636870
Sabula, IA	30	2	86	5	7167636870
Burlington, IA	31	3	211210	0	
Keokuk, IA	32	1	10	1	60
Mark, IA	33	1	21	1	60
Osceola, IA	34	4	36171435	0	
Lamoni, IA	35	1	34	4	60627265
Afton, IA	36	4	38453437	0	
Redding, IA	37	1	36	4	60627265
Tenville, IA	38	4	4143639	0	
Braddyville, IA	39	1	38	4	60627265
Hamburg, IA	40	1	41	4	60627265
Pacific Jct., IA	41	3	183840	0	
Canton, SD	42	1	20	1	69
Williams, IA	43	4	2244149	0	

NU: Internal connected nodes,
NE: External connected nodes

Table A-11 continued ...

Clear Lake, IA	44	4	2027543	0	
De Soto, IA	45	4	4501736	0	
Early, IA	46	5	23322517	0	
Malcom, IA	47	4	1748921	0	
Toledo, IA	48	4	1311147	0	
Ames, IA	49	4	50431317	0	
Beaver, IA	50	4	51224945	0	
Carroll, IA	51	4	746504	0	

Table A-12 Input-Output Analysis for Food Industries

Commodity Producing Input Industries

Total production of STCC20 equals 24.641 million tons

STCC	Input Commodity	TONS/TON	%	Cum %
20	Food and kindred	1.29676	53.7	53.7
29	Petroleum	0.39051	16.2	69.9
1	Livestock and products	0.30540	12.6	82.5
28	Chemicals and allied	0.11806	4.9	87.4
32	Stone, glass, clay	0.10331	4.3	91.7
26	Pulp and paper	0.09543	4.0	95.7
33	Primary metal	0.05275	2.2	97.8
34	Fabricated metal	0.01835	0.8	98.6
24	Lumber and wood	0.01637	0.7	99.3
30	Rubber and plastic	0.01090	0.5	99.7
35	Machinery	0.00286	0.1	99.8
37	Transportation equipment	0.00142	0.1	99.9
22	Textiles and fabrics	0.00121	0.1	100.0
36	Elec. machinery	0.00087	0.0	100.0
39	Misc. manufacturing	0.00022	0.0	100.0
38	Instruments	0.00007	0.0	100.0
		2.4144942		

Table A-13 Input-Output Analysis for SIC 352 (farm and garden machinery)

SIC	Input Commodity	Tons/Ton	%	Cum %
33	Primary metal	2.23292	31.1	31.1
29	Petroluem refining	1.52137	21.2	52.3
352	Farm and garden machinery	1.07345	14.9	67.2
24	Lumber and wood	1.06861	14.9	82.1
28	Chemicals	0.33876	4.7	86.8
32	Stone, glass, and clay	0.28915	4.0	90.8
35	Machinery	0.19735	2.7	93.6
26	Paper and allied	0.13305	1.9	95.4
30	Rubber and plastic	0.12739	1.8	97.2
37	Trasportation equipment	0.07253	1.0	98.2
34	Fabricated metal	0.05159	0.7	98.9
20	Food and kindred	0.03222	0.4	99.4
36	Electric machinery	0.02310	0.3	99.7
1	Agricultural	0.01162	0.2	99.8
22	Textiles	0.00872	0.1	100.0
39	Misc. manufacturing	0.00136	0.0	100.0
38	Instruments	0.00054	0.0	100.0
25	Household furniture	0.00040	0.0	100.0
		7.18413		

Table A-14 Input-Output Analysis for SIC 353 (construction machinery)

Total production of STCC 353 is 390,757 tons

STCC	Input Industry	Tons/Ton	%	Cum %
33	Primary metal	2.64102	39.6	39.6
29	Petroluem refining	1.59404	23.9	63.5
353	Construction machinery	1.08275	16.2	79.7
32	Stone, glass, and clay	0.42613	6.4	86.1
28	Chemicals	0.31355	4.7	90.8
35	Machinery	0.16368	2.5	93.2
26	Paper and allied	0.09708	1.5	94.7
30	Rubber and plastic	0.09154	1.4	96.1
24	Lumber and wood	0.07763	1.2	97.2
34	Fabircated metal	0.05381	0.8	98.0
37	Tranportation equipment	0.05150	0.8	98.8
20	Food and kindred	0.03376	0.5	99.3
36	Elec. machinery	0.02419	0.4	99.7
1	Agricultural	0.01144	0.2	99.9
22	Textiles	0.00698	0.1	100.0
39	Misc. manufacturing	0.00199	0.0	100.0
38	Instruments	0.00062	0.0	100.0
25	Furniture	0.00032	0.0	100.0
		6.67202		

Table A-15 Input-Output Analysis for SIC 359 (miscellaneous machinery)

STCC	Input Commodity	STCC 359	%	Cum %
33	Primary metal	1.62715	30.9	30.9
29	Petroluem refining	1.34311	25.5	56.4
359	Misc machinery	1.08472	20.6	77.0
32	Stone, glass, clay	0.53123	10.1	87.1
28	Chemicals	0.21300	4.0	91.1
26	Paper and pulp	0.17069	3.2	94.4
35	Machinery	0.05760	1.1	95.4
34	Fabricated metal	0.05304	1.0	96.5
24	Lumber and wood	0.05279	1.0	97.5
20	Food and kindred	0.03851	0.7	98.2
30	Rubber and plastic	0.03355	0.6	98.8
37	Transportation equipment	0.02029	0.4	99.2
36	Electric machinery	0.01808	0.3	99.6
1	Agricultural	0.01255	0.2	99.8
22	Textiles	0.00845	0.2	100.0
39	Misc. manufacturing	0.00160	0.0	100.0
38	Instruments	0.00069	0.0	100.0
25	Furniture	0.00032	0.0	100.0
		5.26737		

Table A-16 Consumer Expenditures by Commodity Group

(1977 U.S. Population of 219.76 million)

Commodity	Million Dollars	%	Cum. %	$ ton	Tons million	Tons/ Capita
Agricultural	17707	3	3.3	NA	NA	0
Petroleum refinery products	58448	11	14	83	704	3.2044
Food products	171483	32	46	456	376	1.7112
Chemicals	30767	6	51	267	115	0.5244
Transportation equipment	69142	13	64	1572	44	0.2001
Glass, stone, and clay	3884	1	65	125	31.1	0.1414
Paper and pulp	8894	2	66	327	27.2	0.1238
Furniture	16974	3	69	1149	14.8	0.0672
Apparel	64170	12	81	5048	12.7	0.0578
Miscellaneous manufacturing	24475	5	86	2200	11.1	0.0506
Ruber and plastic	11916	2	88	1223	9.7	0.0443
Textiles	13465	3	90	2030	6.6	0.0302
Electric machinery	19102	4	94	3589	5.3	0.0242
Tobbacco	16980	3	97	3867	4.4	0.02
Lumber and wood	881	0	97	236	3.7	0.017
Machinery, except 352 and 359	2158	0	100.	3017	0.7	0.0033
Farm and garden machinery	205	0	100	3017	0.1	0.0003
Miscellaneous mchinery	62	0	100	3017	0	0.0001

Table A-17 Sample of Estimated Truck Tonnage of Food Products at Internal Zones

Node	County	Production Tons	Originating Rail Tons	Estimated Truck Tons
1	BLACK HAWK	16056	0	16056
2	BREMER	219693	0	219693
3	BUENA VISTA	445915	21600	424315
4	CASS	246646	0	246646
5	CHICKASAW	365931	0	365931
6	CLINTON	1316515	1136602	179913
7	CRAWFORD	375105	24480	350625
8	DUBUQUE	651685	36080	615605
9	JOHNSON	502402	0	502402
10	LEE	1146680	534220	612460
11	LINN	5320045	2071762	3248283
12	LOUISA	349405	22080	327325
13	MARSHALL	287890	7900	279990
14	MONROE	374774	479230	0
15	MUSCATINE	2356564	354346	2002218
16	PLYMOUTH	517507	0	517507
17	POLK	1537072	253128	1283944
18	POTTAWATTAMIE	389083	23920	365163
19	SCOTT	1444092	46080	1398012
20	SIOUX	285976	1680	284296
21	WAPELLO	232663	2920	229743
22	WEBSTER	776776	33800	742976
23	WOODBURY	908013	130400	777613

Table A-18 Average Vehicle Weight by Commodity Carried

STCC	Commodity	Trucks Observed	Weight Tons	Avg. Tons
20	Food and kindred products	2,224	70,170	31.6
24	Lumber and wood produts	357	10,285	28.8
28	Chemicals and allied products	393	11,610	29.5
32	Stone, caly, and glass products	377	11,512	30.5
33	Primary metal products	493	15,655	31.8
35	Machniery products	490	10,712	21.9
352	Farm and garden machinery	179	4,439	24.8
353	Construction machniery	220	4,396	20.0
359	Miscellaenous machinery	22	384	17.4

Table A-19 Distribution of Truck Type by Commodity

Commodity	Type	Number	%
Food and kindred products	2	199	8.9
	3	2016	90.6
	All	2224	
Lumber and wood products	2	50	14.0
	3	302	84.6
	All	357	
Chemicals and allied products	2	41	10.4
	3	349	88.8
	All	393	
Stone, clay, and glass products	2	30	8.0
	3	340	90.2
	All	377	
Primary metal products	2	24	4.9
	3	460	93.3
	All	493	
Machinery products	2	121	24.7
	3	314	64.1
	All	490	

Type 2: Single unit truck
Type 3: Truck trailer combination

Table A-20 Estimated vs. Observed Truck Volumes at Selected Locations

Route	Section	Count	Estimate	Percentage Estimated
I-29	40-41 MO borders	2343	976	41.7
	41-18 south of I-80	2762	1015	36.7
	18-23	1698	1251	73.7
	20-24	2042	1609	78.8
I-35	35-34 MO borders	2234	2091	93.6
	34-17	3049	2585	84.8
	17-40	3351	1265	37.7
	44-27	2525	1546	61.2
I-80	18-4 NE borders	4064	2793	68.7
	45-4 West of US 169	4539	2555	56.3
	47-9 West of US 63	5904	3425	58.0
	9-19 East of Davenport	6851	3752	54.8