REGIONAL FREIGHT FLOW ASSIGNMENT USING GEOGRAPHIC INFORMATION SYSTEMS

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16. Abstract

The movement of freight is an important but often overlooked aspect of the transportation system. While much research and planning has centered on passenger transport, freight demand and modeling have received relatively little attention due to lack of appropriate data from which accurate vehicle flows could be predicted. This report proposes a methodology that can be used to better understand commodity movement.

A method for estimating traffic volumes by commodity type on the transportation network from inter-region commodity flow data is presented. This approach was applied to a case study using the Metropolitan Planning Organization, and has been evaluated for effectiveness. Freight tons of different commodities originiating, traveling within and ending in the Boston area have been converted to truck numbers and distributed to different areas in the state using industrial employment density as an indicator variable. Truck flows have then been assigned to the highway network using the user-equilibrium technique, and the resulting link volumes have been validated against existing survey counts. On comparison, a large percentage of roads showed that the estimated truck counts were within a tolerable error margin.

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Regional Freight Flow Assignment Using Geographic Information Systems

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Abstract

The movement of freight is an important but often overlooked aspect of the transportation system. While much research and planning has centered on passenger transport, freight demand and modeling have received relatively little attention due to lack of appropriate data from which accurate vehicle flows could be predicted. This report proposes a methodology that can be used to better understand commodity movement.

A method for estimating traffic volumes by commodity type on the transportation network from inter-region commodity flow data is presented. This approach was applied to a case study using the Boston Metropolitan Planning Organization, and has been evaluated for effectiveness. Freight tons of different commodities originating, traveling within and ending in the Boston area have been converted to truck numbers and distributed to different areas in the state using industrial employment density as an indicator variable. Truck flows have then been assigned to the highway network using the

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CHAPTER 1

INTRODUCTION

1.1 Background

Until recently, states and Metropolitan Planning Organizations (MPOs) were not overly concerned with increased freight traffic because increasing freight provided additional justification for an improved or expanded highway system, and additional road-user tax revenues. But this situation has changed. Rail line abandonment in the early 1980's had made planning organizations sensitive to the spillover of bulk freight traffic onto the highway system, particularly because of a perceived long term inability to accommodate this added traffic on older systems without pavement strengthening or reconstruction[1]. Since then, MPOs have been making efforts to incorporate freight into their surface transportation planning process.

A major impetus to these efforts was provided by the Intermodal Surface Transport Efficiency Act (ISTEA - passed in 1991), which encouraged modification of the transportation planning process at the state and metropolitan levels. The ISTEA required all MPOs and planning agencies to develop intermodal plans that would focus on methods to enhance efficiency of freight movement in a region and to improve the connectivity of various modal networks within their jurisdictions.

However, a major limitation for regional freight planning has been lack of appropriate data. According to a 1994 survey, 90% of the nation's largest metropolitan planning organizations lacked sufficient freight flow data to conduct adequate freight planning[2]. Although some gross commodity shipment databases exist, such as the

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[1] Frederick Memmott, Roger L. Creighton, Trends in Statewide Freight Planning, *TR News*, Vol. No. 112, pp. 24-27, 1984.
[2] Intermodal Freight Transportation: Projects and Planning Issues. Report prepared for the U.S. General Accounting Office, 1996.

Interstate Commerce Commission (ICC) Rail Waybill and the Commodity Flow Survey (CFS), these aggregate data sources have not been translated into accurate predictions of vehicle flows. Hence current research efforts are being directed to develop a methodology for modeling freight flows using information from existing data sources.

Geographic Information Systems (GIS) are useful analysis tools, as they involve integration of spatially referenced data into problem solving settings. Since transportation planning is also typically thought of as one kind of spatial analysis, a GIS based approach has been chosen for the purpose of freight movement analysis. This approach also conforms to the recent efforts and methodologies in other areas of transportation planning, and thus provides flexibility for understanding spatial effects of commodity flows within a broader planning environment.

1.2 Research Objective

The objective of this research was to develop an approach for distributing and assigning freight flows in a region. This project focuses primarily on modeling inter-regional and intra-regional freight flow movements in a region. A potential output of this research is the development of a quantitative methodology for estimating freight traffic from aggregate measures of inter-regional commodity flows. The results of the above work could then be used by Metropolitan Planning Organizations and other planning agencies for integrating freight into their transportation planning process, and also for developing a framework for evaluation of various policy decisions.

1.3 Organization of Project Report

The following approach was adopted for this research. First, a survey was conducted to obtain information on how MPOs and planning organizations were incorporating freight into their surface transportation planning process. Then, available literature on freight planning efforts, intermodalism, and use of GIS in modeling commodity movement were reviewed. A methodology was then developed for modeling freight flow, and was evaluated using a case study of the Boston Metropolitan Planning Organization. A review of the literature survey is summarized in Chapter 2. A methodology proposed for modeling freight from aggregate data sources is described in Chapter 3. This methodology has been applied to the Boston MPO area, and the results have been evaluated to ascertain the effectiveness of the methodology. This case study is presented in Chapter 4. Chapter 5 describes insight gained by using the proposed methodology for commodity movement prediction. Limitations of the approach are summarized along with future research areas. The appendices contain detailed derivations, data, and additional information from the case study.

CHAPTER 2

LITERATURE REVIEW

This section discusses the results of a literature survey conducted to investigate earlier research efforts in areas on, and peripheral to, the topic of this report, and a mail survey that was carried out to investigate the freight planning efforts of various MPOs and regional planning organizations in New England. The synthesized literature was divided into the following sections to present freight issues in a clear and comprehensive manner.

1. Current freight planning practices (statewide & regional case studies)
2. Freight forecasting techniques and evaluation of intermodal/multimodal networks
3. Use of geographic information systems (GIS) in freight planning and freight flow modeling.
4. A survey of current freight planning procedures in use in New England.

2.1 Current Freight Planning Practices - Case Studies

To study the current state of the practice in freight planning, several case studies were identified and analyzed. The case studies were divided into statewide and regional approaches, depending on the level at which planning was performed.

2.1.1 Statewide Studies

2.1.1.1 Oregon. The Oregon Intermodal Council, established in March 1992, was one of the earliest Freight Advisory Councils (FAC) in the country. The Council has been functioning as a lobbying group and sometimes takes an opposing political position to the Federal DOT (1). An Intermodal Facilities and Systems Management System (IMS) was developed to provide a basis for better integration of and connection between all transportation facilities and services. It also provides information for the Intermodal Plan.

In the first phase, a systems inventory was conducted, the system was defined, gaps in the data were assessed, policy implications were assessed, and a work plan was prepared for the second phase. With inputs from key public groups, freight performance measures were established for lost time, accessibility/availability, safety, and reliability. Criteria have been developed to narrow the content of the intermodal system, and performance measures are being examined in terms of reasonableness and data availability. Final performance measures would be established after the participants agreed on policy questions implied by the facilities selected for inclusion in the system. After that, the effort to collect data to support the application of performance measures to policy questions would begin.

Simultaneously, forecasts would be developed which would disaggregate commodity flows by domestic versus international orientation, origin and destination, commodity, mode, and specialized handling requirements.

As of the date of this report, the state had begun to prepare a program for the integration of freight forecasting into the region's established traffic modeling process. It had developed a truck routing model for application in one particular corridor.

2.1.1.2 Wisconsin – Translinks. The state of Wisconsin has undertaken one of the most ambitious programs in the country to create a performance-based, multimodal transportation plan. Statewide freight planning is a part of Wisconsin's Translinks21, the Statewide Multimodal Transportation Planning Program (1).

In the area of freight forecasting, the Wisconsin team concluded that no models existed for freight forecasting by mode. Thus, preliminary projections of freight traffic were developed through extrapolation of historical trends. An innovative approach involved review of the initial projections by a panel of freight experts.

A parallel effort developed a freight database. Data on motor carrier commodity flows, as well as on air, rail, and waterborne freight movements were assembled, and flows were mapped to a principal arterial network, with analysis conducted at the corridor level. The end result was a first generation multimodal plan that would guide future system and multimodal corridor planning.

A summary of the six steps identified for the freight planning process include:

(i) Develop transportation goals and socio-economic environmental values.
(ii) Inventory existing freight systems and usage.
(iii) Compile commodity flow data.
(iv) Prepare trend line forecasts by mode.
(v) Develop scenarios for multiple modes and component sketch systems for highway/truck/air cargo, rail, and waterborne modes.

Following statewide planning efforts, an IMS was created to provide guidance for identification of intermodal facilities, development of system level performance measures, system level deficiency analyses, data collection, and determination of deficiencies in current intermodal access and connectivity or the need to build new facilities or consolidate existing ones.

2.1.1.3 California. The State of California is making efforts to develop an intermodal planning tool that could be applied in the IMS process, policy analysis, and corridor analysis phases of planning (1). This effort could emerge as one of the most comprehensive efforts ever to incorporate freight considerations into systems-level multimodal planning.

The main purpose behind developing an Intermodal Traffic Management System was to assist federal and state entities, MPOs, and other local agencies in considering project selection decisions, and to provide quantitative modal data, inventory, database analysis methodology, forecasting capability and evaluation process for making efficient and cost effective decisions in urban and rural areas of the state at a system level, and facility improvement level. The development of the ITMS included the following steps.

1. Development of the study design.
2. Development of the inventory and data.
3. Development of the database and GIS components.
4. Development of the analysis methodology, performance measures, and algorithms.
5. Development of forecasts.
6. Evaluation of intermodal effectiveness and recommendations for future enhancements.

The selected performance measures went beyond the traditional reliance on the concept of vehicle movement to one of unit movement. Thus, person-miles of travel were used in place of vehicle-miles of travel and commodity-miles of travel rather than truck miles of travel.

The ITMS was designed to predict changes in freight movement. Ten, twenty and thirty-year forecasts would be developed from an extrapolation of the standard Transearch ten-year forecasts, using econometric models.

2.1.1.4 Florida. The state of Florida undertook research in IMS preparation strategies, and has developed a set of tools to help planners weigh strengths and weaknesses of intermodal connection for both passengers and freight facilities (1). Similar in approach to that adopted by Wisconsin, Florida is now undertaking analysis of key points of the transportation systems' intermodal connection. It emphasizes the operations of the facility at the point of interconnection.

2.1.1.5 Ohio. In development of the Access Ohio plan, great effort went into establishing the statewide intermodal system for analysis (1). A part of this effort was a highly quantitative process that included the use of performance criteria to determine which facilities should be included in the macro level plan. Five corridor identification criteria were established - traffic, population, economic activity, trade/international centers, and natural resources/agriculture. A series of performance standards and measures was proposed to monitor and evaluate the performance of the system.

2.1.2 Regional Studies

2.1.2.1 Southwest Washington. The Southwest Washington Regional Transportation Council (RTC) serves as an MPO for the Washington State portion of the Portland-Vancouver metropolitan area. In 1993, it initiated a Regional Freight Transportation study for the Clarke County Region (2). The purpose of the study was to address freight transportation issues, compile available data on freight transportation, and analyze freight transportation in the context of facilities, operations and accessibility. The study focused on truck freight movement and examined means for integrating truck movement information into the regional travel demand model. An objective of this study was to incorporate this information into the regional transportation database and into an ArcInfo GIS transportation database, which would allow for storage and mapping of the information.

2.1.2.2 Worcester. The Worcester MPO in Massachusetts, in cooperation with the American Truckers Association (ATA) foundation, has undertaken a study of freight needs (1). It requested assistance from the ATA in developing information on freight flows that could be used for planning purposes. Desired information included major routes of travel, impediments to travel, origins/destinations, intermodal operations, and companies' future plans. As a result of their survey, the following were accomplished.

(i) The locations and types of travel impediments were identified and mapped.
(ii) An origin-destination matrix was constructed for regional commodity flows.
(iii) An inventory of intermodal facilities was assembled, and user patterns were studied.
(iv) Expansion plans proposed by various companies were studied.

2.1.2.3 Monterey Bay Area. As a part of their planning activities, this California MPO overcame data limitations and developed innovative solutions to regional agricultural freight transportation problems (3). Data from government agencies and trade groups on annual fruit and vegetable production, fish landings, and wine productions were combined with survey data on truck volumes and loading practices to develop approaches for estimating truck and rail trips. Similar methods were used to project future freight volumes. Population, income, and agricultural productivity indices were used to project agricultural production volumes, and employment forecasts in the processed food industries were used to forecast freight volumes in these industries. To identify problems and deficiencies in the system, new performance indicators such as number of truck trips per outbound line haul truck trip distributions, and truck trips as a percentage of total traffic volume on roadways with poor level of services were used.

2.1.2.4 San Francisco Bay. The Metropolitan Transportation Commission (MTC) set up a Freight Advisory Council to build consensus among public and private sector freight interests for improving the safety and efficiency of freight movement (1). The MPO first asked the freight community about any problems. Next, members of the freight community gave the MPO staff input into congestion pricing study and became involved in planning of ITS. A freight workshop was conducted, wherein the freight community explained the importance of reliability of arrival time to policy makers.

The committee then began a project to establish a highly quantified freight forecasting and analysis process.

2.1.2.5 Boston. The Central Transportation Planning Staff (CTPS), which supports the Boston area MPO, has hired a freight planning expert to increase their capability to analyze freight movements (1). The IMS is being designed as a system of software and data to support intermodal strategic decision making. This information would be useful in the analysis of the following issues:

- Double-stacking
- Trade-off / mode split
- Regional airport freight issues
- Landside access issues
- Congestion
- Rail-road abandonment

In addition, the role of freight in the analysis of congestion and railroad abandonment will be a major consideration in the development of the Massachusetts IMS.

2.1.2.6 Pudget Sound Region. The Pudget Sound Regional Council undertook a study for the analysis of freight flow in the region in 1994 (4). This study used freight flow data from a number of sources to build an overall picture of freight flows in the region. Although the data were from different sources, and were incomplete, and in some ways incompatible, the use of the County Business Patterns as the unifying element allowed the different sources to be drawn together and used jointly to present a unified picture of freight movements as a whole. The data developed here were useful for policy analysis and evaluation. The databases could be used for additional, more detailed investigations in the freight sector. Future work would involve using this information to develop freight trip generation and attraction rates on a trips-per-employee basis for different types of land use.

2.1.2.7 Greater Lafayette Region. Goods movement analyses in the Lafayette region were grouped into three main categories (5). The first category focused on an appraisal of the community's goods distribution system through personal interviews, creation of an advisory council, a fleet survey, and a mail in survey of area truck operators. The second category evaluated the problems and opportunities identified during the detailed appraisal by development of truck travel and commodity flow forecasts to assist in evaluating the magnitude of a single particular problem. The final category was the development of a set of Transportation System Management and Light Rail freight plans that could be incorporated into the Transportation Improvement Plan.

2.1.2.8 Southern California. The Southern California Association Governments (SCAG) is planning a major study to evaluate the existing freight shipping system in the metropolitan area and to test recommended future scenarios (6). To address the impacts of goods movement on the region's mobility and economy, SCAG established a subcommittee made up of representatives from the freight shipping industries. This group will evaluate the relationship between goods movement and the regions' mobility, economy, and air quality. Specifically the committee will focus on obtaining a better understanding of the characteristics of freight shipping in the region including the level of inter-regional and intra-regional demand for service by all modes, available capacity, and capacity utilization at the terminals, rail yards and transfer facilities.

2.1.2.9 Albany, New York. In Albany, efforts were made to tie freight performance measures to the rest of the congestion management process (1). This approach allowed for analysis of freight flows in terms compatible with non-freight flows.

2.1.2.10 Summary. Most planning activities that were reviewed generally follow some form of the following activities.

1. Examining available data by mode.
2. Identifying gaps in data.

3. Devising means to fill gaps, such as the use of commodity production and consumption data, industry specific sources, and others.
4. Determining modal splits from existing trends and characteristics.
5. Identifying origin-destination pairs.
6. Identifying, obtaining, and using existing forecasts.
7. Identifying likely impacts on intermodal facilities.

2.2 Freight Forecasting Techniques

2.2.1 Freight Data Requirements for Statewide Transportation Systems Planning, (NCHRP Reports 177/178, 1977)

NCHRP Reports 177/178 were an outcome of the Transportation Research Board conference on statewide transportation planning held in 1974 (7). They focused on the data requirements for statewide transportation systems planning. NCHRP Report 177 provided a detailed assessment of existing freight issues and identified the data required for applying related analysis techniques. NCHRP Report 178 provides a detailed catalog of then existing data sources and methods to obtain them, and guidelines for data collection and management activities by state DOTs (8).

2.2.2 Applications of Statewide Freight Demand Forecasting Techniques, (NCHRP Report 260, 1983)

NCHRP Report 260 was one of the earliest comprehensive treatments of a systematic freight analysis process (9). It focused on documenting the current state-of-the-art in freight demand forecasting. In particular, a technique was documented to: a) quantify freight flows by highway, rail, and water for the current year; b) forecast the likely annual freight volumes and shifts among modes over the short term (5 years or less); and c) provide origins and destinations by commodity within a corridor or region at substate, state, or multistate levels. This would prove useful for state DOTs in their forecasts and in prediction of deterioration of pavement surface due to repetitive loads.

The classic four-step process of the 1960's was applied to freight movement, as shown in figure 2.1.

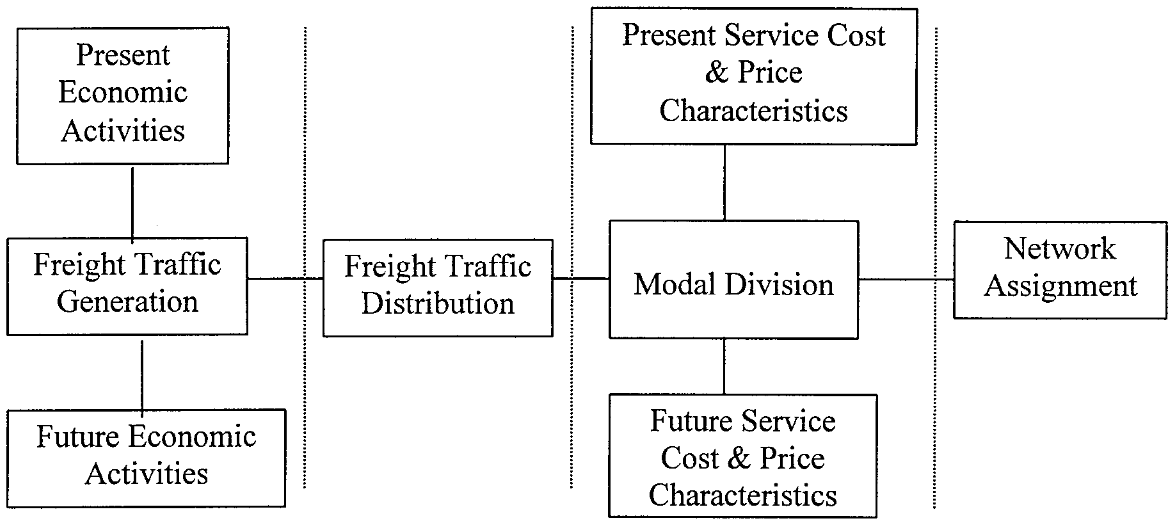

Figure 2.1: Classic four-step planning process (9)

Freight traffic generation involved the development of a base case commodity origin-destination flow data matrix from which future flows could be predicted. Freight distribution, in terms of disaggregating freight origin data geographically, was done using data on county employment. Forecasting the future-year freight origin-destination matrix was divided into three categories – causal methods, time series analysis, and qualitative methods. The modal split model employed the least cost or rate strategy to split freight movement between truck and rail, and exhaustive costing procedures for these two modes were also provided. A conceptual technique was provided for converting commodity weights to vehicle equivalents. Sufficient allowance was given for different types of vehicles, maximum carriage capacities, and fronthaul/backhaul characteristics provided in the procedure.

2.2.3 Guidebook for Forecasting Freight Transportation Demand, (NCHRP Report 388, 1997)

NCHRP Report 388 is the most recently published guidebook for freight planning. This report aims at assisting planning practitioners and policy analysts to integrate freight planning and demand forecasting effectively into the broader process of multimodal planning, which has been emphasized since the passage of the ISTEA in 1991 (10). Given the capacity of existing facilities, this report focuses on using economic indicator variables such as employment and population to arrive at a growth rate to estimate future commodity flows.

The potential demand of and shift to new facilities are computed by estimating proximity and level of service measures on different approach corridors. Conceptual techniques for evaluating impacts of policy changes on freight demand forecasts have also been highlighted.

2.2.4 Commercial Vehicles in Urban Transportation, (Starkie, 1970)

Starkie performed one of the most influential and innovative studies of goods-vehicle trip generation (11). It consisted of using a disaggregate analysis, and involved a nonlinear functional form for truck trip generation. His quantitative analysis entailed the estimation of a variety of simple, univariate regression models relating to daily volume of truck trips observed at the plants to measures of employment and floorspace. Some of the equations that resulted from his analyses are shown in table 2.1.

Although his model revealed an important relationship between trip generation and the type of manufacturing activity, many important factors such as the proportion of inbound and outbound trips and consignment sizes were omitted from his model specifications.

Table 2.1: Starkie's Trip Generation Equations (11)

Dependent Variable (Y) Goods vehicle trip generation in:	**No. of observations**	**Regression Equation** E = employment, F = floorspace	R^2
All Manufacturing Establishments	77	Y = 26.96 + 0.0377 E	0.25
”	70	Y = 19.44 + 0.0003 F	0.37
”	77	Log Y = 0.2568 + 0.5595 Log E	0.54
”	70	Log Y = -1.1749 + 0.5714 Log F	0.60
Engineering and Allied Trades	37	Y = 21.83 + 0.0343 E	0.60
”	37	Log Y = 0.401 + 0.4996 Log E	0.87

2.2.5 The Transport of Goods and Urban Spatial Structure, (Slavin, 1979)

In his doctoral thesis, Slavin suggested the importance of building separate models representing vehicle trips for different commodities (12). He developed disaggregate trip generation and distribution models using data from the Boston metropolitan region to arrive at statistical models for three different industrial sectors - manufacturing, local for-hire transport, and wholesale/retail trade. His results, presented in table 2.2, showed that activity employment levels, vehicle supply, and degree of trip chaining were among the principal determinants of transport provider trip frequencies for these activity groups. He also pointed out a deficiency in Starkie's analysis by proving the importance of incorporating trip chaining, which is critical for short haul trips.

Table 2.2: Slavin's Empirical Analysis Results (12)

Explanatory Variables	Manufacturing	For hire -Transport	Wholesale/Retail
Employment/Zone	positive	positive	positive
Vehicles/Zone	positive	positive	positive
% Large Vehicles	negative	negative	negative
Degree of trip chaining	positive	positive	positive

2.2.6 Freight Planning in Public Sector, (NCHRP Synthesis 230, 1996)

This synthesis describes the process by which state DOTs and MPOs integrate freight planning into the surface transportation planning process (1). It discusses the requirements for freight planning resulting from ISTEA with particular emphasis on the development of an intermodal management system. It describes the methods used by selected agencies for forecasting freight flows, data collection practices, and techniques for integrating freight planning into the established surface transportation planning process at the state and regional levels.

2.2.7 Quick Response Freight Manual Final Report, (TMIP - September 1996)

A recent guide to freight demand forecasting and planning is the final report of the Quick Response Freight Manual (17). This Report provides comprehensive information on the freight transportation system and factors affecting freight demand. It identifies available data and freight related forecasts for specific facilities. It also provides simple techniques and transferable parameters that can be used to develop commercial vehicle trip tables, which can then be merged with passenger vehicle trip tables developed through the conventional 4-step planning process. This manual addresses freight issues at different levels of analysis, from the more detailed level of site planning to the more aggregate level of corridor or metropolitan area planning.

2.2.8 Truck Transportation Planning, (Biddle & Siarusaitus, 1997)

Biddle and Siarusaitus worked with bulk commodity flow between National Transportation Analysis Regions (NTARs) in Virginia to develop a comprehensive forecasting model that is both spatially, and temporally transferable (18). Using the MINUTP programming interface, they developed a four-step planning procedure. They aggregated the different commodities into four discrete groups, and distributed them based on the number of industries producing a given commodity, quantity produced, and employment figures in each of those industry types in each county. Annual totals were converted to daily trips by dividing by 260, the average number of working days in a year. Mode split was defined by dividing truck trips into three categories: long haul, short haul, and local. A MINUTP trip assignment was performed. The results were then compared with existing truck counts, and it was found that the calculated truck percentages were over-estimated in most cases. Model results summarized in terms of road classifications are listed in table 2.3.

Table 2.3: Truck Transportation Planning Model Results (18)

Road Classification	Validation Truck Percentage (all trucks)	Base-year Model Results (all trucks)	Percentage Difference
Interstate	9.9%	7.8%	-21.2%
Major Arterial	5.3%	4.7%	-11.3%
Minor Arterial	5.7%	4.2%	-26.3%
Collector	7.9%	8.5%	7.6%
Overall	7.5%	6.9%	-8.0%

The procedure is simple and easily adaptable, but they considered only a single type of truck (semi-tractor trailer) combination.

2.2.9 Federal Truck Size and Weight Study, (Stowers et. al, 1983)

Truck weight and size issues are important considerations in assessing highway safety and road pavement conditions. These characteristics become critical when a quantitative relationship between number of trucks and commodity weight is desired. Higher truck weight and size limits will increase the allowable tonnage and volume of freight (per trip) that can be carried, leading to a lesser number of trucks for a given weight of commodity. Stowers et al, in their federal truck size and weight study, suggest different scenarios for arriving at uniform maximum truck length and weight limits throughout the United States (16). This work would prove very useful when a high degree of portability of freight planning procedures is desired between the different states.

2.2.10 Summary

These research efforts show that a good correlation exists between economic indicator variables such as employment, employment density, tonnage produced, and commodity distribution. These variables have been used to apportion statewide commodity flows, and level-of-service and proximity ratings have been used to apportion flow to the various entry-exit points of a region. The results were found to be more accurate when disaggregate (i.e. commodity-wise) analysis was performed. However, results obtained were found to be not sufficiently accurate due to lack of appropriate data regarding the proportion of inbound and outbound trucks, and sizes of the consignments.

2.3 Multi-Modal and Intermodal Transportation Planning

2.3.1 Development and Application of Statewide Multimodal Freight Forecasting Procedures for Florida, (Middendorf D.P. et. al, 1982)

Middendorf developed a multimodal freight forecasting procedure for the state of Florida (13). The methodology involved two steps. First, the generation and distribution of freight were projected through a Fratar model that applied growth factors to current commodity flows. In the second step, the projected freight flows were distributed among competing modes through modal split models. The Fratar model was successful in producing reasonable projections of freight traffic, to, from, and within Florida in 1985 and 2000. One advantage of this approach was that the Fratar model was based on existing secondary sources of data. Because these sources exist in the same analogous form for other states, a similar modeling approach could be developed and applied elsewhere.

2.3.2 Model for Statewide Freight Transportation Planning, (Kim et. al, 1982)

A planning model for statewide freigth transport systems planning was proposed, which was a modification of the existing and readily available Urban Transportation Planning System (UTPS) package (14). The model was modified such that it could be used for analysis of multicommodity freight flows by highway, rail, water, and pipeline, for a region or state. The proposed model was divided into five sub-models:

1. Network analysis models,
2. Freight transport demand analysis model,
3. Vehicle requirement model,
4. Assignment model,
5. Evaluation model.

The issues and problems that could be analyzed by using this process included the identification of anticipated impacts of deregulation, rail mergers, shifts in the economic base of an area, and changes in transportation rate, energy availability, and service.

This model could be used for both freight and passenger transportation analyses, since the network would be coded using the UTPS framework. However, a major drawback of this method is that no application had been performed.

2.3.3 Network Analysis of Highway and Intermodal Freight Traffic, (Kornhauser & Bodden, 1983)

Kornhauser and Bodden developed the first elements of a nationwide analysis of freight and intermodal movement (15). They used a bi-modal network consisting of the highway and railway networks in Princeton. They classified the highways into four categories of Interstates, toll roads, divided and undivided links. The railway network was a subset of the total rail links with only those that contributed to intermodal traffic being considered. Intermodal ramps across the United States connected these two networks and these links were capacity coded with the total carload volume of the interchange. Intermodal origin destination data were obtained from the 1980 one-percent Waybill Sample, which has the rail portion on a ramp to ramp basis. Routing was accomplished using a minimum cost, unconstrained path finding algorithm, various cost functions of user-specified mileage rates for highway and rail portions, and ramp interchange costs. Finally, 1980 intermodal traffic was plotted on a graphical interface, and this revealed distinct patterns. Trailer-on-flatcar (TOFC) volumes were heavy between California and Chicago, and Boston and New Jersey. Each of these major flows was well balanced directionally. Container-on-flatcar (COFC) was heavy at the ports where containerized ocean freight moved onto rail and truck. Thus, Kornhauser and

Bodden are believed to have developed the first computer generated US highway and railway intermodal traffic density maps.

2.3.4 Summary

To achieve the objective of analyzing intermodal freight flows, it is necessary to connect modal networks by pseudo links representing transfer terminals. A multimodal terminal database needs to be constructed for modeling the properties of terminals as a function of the type of freight. Transfer impedances should be preferably modeled as a function of transit time and cost of unloading/loading, but in the present non-econometric framework, transit time is a good approximation. Transfer capacity of the terminal can be modeled as the capacity of terminal or the amount of freight handled over a given time.

2.4 GIS in Freight Flow Modeling

2.4.1 Modeling Washington State Freight Flows Using GIS-T : Data Collection and Design, (Casavant et. al, 1995)

Casavant, et al, modeled Washington State truck freight flows using Geographic Information Systems (19). Since movement of goods by rail and water could be identified using the ICC Waybill sample and Waterborne Commerce data, they focused their work on truck flow. The objective of their study was to develop a Washington State truck movement database that could be studied using a GIS foundation, and incorporate it into other planning and policy operations. Such a study would provide the required data for infrastructure improvement analysis, improved pavement management, and research into increasing efficiency in Washington's intermodal system. Survey stations were set up at major entry points into the state and at important highway intersections. Interviews were conducted for a continuous 24-hour period at four different times of the year. Since databases could be dynamically interlinked with existing data sets such as the US Department of Commerce County Business Patterns, GIS was chosen as the data management platform. Such links would help visualize the changing scenario in truck flow patterns. Each interview record had a field containing the Standard Industrial Classification (SIC) code, consistent with the commodity being transported. When joined to the industrial databases and using the expected growth of the particular commodity, the model provided a reasonable estimate of the change in the number of trucks. A flow chart of the analysis procedure is shown in figure 2.2.

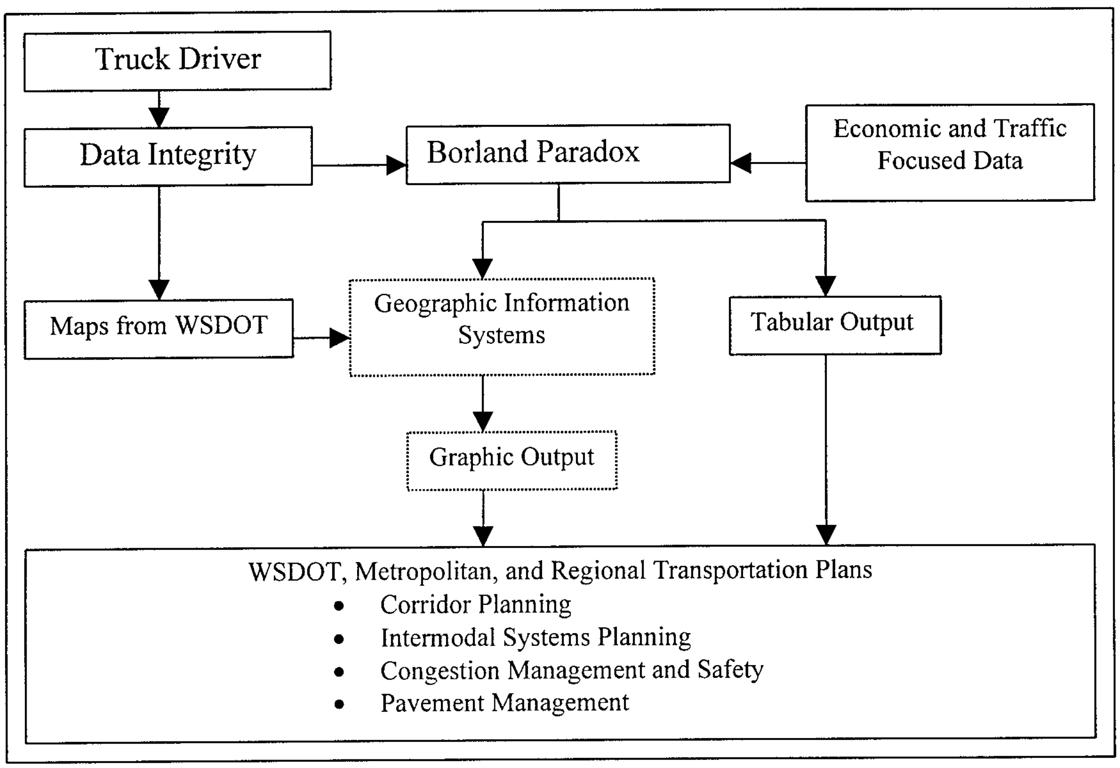

Figure 2.2: WSDOT – GIS Freight Movement Analysis Procedure (19)

2.4.2 Transportation Terminals Database Structure, (Middendorf D.P., 1996)

Middendorf, et al, have worked on the network modeling and representation aspects of multimodal terminals in a GIS framework (13). They have considered various aspects of transportation terminal modeling, such as the constituents of the terminal, the appropriate geographic scale of each terminal, transportation modes operating in the terminal, means of access to these facilities, quantification of their capacity, and measurement of the terminal costs and impedances. For the structure of the GIS database, they discussed the issue of including physical boundaries and the internal structure of the terminals in the database, to resolve issues where three or more bi-modal terminals are located close to each other. Another issue put forth was to represent terminals as network nodes that would serve as modal access points for the terminal. In this way, inclusion of all streets, roads and rail branches leading to the terminal could be excluded, as they could increase the network size considerably. Further, notional links could be constructed between these links to facilitate transfers. Such a model, though easy, would fail to capture the spatial aspects of the terminal.

A more sophisticated method would be to dynamically segment the nearby traffic links, and construct artificial links from these to the terminal area cordons as shown in figure 2.3. These terminal entry points (end points of the artificial links) could then be internally connected by other artificial links that do not violate commodity type transfer characteristics and line capacity. Many links connecting the same pair of modes may become necessary for different commodity groups that will differ in terms of capacity and transfer time characteristics.

Another important characteristic to be aware of is the directionality of the transfer since the terminal may be equipped for freight movement in a particular direction only (i.e. from rail to truck or vice versa), which may also be specific to commodity type.

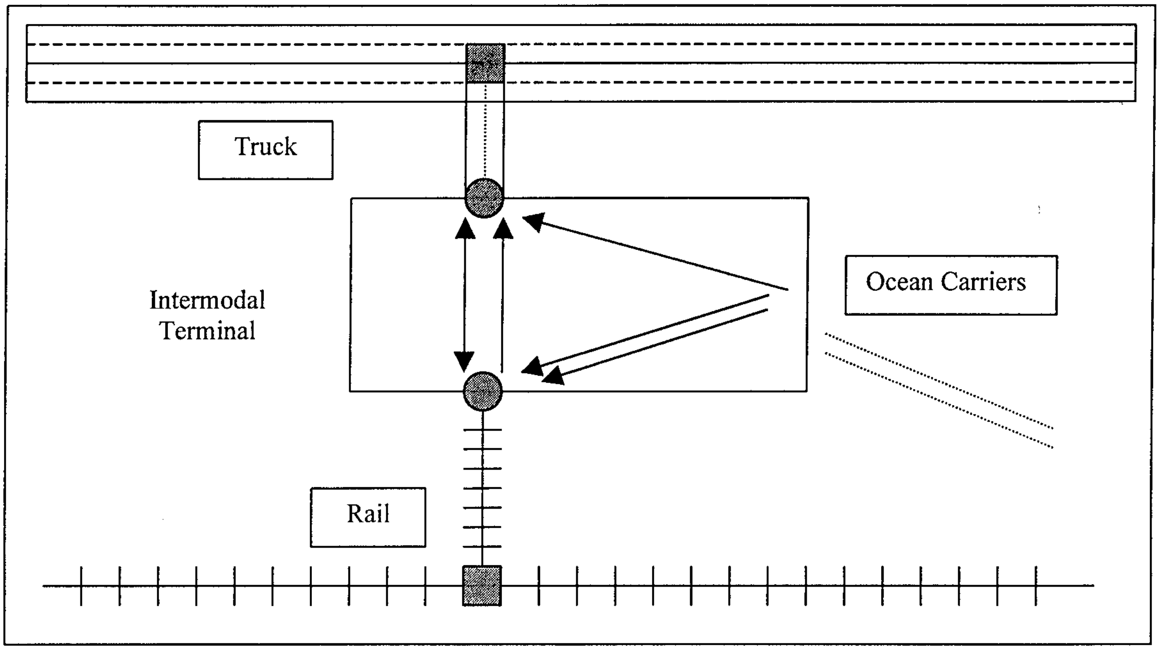

Figure 2.3: Modeling Intermodal Terminals (13)

2.4.3 Statewide Transportation Planning Model and Methodology Development Program, (Souleyrette et. al, 1996)

Souleyrette et al developed a tactical model for freight transportation demand in Iowa, at the Iowa Department of Transportation (25). The primary function of this planning tool was to analyze the potential impacts of policy and industry changes on freight transportation within the state. The model was constructed using a layered approach. This was based on the assumption that the demand for truck transportation in one economic sector is independent of truck transportation demand in other economic sectors and, therefore can be modeled separately. Commodity movement data were obtained from Reebie and Associates, and employment data were used to disaggregate origin data from BEA-level into the county level, and county level population estimates were used to disaggregate destination totals. TRANPLAN was used to assign the trips to the network using all-or-nothing assignment (which assumes no effect of congestion on route decisions). Finally the results obtained were validated against DOT estimates of total truck flows on state highways.

The limitations of this work included: a) demand for truck transportation in one sector was assumed to be independent of truck transportation demand in other economic sectors, b) trucks assigned to transportation network from different industry sectors were assumed to interact with the transportation system independently, and c) the economic activity producing truck traffic were assumed not to be uniformly distributed across an entire region but to be concentrated within a few locations.

2.4.4 Highway Freight Flow Assignment Using Geographic Information Systems, K. L. Hancock & Krishnan V., 1997)

Hancock and Krishnan developed a GIS-based approach for distributing and assigning freight flows in Massachusetts (20). The basic framework for this analysis consisted of dividing Massachusetts into smaller regions and apportioning the freight flows from the neighboring states to these regions, using a socio-economic indicator variable. This data were available in the form of tonnage units and hence a quantitative procedure was used to convert weights into truck numbers. An origin-destination matrix between the internal origins and exit points from Massachusetts was constructed and assigned over major highways in the state using various assignment procedures such as capacity restraint and user equilibrium. The resulting link volumes were validated against an extrapolated Highway Performance Monitoring Systems (HPMS) count, and it was found that the values obtained were generally within a tolerable limit of $\pm$ 15 percent on most highways. However, the analysis was performed at a state level, and also the tonnage to truck conversion formulae was assumed to be uniform for all commodities.

2.4.5 Development of Analytic Intermodal Freight Networks for Use within a GIS, (Middendorf et. al, 1997)

Middendorf et al worked on the practical issues involved in constructing intermodal freight networks in GIS. They proposed the following:

1) Linking together different primary modal networks through an intermodal terminal network database using three sets of "notional" links. These sets include,

    a) traffic generator/traffic attractor links,
    b) intermodal terminals transfer links, and
    c) intra-modal, carrier-based interlining links.

2) Developing carrier, and in some cases, service-specific subnetworks necessary for the generation of sensible intermodal routing alternatives,

3) Attaching intermodal networks to a set of traffic analysis zones using geographic centroids of analysis zones, or centroids at the population-weighted or activity weighted center of the zones, depending on the sparseness of the network relative to the number and size of the Transportation Analysis Zones (TAZs) used.

They also specified that the intermodal database should contain appropriate representation of intermodal transfer terminals and intra-modal carrier transfers as well as traffic origin and destination links to each of the modes of interest.

2.4.6 Transport Flows in the State of Indiana: Commodity Database Development and Traffic Assignment, (William R. Black, 1997)

In cooperation with the Indiana Department of Transportation and the Federal Highway Administration, Black conducted an extensive project for freight planning for the entire state of Indiana. The primary objective of the project was to gather information on commodity flows into and out of the counties of Indiana, and to allocate this commodity traffic to the transportation network of the state (24).

The planning work carried out resembled the urban transportation planning process. Commodity data were obtained from the 1993 Commodity Flow Survey and ICC Rail Waybill, and traffic generation models were developed using economic indicator variables. These variables included employment in the various industrial sectors, population etc. Trip Distribution was achieved using a fully constrained Gravity model. Modal Split was achieved by a computer program called NEWMODE, which splits traffic by examining the lengths of shipments and knowing the product of interest. A new mathematical function was defined for speeds viz.

$$\text{New Speed} = \text{Old Speed} + (2*\sqrt{(65 - \text{Old Speed})} \qquad (2.1)$$

and traffic assignment was performed using the "all-or-nothing" traffic assignment routine. A similar procedure was carried out for rail freight.

The results obtained were fairly accurate and hence the resulting database was used for conducting Economic Analyses, Transportation Analysis, and for Transport Policy formulation.

2.4.7 Summary

Freight assignment essentially involves splitting the region under consideration into many districts, and assigning the freight to the districts according to a socio-economic indicator variable. For multimodal freight flow assignments, it is necessary to connect modal networks by pseudo links representing the transfer terminals. Various attributes of the transfer terminals need to be represented appropriately, and as an intermediate step, a multimodal terminals database could be developed to model the same as a function of the type of freight.

2.5 Survey of Current Freight Planning Practices in New England

2.5.1 Objective

At the commencement of this research in October 1997, a survey was conducted to identify and review current freight planning activities in New England. The purpose of the survey was to gather basic information about how MPOs were conducting freight transportation planning, what resources they had to do so, and what planning methodologies were being adopted. Copies of current Transportation Improvement Plans (TIPs), and Regional Transportation Plans (RTPs) were obtained and reviewed. This survey was intended to help understand problems in regional freight transportation planning, and also to help identify the areas which needed work.

Seventeen agencies in the New England area were contacted. About fifty percent of them responded, of which only thirty percent were working on freight transportation planning. Results of the survey are presented in table 2.4. A detailed report of the freight planning activities in each of these regions is presented in Appendix A.

2.5.2 Summary of Survey Results

From the responses received and from the above findings, it was concluded that although many MPOs are making efforts towards monitoring freight movements and identifying the issues related to them, most have not yet considered the issue of freight planning due to lack of data or expertise in the field. Therefore it was recognized that these MPOs need an approach, which would give them flexibility to evaluate existing conditions, and to consider the effects that future decisions would have within their jurisdiction. To achieve this, a GIS based approach for intermodal freight planning needed to be established, which would provide the planning organizations with a tool to obtain and evaluate freight movements.

Table 2.4: Summary of New England Freight Planning Activities Survey

	Name of Organization	Response Received	Documents Reviewed	Current procedures that address freight	Specific Surveys Conducted	Recommended Work
1	Central Massachusetts Regional Planning Commission	YES	TIP / RTP	YES	ATA Survey in 1993	(i) Preparation of terminal location map of region's major trucking terminals using GIS. (ii) Another trucking survey with ATA in 1997 to develop a regional trends analysis.
2	Montachusetts Regional Planning Commission	YES	TIP / RTP	YES	Truckers & Shippers Survey	-[2]
3	Franklin County Commission	YES	RTP	YES	Freight & Goods Survey	-
4	Old Colony Planning Council	YES	TIP, Freight Section of RTP	YES	Truckers Survey	none
5	Merrimack Valley Regional Planning Commission	YES	TIP / RTP	YES	Truckers Survey	none
6	New Hampshire Department of Transportation	YES	TIP / RTP	none	none	none
7	Boston Metropolitan Organization	YES	RTP	none	none	none

[2] Not mentioned in the documents received.

Table 2.4: Summary of New England Freight Planning Activities Survey (continued)

	Name of the Organization	Response Received	Documents Reviewed	Current procedures that address freight	Specific Surveys Conducted	Recommended Work
8	Northern Middlessex Council of Governments	YES	TIP	none	none	none
9	Pioneer Valley Regional Planning Commission	YES	TIP	none	none	none
10	Berkshire Regional Planning Commission	NO	none	.....	.....	.....[3]
11	Southeastern Regional Planning & Economic Development District	NO	none	.....	.....	.....
12	Strafford Regional Planning Commission	NO	none	.....	.....	.....
13	Rockingham Planning Commission	NO	none	.....	.....	.....
14	Southern New Hampshire Planning Commission	NO	none	.....	.....	.....
15	Nashua Regional Planning Commission	NO	none	.....	.....	.....
16	South Central Regional COG	NO	none	.....	.....	.....
17	Connecticut Department of Transportation	NO	none	.....	.....	.....

[3] Did not receive any information.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The literature review has provided insight into important aspects that must considered while developing a methodology for understanding and analyzing freight flow as presented in this Chapter.

The basic framework for analysis consists of dividing the area in and around the unit of analysis into smaller regions, and apportioning freight flow from the neighboring states/regions into these regions using an socio-economic indicator variable. A set of origin-destination matrices for the volume of annual freight flow by truck between the internal origins (centroids of regions created) and exit points of the area are constructed, and assigned over the major transportation links in the area. The resulting link volumes are validated against existing survey counts.

'Travel Time' and 'Capacity' attributes of these connecting links are determined and a multimodal freight assignment is performed. With an understanding of the spatial distribution of freight flows, methods for improving efficiency of intermodal terminals, total shipment time and cost could be studied, and these could ultimately help in recommending methods to improve efficiency the overall transportation system in the region. A framework of the entire framework is depicted in figure 3.1. Detailed descriptions of the various steps are presented in the subsequent sections.

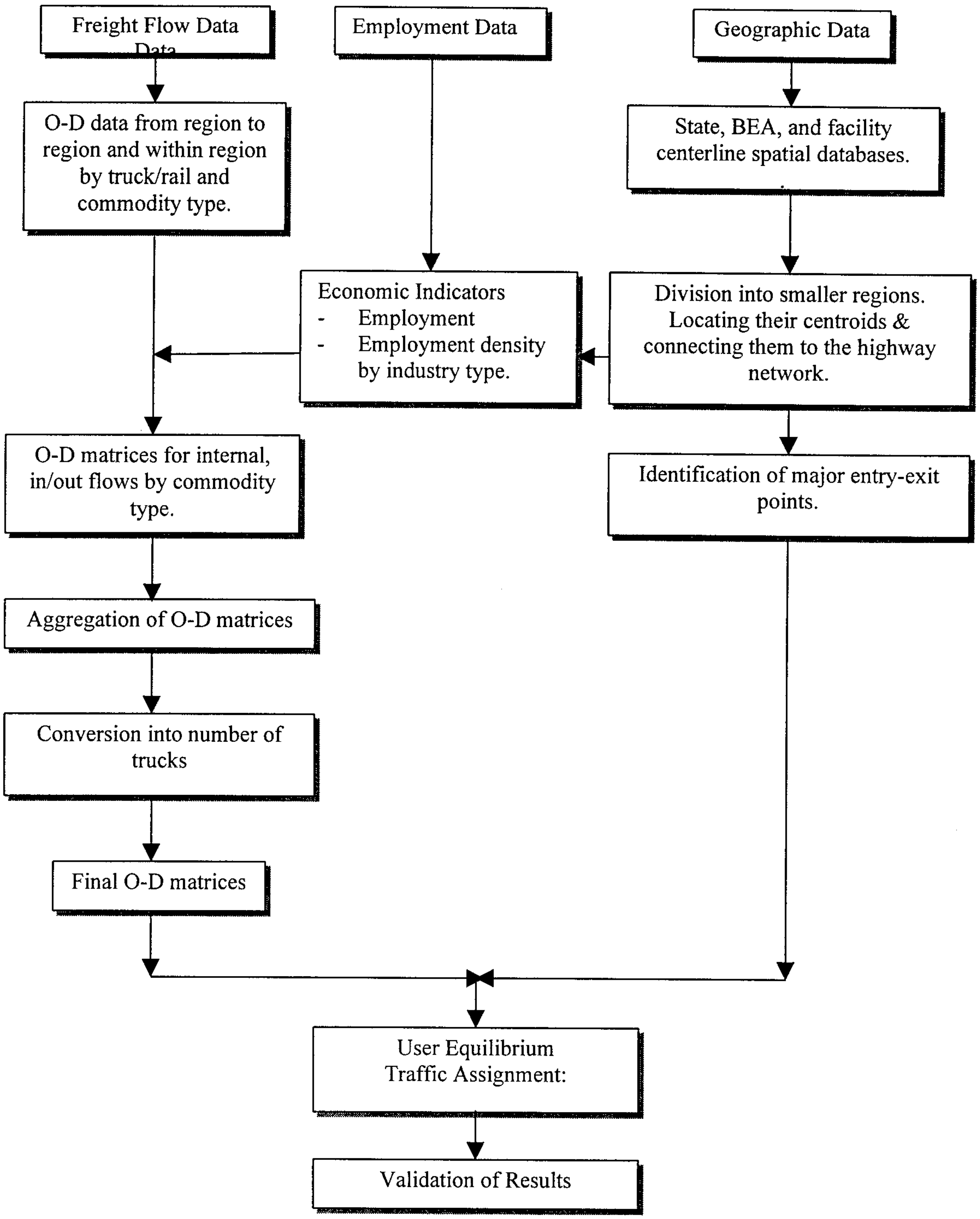

Figure 3.1 Methodological Framework

3.2 Freight Data Review and Collection

For the purpose of freight traffic assignment, different kinds of data are needed at each step: regional commodity movement and socio-economic data for freight trip generation and distribution; spatial geographic highway and railway network databases for traffic assignment, and; existing survey counts of freight traffic for validation. The following sections discuss these data, their sources, and the reason/s for their inclusion in the assignment methodology.

3.2.1 Commodity Movement Information

A major problem with obtaining freight movement data is that it is proprietary as it specific movements become apparent. For instance, total manufacturing commodity flow between two states is easier to obtain than flow between two neighboring zip codes. This is because, at the zip code level, the individual manufacturing units become distinguishable and marketing strategies protect this information from competitors. In some cases, though the latter information may be available, it is often very expensive to purchase. But such detailed and commodity specific information is very necessary for estimating the number of trucks from freight tons, as the loading operations and styles differ depending on the type of commodity. For instance, bulk commodities such as agricultural products may be packed more closely than fragile and costly equipment such as electronic goods. This gets more critical when it comes to monitoring intermodal transfers. Hence detailed information is needed for more accurate freight flow predictions.

Previous planning activities in this area have made use of the Commodity Flow Survey Data. However, more accurate and detailed regional and internal freight data, classified in terms of type of commodity and mode of transfer, can be obtained from a database maintained by Reebie and Associates of Stamford, Connecticut. This data set provides information on movement of freight between regions as defined by the Bureau of Economic Area (BEA) boundaries, which basically group areas of major economic activities, surpassing the political boundaries of states.

Another source of commodity movement data would be the annual index of Importers and Exporters by state for the base year.

Data on rail freight can be obtained from the Interstate Commerce Commission (ICC) Railroad Waybill Sample (26). These data contain the Carload Waybill Sample public-use records, which are samples of the freight waybills submitted by Class I railroads to the ICC. It has freight data indexed by several attributes, including origin and destination BEAs, type of commodity, number of cars, tonnage of freight shipped, length of haul, participating railroads and interchange locations. Movements are reported at the BEA-to-BEA level.

3.2.2 Spatial Transportation Networks

Geographic centerline representations of the major highways and railways are required for GIS modeling. Required networks can be extracted from the National Transportation Atlas Database (NTAD) (33). The NTAD is a collection of geo-spatial databases developed by the Department of Transportation and other federal agencies depicting transportation facilities, networks, and services of national significance. They are designed to be used with GIS software packages to locate transportation features and provide a framework for transportation network analysis. The attributes of these links, such as the number and width of lanes, functional classification etc. are useful in computing link travel times and capacities.

3.2.3 Data for Freight Distribution and Assignment

Aggregated freight flows need to be apportioned to the different parts of the unit of analysis. Distributions of socio-economic indicator variables such as industrial employment, employment density, and population in the unit of analysis can be used for this apportionment, which can be obtained from the decennial Census database. The data used for this research corresponds to the 1990 census tables STF3A and STF3B (35).

Yet another source for such economic data is the County Business Patterns database (27). This report presents State-to-State and county level employment, total number of establishments, and the number of establishments by employment size class. County Business Patterns is the only source that provides annual sub-national data at the two, three, and four digit levels of the Standard Industrial Classification (SIC) system. It is most useful for making basic economic studies of small areas.

3.2.4 Data for Validation and Analysis

To check the effectiveness of the analysis procedure, the results obtained have to be compared with real-world existing truck traffic counts. One such truck traffic count can be obtained from the Highway Performance and Monitoring Services (HPMS) surveys (28). These surveys are conducted on selected sections of the highways and represent a random sample of the actual number of trucks on all relevant links. These counts may vary daily and seasonally. This variation was not addressed in this research and requires a more detailed study. For this research, an average percentage of commercial vehicles during peak hours was multiplied with the ADT to give daily trucks.

3.3 Develop GIS Data Structures

3.3.1 Construct Regions and Connect their Centroids to the Network

To analyze freight movement on a smaller scale, regional freight movement data should be disaggregated to smaller zones. Hence states must be divided into smaller regions for analysis. The configuration of the regions depends on the scale of accuracy of analysis involved. The size of the regions should be such that they capture effectively the economic activity in the region. Sometimes when using an economic variable such as total employment to apportion the flows, freight of a particular type, say manufacturing, may get assigned to a region when, in reality, no manufacturing units exist in the area. Secondly, the size of the state is also an important criterion. For large states, three-digit zip codes may be a good approximation, whereas, for smaller areas, five-digit zip codes or Transportation Analysis Zones (TAZs) may be appropriate.

Centroids of the regions can be assumed to be the points of origin and destination of freight in that region. Centroids are defined based on population, geography, or some other measure indicating the hub of economic activity. These are then joined to the network with artificial links called centroidal connectors. These connectors are links that are created only on the network to facilitate the movement of freight destined to the region to the centroid. These connectors allow for flow only in a single direction, and prevent flow "through" them.

3.3.2 Calculate Time and Capacity Fields for Transportation Links in the Network

The traffic assignment process makes use of important network attributes, the time and capacity of the various links in both directions. Travel times for highway links can be approximated as free flow travel time that can be calculated by dividing the length of the link by the posted speed limits. As a minor adjustment, posted speed limits can be increased by 10 mph to account for motorists travelling closer to the design speed. Unless markedly different, the same travel times can be assumed for both travel directions.

Capacity can be calculated according to the Highway Capacity Manual, HCM (29). This method takes into account the roadway geometry and traffic characteristics in terms of mix of traffic, and service conditions. Capacities of basic freeway segments have been computed using the following formula.

$$SF_i = MSF_i * N * f_w * f_p * f_{HV} \qquad (3.1)$$

where, SF_i = Service flow rate under prevailing conditions for Level Of Service (LOS) i.
MSF_i = Maximum service flow rate under ideal conditions = $c_i\,(v/c)$
c_i = capacity of a freeway lane under ideal conditions
(v/c) = maximum allowable v/c ratio for LOS i.
N = Number of lanes in one direction.
f_w = adjustment factor for restricted lane width and lateral clearances as a function (lane width, number of lanes, obstructions on the roadway).
f_p = Driver-population adjustment factor as a function (recreational versus commuter traffic magnitude).
f_{HV} = Heavy-vehicle adjustment factor as a function (% trucks, number of lanes, type of terrain/grade).

Interstates can be analyzed using formula 3.1. All three adjustment factors can be taken equal to one, because they do not influence truck volumes largely. The LOS can be fixed at '*C*' to arrive at conservative capacity values. Capacity values of state and US highways can be calculated using a similar formula based on rural highways.

Centroidal connectors are given a travel time of zero as they are merely allowing flow into the region in the analysis and are not physically carrying any freight. They can be capacity coded with very high values to maintain the completeness of the data needed for assignment.

3.4 Develop Methodology for Assigning and Apportioning Flows.

3.4.1 Develop Distribution Ratios

The data obtained for the region of analysis has to be apportioned to the various districts created. The distribution ratios were calculated from socio-demographic characteristics, such as employment. Since this formula would be applied to smaller areas under the purview of MPOs, employment density in the various industry sectors considered was chosen as the indicator variable. District shares of commodity tonnage were hence calculated using the function:

$$DR_{ij} = (e_{ij} / a_i) / (e_{ij} / a_i)_{tot} \qquad (3.2)$$

where, DR_{ij} = distribution ratio for district i in industry j
e_{ij} = employment in district i in industry type j
a_i = area in square miles of district i

3.4.2 Identify Entry and Exit Points for the Area of Analysis

Because freight enters and leaves the analysis region, entry and exit points must be defined. These points can be located as nodes on the network that lie on the borders of the analysis region, which then correspond to external origins and destinations. As discussed in section 3.3.1, internal origins are the centroids of the smaller regions created.

3.4.3 Apportion Flows at Entry and Exit Points

Inbound and outbound freight are apportioned to entry/exit points based on the proximity of the centroid of the external area or district and the importance and LOS of the transportation link. Proximity was calculated as the shortest network distance between the centroid of the external area and the entry/exit point. As the distance to a given entry/exit point increases, the probability of using that highway decreases.

The distribution of freight tonnage to the regional entry/exit points was performed using the product of the proximity and the level-of-service.

3.4.4 Construct Relationships between Weight of Commodity and Number of Vehicles

Procedures described in sections 3.4.1 and 3.4.2 provide matrices of origins and destinations represented by internal centroids and external entry/exit points and the apportioned values consisting of commodity movements in tons. These O-D matrices in terms of tons of commodities need to be converted to O-D matrices representing the movement of commodities in number of freight trucks and carloads. Such O-D matrices can be assigned over the transportation network to obtain flows on all the links in terms of numbers of trucks, and these results can be validated against existing survey counts.

Since a vast difference exists in the distribution of densities of the various products, conversion formulae for each of the different commodity categories have been formulated as below. The basic equation is:

$$N = \frac{W_I}{\rho_{i\,(avg)} \Sigma\, p_i v_I} \qquad (3.3)$$

$$N = \frac{1.3 W_I}{\rho_{i\,(avg)} \Sigma\, p_i w_i (1 - p_{ei})} \qquad (3.4)$$

where, N = Total number of trucks carrying commodity belonging to industry type *i*
W_i = Weight of commodity of type *i* shipped annually between any two O-D pairs
$\rho_{i\,(avg)}$ = Average density of freight of commodity type *i* being shipped (kg/m^3)
p_j = Average percentage of truck type *j* (as defined in figure 3.2)
v_j = Average volume of truck type *i* (m^3)
w_j = Average weight of non-empty trucks of type *i* (kg)
p_{ej} = Average percentage of empty vehicles of type *i*

The theoretical basis for equations 3.3 and 3.4 include:

1. Weight translates into volume for a given density.
2. Empty trucks will bring down average density of goods shipped.

3. Average weight of the trucks range from 25% to 35% of the commodity weight they carry (hence total weight of truck in equation 3.3 is 1.3 * W)
4. Trucks of type 4 *(i=4)* are buses and are not considered here.

This conversion incorporates the effects of various truck sizes and dead hauls (trucks returning empty after delivery). Using a low value for density in equation 3.3, a dead haul component gets added automatically to each direction of movement into and out of the region. Further, the density value corresponds to commercial vehicle flow as opposed to just freight flow. Hence, this conversion results in the commercial flows for a give commodity weight. Freight density has an inverse relationship to truck number and, therefore, small changes in density can produce large changes in the latter. Because of such high sensitivity, further research should be undertaken for more accurate formulae. Information about various truck loading practices should also be gathered for the analysis of multi-commodity flows.

3.4.5 Origin-Destination Matrix Structure and Variations

Using equation 3.3 or 3.4, O-D matrices for each commodity type representing the annual number of vehicles moving between the entry/exit points and centroids are developed. Values in these matrices are then divided by the number of working days, to obtain the average daily vehicle flows, which can be validated against available survey data. The resulting final O-D matrix has four major divisions as shown in figure 3.2. O-D matrices of such type are obtained for each of the major commodity types and are assigned over the network and then summed to obtain the total truck flow over each link.

3.4.6 Assign the O-D Matrix Over the Multimodal Network

Once the O-D matrices and transportation network have been established, they are now assigned over the network using the User Equilibrium assignment process.

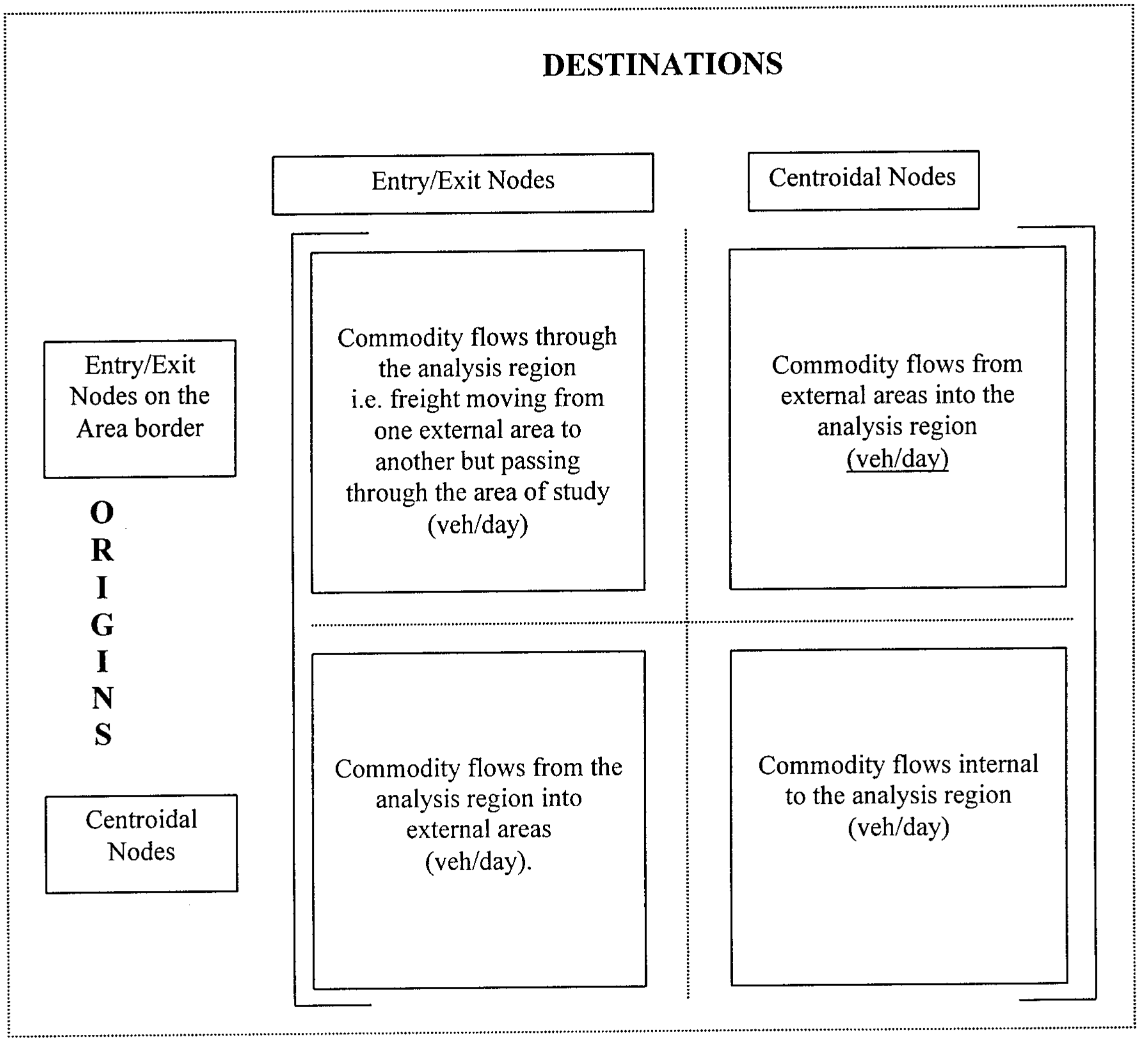

Figure 3.2: Structure of the Origin-Destination Matrix

This process basically utilizes an iterative process to achieve a convergent solution in which no vehicle can improve its travel time by shifting routes. Many software packages formulate this problem as a mathematical program using the Frank-Wolf solution method as applied to LeBlanc (30). In each iteration, network link flows are computed incorporating link capacity restraints effects and flow dependent travel times.

However, this method is not directly applicable to freight movement because of the presence of a cyclic relationship between the number of trucks and the classification of the highway. The number of trucks for a given commodity weight is a function of the percentage mix of the type of trucks (see equations 3.3 and 3.4), which depends on the type of highway. However, highway characteristics enter the analysis at the assignment stage, wherein the number of trucks needs to be calculated before hand. Hence, an iterative procedure using principles of the User Equilibrium assignment mentioned above can be applied.

3.5 Validation of Assignment Results with Observed Data

Once the assignment has been performed, the results should be validated against observed data. Truck counts can be obtained from HPMS surveys. HPMS is a continuous survey conducted by state agencies at specific highway sites to measure, among other items, truck traffic, providing an understanding of the ADT on these segments. These counts can be used to validate against those obtained from assignment results. Differences between assignment results and survey counts can be calculated and their magnitude checked against a specified error margin of the survey count for that link. The number of segments in this error margin provides a measure of the effectiveness of the methodology.

3.6 Summary

This chapter presents a procedure to assign freight flows to transportation networks for planning purposes. A review of the available freight data sources and their collection details were provided. A procedure for apportioning bulk commodity flow into and from the area of analysis was developed. The methodology also provides some insight into assigning freight flows over the transportation network and comparing the obtained vehicle movements against real world data. The next chapter presents a case study in which this methodology has been applied to the Boston MPO region.

CHAPTER 4

CASE STUDY – BOSTON MPO

4.1 Introduction

In the previous chapter, a methodology for analyzing freight movement was outlined. This procedure was applied to Eastern Massachusetts to analyze freight flows in the region under the jurisdiction of the Boston Metropolitan Planning Organization. Commodity movement studies were conducted using geographical boundaries of states and BEAs. This chapter explains the details of this case study.

This chapter gives a brief background of freight movement around Boston, notes on the software, and data sources that were used for analysis. The procedure of extraction of relevant data and the step by step procedure for freight flow assignment are also explained. A comparison of the results obtained against existing survey counts and the interpretations of traffic patterns observed have been presented at the end.

4.2 Background

4.2.1 Geographic Orientation

Boston, the economic nucleus of the state of Massachusetts is the seventh largest consolidated statistical metropolitan area (CSMA) in the United States. Covering roughly 1400 square miles, the Boston metropolitan area consists of 101 cities and towns and is home to nearly three million people.

The city holds 9.5% of the state's population, produces 24% of the goods and services, and generates 21% of the total earned income and 18% of the state tax revenues.

Boston's array of world-renowned institutions also helps make it the cultural, medical, educational, and governmental capital of New England.

4.2.2 Highway Transportation

The economic vitality of Massachusetts is dependent upon a strong transportation infrastructure. From commuting to commerce, the means by which people and goods move impacts the ability of the area to attract new growth, support existing industry, and position itself prominently in the global marketplace. Massachusetts has a reasonably dense highway network, in and around the Boston metropolitan area. Important highways including I-90, I-95, I-495, I-93, and U-3 traverse the Boston area as shown in figure 4.1. Interstate 90 is the major east-west highway that connects Boston to New York and other states in the midwest. Because Boston is a primary point of exchange, trucks form a dominant mode of freight transportation (21). Freight heading towards and originating in the Mid-Atlantic region is mostly shipped on I-90 and I-84. Freight to and from the northern New England states is transported via I-495 and US Highway 3, while freight heading towards or originating in the Southern New England states of Connecticut and Rhode Island takes I-90, I-84 or I-395, and I-95/I-495.

Because Springfield is another big hub of intermodal activity, a large percentage of freight is shipped to the terminals there via I-90. Much of the freight originating in northern of Massachusetts, which is heading south to the Mid-Atlantic and other southern states, takes Interstate 495. A significant imbalance exists between inbound and outbound freight movements in the region due to location and consumer nature of the population. Greater amounts come into the region than leave it.

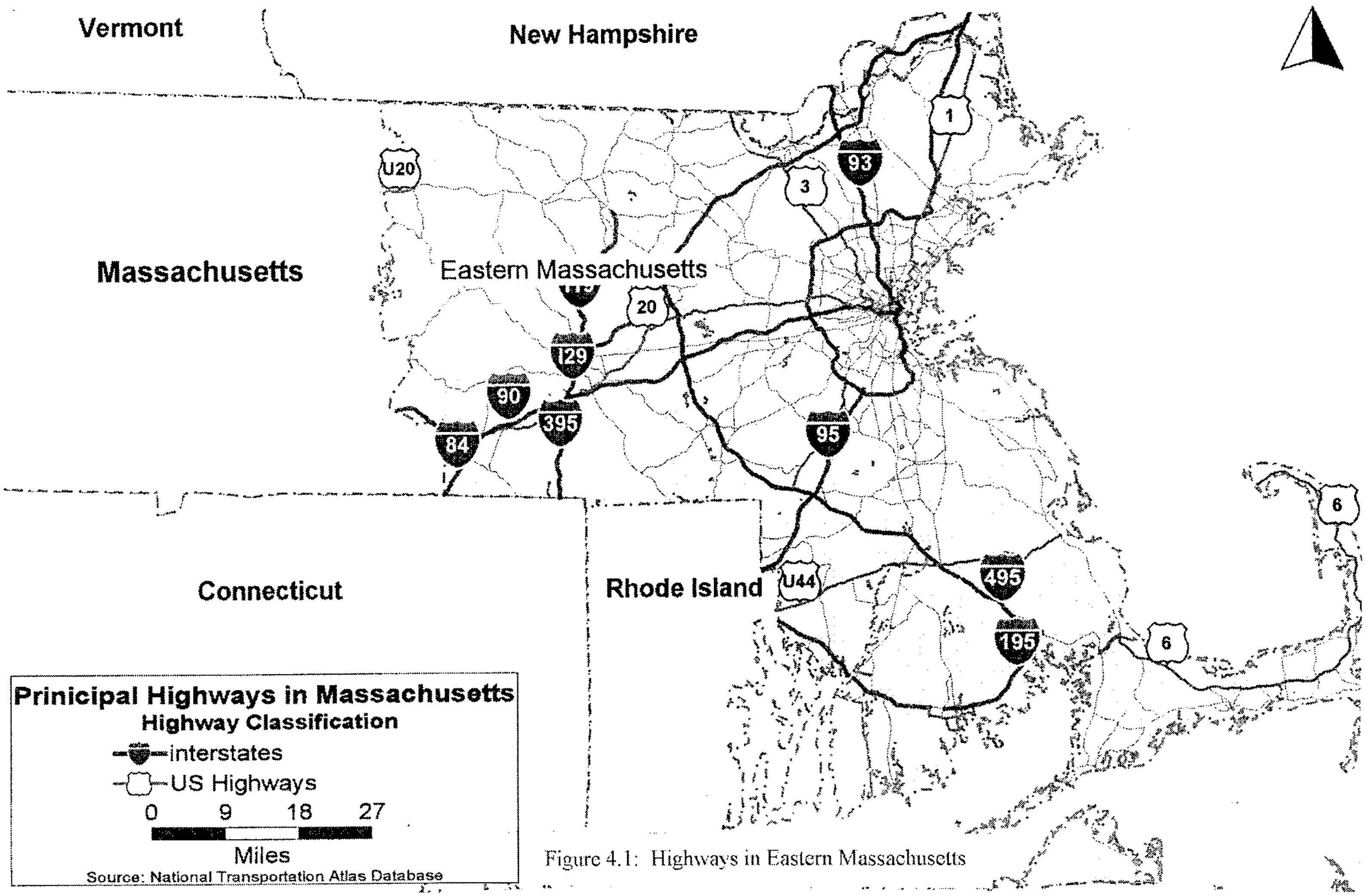

Figure 4.1: Highways in Eastern Massachusetts

4.3 Software Used for the Case Study

The software used for spatial analysis and traffic assignment was TransCAD®, by Caliper Corporation (32). TransCAD was chosen because of the following main features:

- a powerful geographic information system (GIS) which works in a Windows environment,
- modeling facilities that provide essential tools for display, manipulation, and analysis of transportation network data,
- a broad and comprehensive sets of geographic, demographic and transportation data, and
- a powerful development language for creating macros, add-ins and server applications.

TransCAD combines a unique set of capabilities for digital mapping, geographic database management, and presentation graphics, with tools to apply complex and sophisticated transportation, operations research, and statistical models.

4.4 Data Used for the Analysis and their Sources

Details of the different data, their sources and use in the analysis are described below.

4.4.1 Freight Movement Information

Freight movement information was obtained from a data set provided by Reebie and Associates, Stamford, Connecticut on 1995 regional commodity flows. This data set has information on tonnages of different commodities by SIC (Standard Industrial Classification Code) code being shipped into and out of the Boston and Worcester areas by different modes. Based on the three-digit SIC code, commodities were classified into six categories:

- Agriculture Services, Fishing, and Forestry
- Mining
- Manufacturing – Non-Durables

- Manufacturing – Durables
- Transportation
- Wholesale

Individual movement tables for each of these groups were constructed and analyzed. Tables 4.1 to 4.6 present the total commodity movements by category in the area.

Table 4.1: Total Agriculture Services, Forestry and Fishery Commodity Flows by Truck in Eastern Massachusetts (tons)

Origins	Destinations					
	Boston	**Mid Atlantic**	**Mid West**	**New England**	**Springfield**	**Others**
Boston	1135	970	3167	10293	2927	14329
Mid-Atlantic	82650	-	-	-	-	-
Mid-West	9805	-	-	-	-	-
New England	56935	-	-	-	-	-
Springfield	1239	-	-	-	-	-
Others	438238	-	-	-	-	-

Table 4.2: Total Mining Commodity Flows by Truck in Eastern Massachusetts (tons)

Origins	Destinations					
	Boston	**Mid Atlantic**	**Mid West**	**New England**	**Springfield**	**Others**
Boston	-	-	-	-	-	-
Mid-Atlantic	14543	-	-	-	-	-
Mid-West	266	-	-	-	-	-
New England	-	-	-	-	-	-
Springfield	-	-	-	-	-	-
Others	1881	-	-	-	-	-

Table 4.3: Manufacturing – Non-Durable Commodity Flows by Truck in Eastern Massachusetts (tons)

Origins	Destinations					
	Boston	Mid Atlantic	Mid West	New England	Springfield	Others
Boston	1617964	507833	203107	668476	243261	233460
Mid-Atlantic	746433	-	-	-	-	-
Mid-West	542864	-	-	-	-	-
New England	8697433	-	-	-	-	-
Springfield	164795	-	-	-	-	-
Others	840078	-	-	-	-	-

Table 4.4: Manufacturing – Durable Commodity Flows by Truck in Eastern Massachusetts (tons)

Origins	Destinations					
	Boston	Mid Atlantic	Mid West	New England	Springfield	Others
Boston	22560267	2407692	587978	5696971	4148664	950969
Mid-Atlantic	1778914	-	-	-	-	-
Mid-West	1625516	-	-	-	-	-
New England	2116652	-	-	-	-	-
Springfield	1626455	-	-	-	-	-
Others	4190309	-	-	-	-	-

Table 4.5: Total Transportation Commodity Flows by Truck in Eastern Massachusetts (tons)

Origins	Destinations					
	Boston	Mid Atlantic	Mid West	New England	Springfield	Others
Boston	198993	66268	52628	55170	23960	67375
Mid-Atlantic	32975	-	-	-	-	-
Mid-West	44304	-	-	-	-	-
New England	7758	-	-	-	-	-
Springfield	20345	-	-	-	-	-
Others	68925	-	-	-	-	-

Table 4.6: Total Wholesale Commodity Flows by Truck in Eastern Massachusetts (tons)

Origins	Destinations					
	Boston	Mid Atlantic	Mid West	New England	Springfield	Others
Boston	4051980	399228	127898	1029741	429718	31567
Mid-Atlantic	1108354	-	-	-	-	-
Mid-West	217469	-	-	-	-	-
New England	700655	-	-	-	-	-
Springfield	423553	-	-	-	-	-
Others	389212	-	-	-	-	-

4.4.2 Spatial Transportation Networks

Spatial transportation networks were extracted from the National Transportation Atlas Database (NTAD) (33). Major highways, shown in figure 1, were exported from the NTAD including data attributes such as posted speed limits, number of lanes etc.

Boundaries of Boston and Worcester areas were extracted from the Census Transportation Planning Package (CTPP), BTS 15-02 (34).

Data for validation of analysis was obtained from the Highway Performance Monitoring Service (HPMS) survey counts. These counts provide average percentages of peak and off-peak daily commercial traffic. These averages were averaged over three years, 1990, 1991, and 1992 and were multiplied by ADT (Average Daily Traffic) values to obtain the average number of commercial vehicles on highway segments. To maintain continuity, the values were extrapolated over highway segments.

4.4.3 Data for Freight Distribution and Assignment

Demographic data required for freight distribution and assignment were obtained from the 1990 Census (35). Employment data corresponding to the census were used to determine distribution ratios for the regions created. Employment in the standard industrial sectors, corresponding to the commodity groups that were mentioned in Chapter 3 was used to calculate distribution ratios for each district. The procedure for this is provided in Appendix B, and the distribution values are shown in table 4.7.

4.5 GIS Database Development

The area of Eastern Massachusetts was divided into thirty regions as shown in figure 4.2. A majority of the regions were 3-digit zip code areas, while the remaining were formed by grouping smaller 5-digit zip code areas. Geometric centroids of these regions were connected to the highway network.

Travel time for highway links was calculated as the time required for traveling that segment at the posted speed limit. This was assumed to be same for both directions of movement. Capacity values were calculated using the Highway Performance Capacity Manual (HPCM) (29) procedures for freeways and rural highways, assuming a level of service (LOS) 'C'. Centroidal connectors were given a travel time of zero and a capacity value of 100,000 vph.

4.6 Commodity Flow Distribution and Assignment

4.6.1 Distribution to the Districts

Distribution ratios for the analysis districts were computed using the total employment as the economic indicator variable. The distribution factor for a region was calculated as the ratio of the total employment in a given industrial sector for that region and the total area of the geographic unit of analysis using equation 4.1.

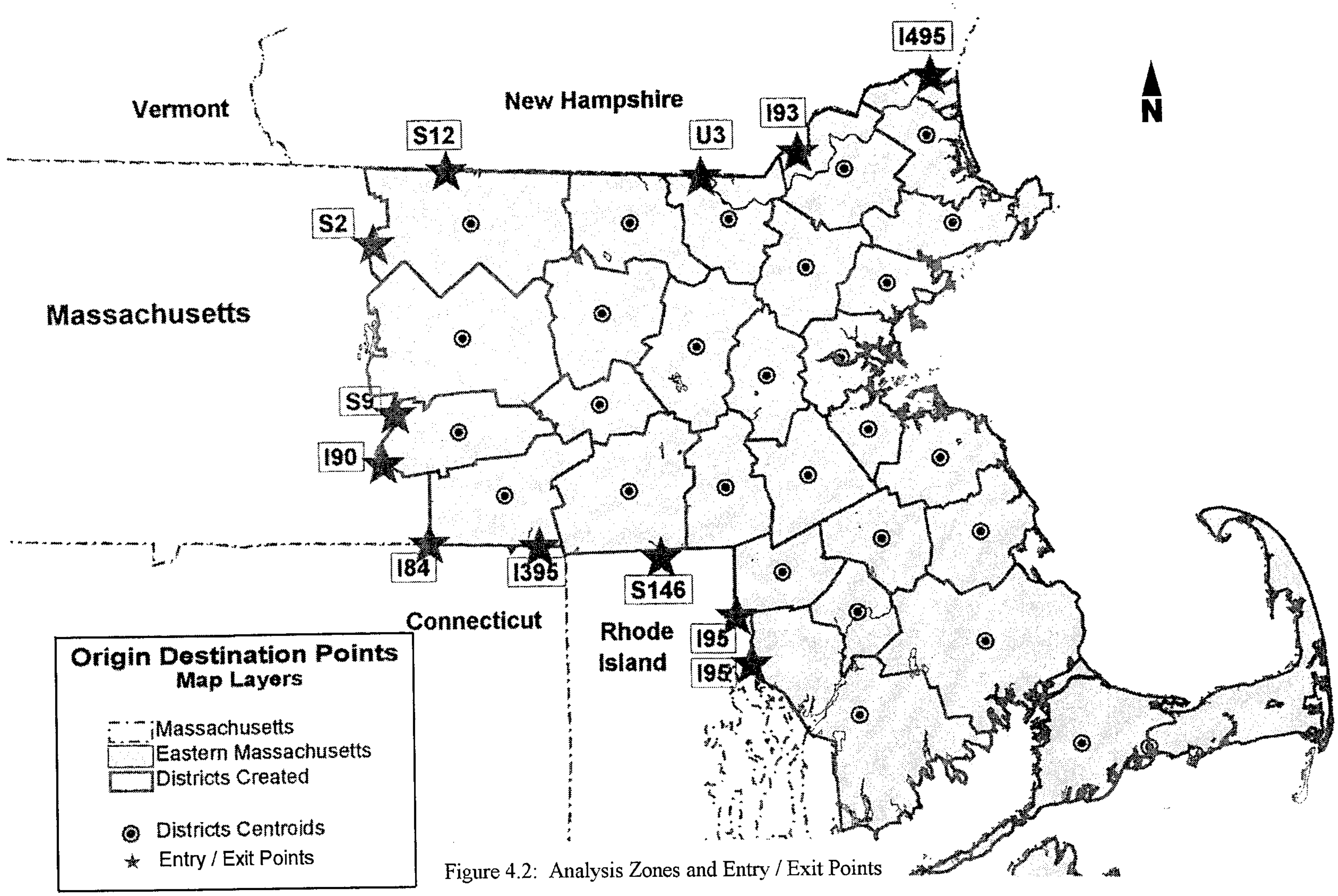

Figure 4.2: Analysis Zones and Entry / Exit Points

$$DR_{ij} = (e_{ij} / a_i) / (e_{ij} / a_i)_{tot} \quad (4.1)$$

where,

DR_{ij} = distribution ratio for district i in industry j
e_{ij} = employment in district i in industry type j
a_i = area in square miles of district i

Employment density better represents thickly populated areas and was chosen for the Boston area. Graphs of the employment densities in the six industrial sectors are shown in figures 4.3 to 4.8. In general, the peaks correspond to districts in central Boston which represent areas of major economic activity.

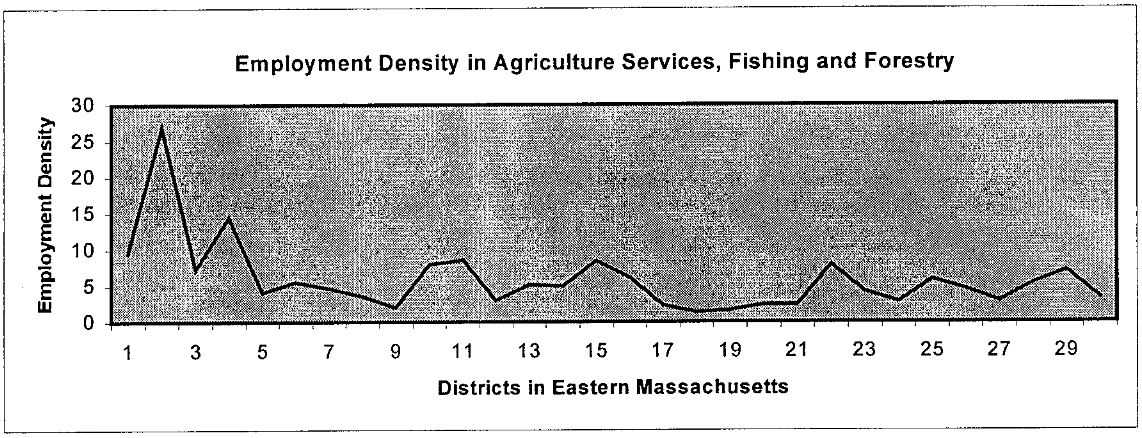

Figure 4.3: Employment Density in Agriculture Services, Fishing, and Forestry (person/sq mi)

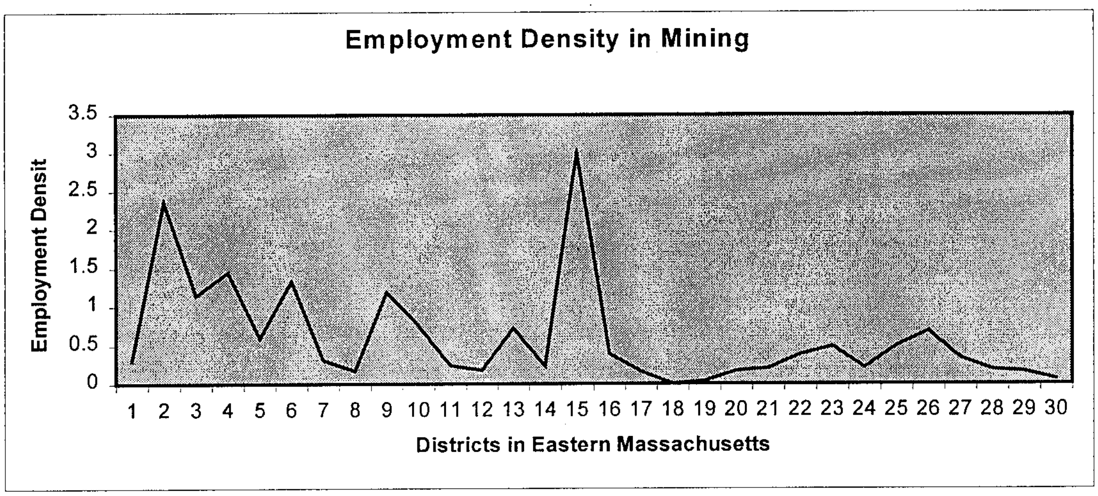

Figure 4.4: Employment Density in Mining (persons/sq mi)

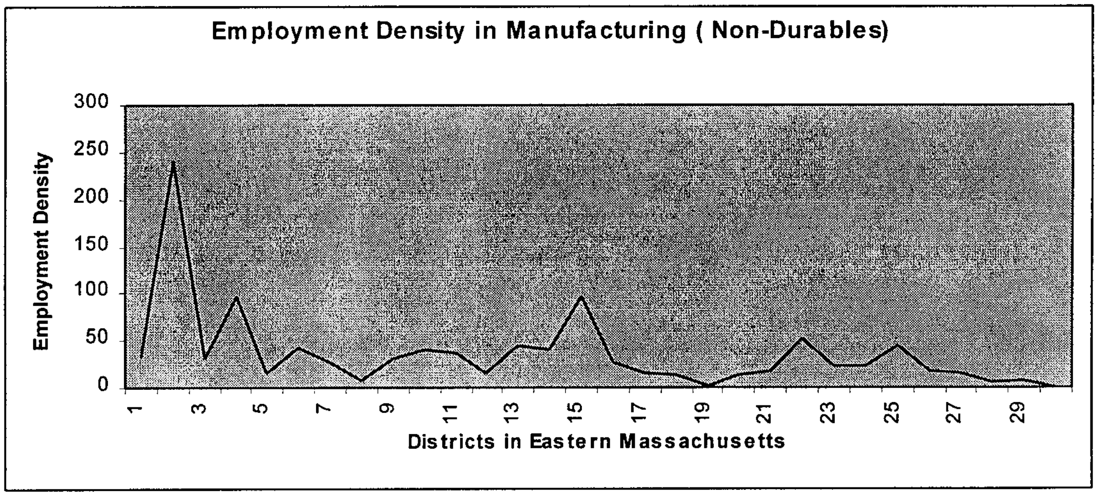

Figure 4.5: Employment Density in Manufacturing: Non-Durables (persons/sq mi)

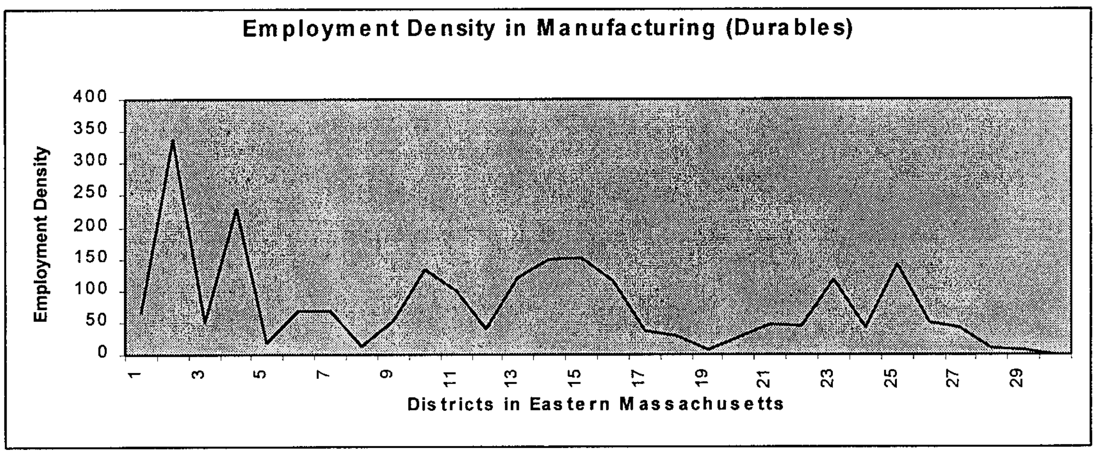

Figure 4.6: Employment Density in Manufacturing: Durables (persons/sq mi)

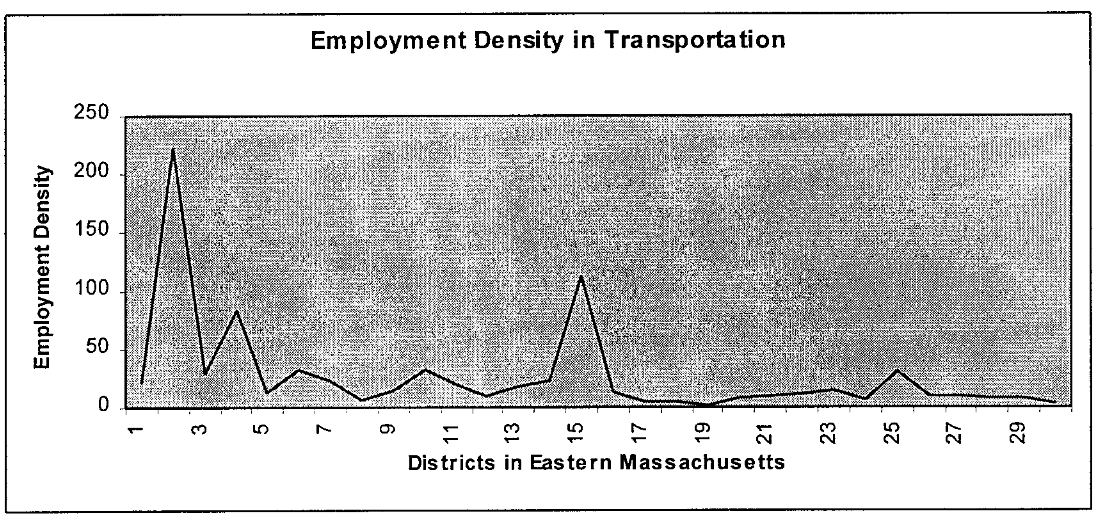

Figure 4.7: Employment Density in Transportation (persons/sq mi)

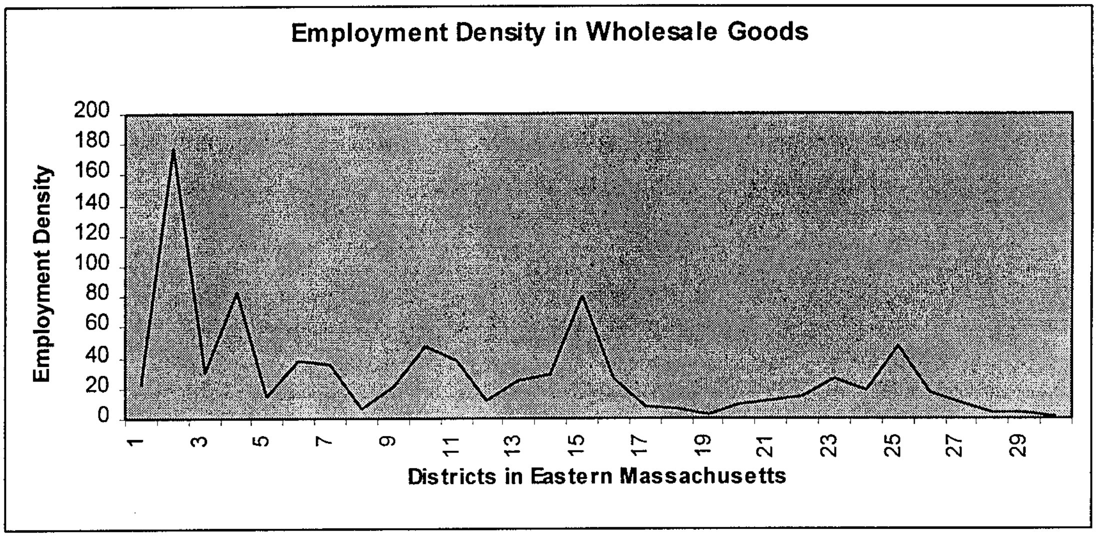

Figure 4.8: Employment Density in Wholesale Trade (persons/sq mi)

4.6.2 Distribution to the Entry/Exit Points

Intersections of the major highways with the area of analysis were identified and chosen as entry/exit points into the area as shown in figure 4.2.

Total freight entering or leaving the area of analysis was apportioned to each of these locations based on the distance between the entry point and the centroid of the external region, and also based on the relative importance of the highways. Commodity leaving the area for other states was assumed having same ratios as that for the freight coming into the state. The entry/exit point proportion ratios for the various regions are given in table 4.7. Calculations are provided in Appendix B.

Freight coming into Massachusetts from each state was multiplied by the ratios provided in table 4.7 to estimate the amount of freight moving through an entry point. Total freight arriving at each entry point was then aggregated commodity-wise, and redistributed among the districts.

Table 4.7: Apportionment Ratios for the Entry/Exit Points

State Highways	Mid-Atlantic	Mid-West	New England	Springfield	Rest of U.S.
I-495	0	0	0.064049	0	0
I-93	0	0	0.126706	0	0
US-3	0	0	0.080201	0	0
SH-12	0	0	0.068226	0	0
SH-2	0.097423	0.1009330	0.062378	0	0.092154
SH-9	0.073681	0.0763359	0	0.320919	0.069696
I-90	0.143269	0.1484309	0	0.679046	0.135520
I-84	0.200577	0.2671756	0.194932	0	0.243936
I-395	0.229230	0.2374894	0.155945	0	0.216832
SH-146	0.092102	0	0.062657	0	0.087120
I-95u	0.163736	0.1696353	0.111390	0	0.154880
I-95d	0	0	0.073517	0	0

Conversion of commodity tons to truck numbers was done using equation 3.3. Values of the average bulk densities of shipments of various commodity groups were taken from data provided in NCHRP Report 260 (9). Data from work at the University of Massachusetts (36) were used to estimate the truck percentage variables provided in Appendix C. Tonnage of freight belonging to each category moving from various origins to destination pairs was substituted for 'W', and the annual number of trucks carrying each of the six different groups of commodities, moving between these pairs was determined. To account for empty trucks these values were increased by a factor corresponding to the percentage of empty trucks in the average daily truck traffic in New England (37). This number was divided by 260, the average number of annual working days, to estimate the daily truck volumes, by commodity, between OD pairs. Average numbers of flows obtained were then compared against peak percentage of HPMS commercial traffic counts. Equations shown in table 4.8 give the final conversion equations for each commodity classification. Further calculations are given in Appendix D.

Table 4.8: Tonnage to Trucks Conversion Equations

Commodity	Conversion Equation
Agriculture, Fishing and Forestry	N = 0.00120 W
Mining	N = 0.00132 W
Manufacturing – Non-Durables	N = 0.00066 W
Manufacturing – Durables	N = 0.00170 W
Transportation	N = 0.00290 W
Wholesale Goods	N = 0.11270 W

'N' is the number of all types of trucks for commodity weight 'W' (tons).

4.6.3 Freight Assignment

Origin-destination matrices were assembled as in chapter 3, origins and destinations being represented by the entry and exit points and centroids in the analysis region. The analysis OD matrices are:

1. Region to region flows for all commodities.
2. Region to region flows for the six different commodity groups.

The first matrix represents total commodity flows in the area of analysis. The second is a set of six different OD matrices, each representing a commodity group. Owing to the large size of the matrices, only case 1, all commodities, is presented in Appendix E.

The OD matrices were assigned over the highway network to obtain truck flows in the region of analysis in two phases. In Phase 1, the region to region flows for all commodities were assigned, and in Phase 2, the region to region flows for the six individual commodity groups were assigned. User Equilibrium assignment was used and the results are shown in figure 4.9.

4.7 Interpretation of Results

From the results of the assignment in Phase 1, it was seen that high flows were obtained as expected on most of the interstates, I-90, I-495, and I-93. As shown in figure 4.10, truck counts obtained at about 53% of the HPMS survey sites fell within the tolerable category of + 20%. The calculated flows were underestimated at 28% of the sites and overestimated at 19% of the sites. These results can be explained as follows.

1. Through flows, which account for a large percentage of truck traffic on interstates I-495, I-93 and U-3 were not included.
2. Less-than-truckload shipments were also not considered. These constitute 10-15 % of total truck freight.
3. Marine freight moving to and from the Port of Boston was not included in the Reebie data.
4. Other kinds of trucks such as the ones used for local deliveries, garbage pick-up, and mail vans were also not included in the Reebie data.

High truck traffic is seen on I-90 and I-495, which is expected, because these are the two major highways connecting east-west and north-south regions. A high volume of truck traffic is also observed on I-95, which is due to the large amount of economic activity in that region for all industrial sectors. This can be inferred from the high employment density values shown in figures 4.3 to 4.8. Overall underestimation could also be attributed to the fact that the values of average bulk densities used in the conversion equations require modification to represent the variation in values of freight density more accurately.

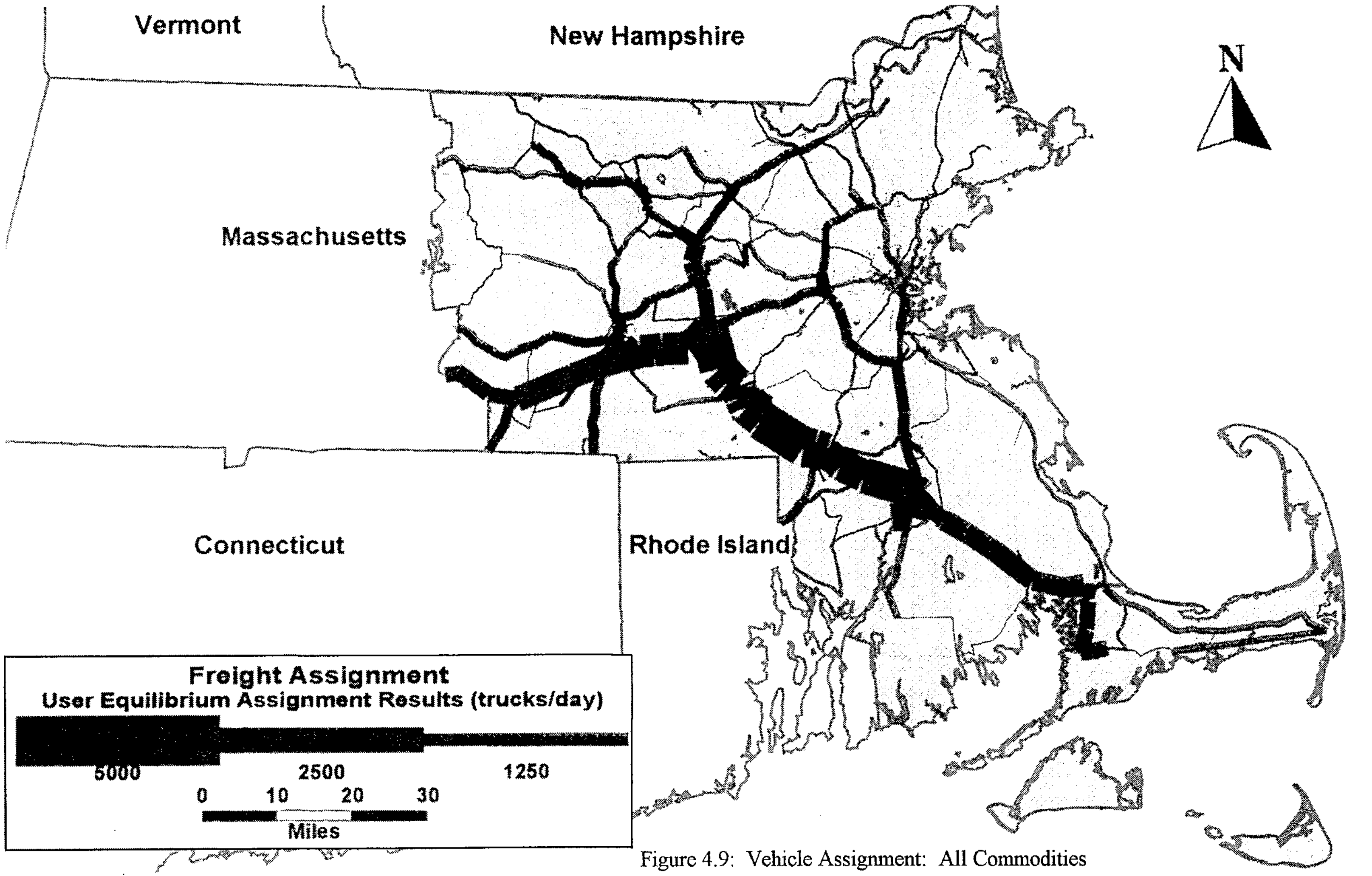

Figure 4.9: Vehicle Assignment: All Commodities

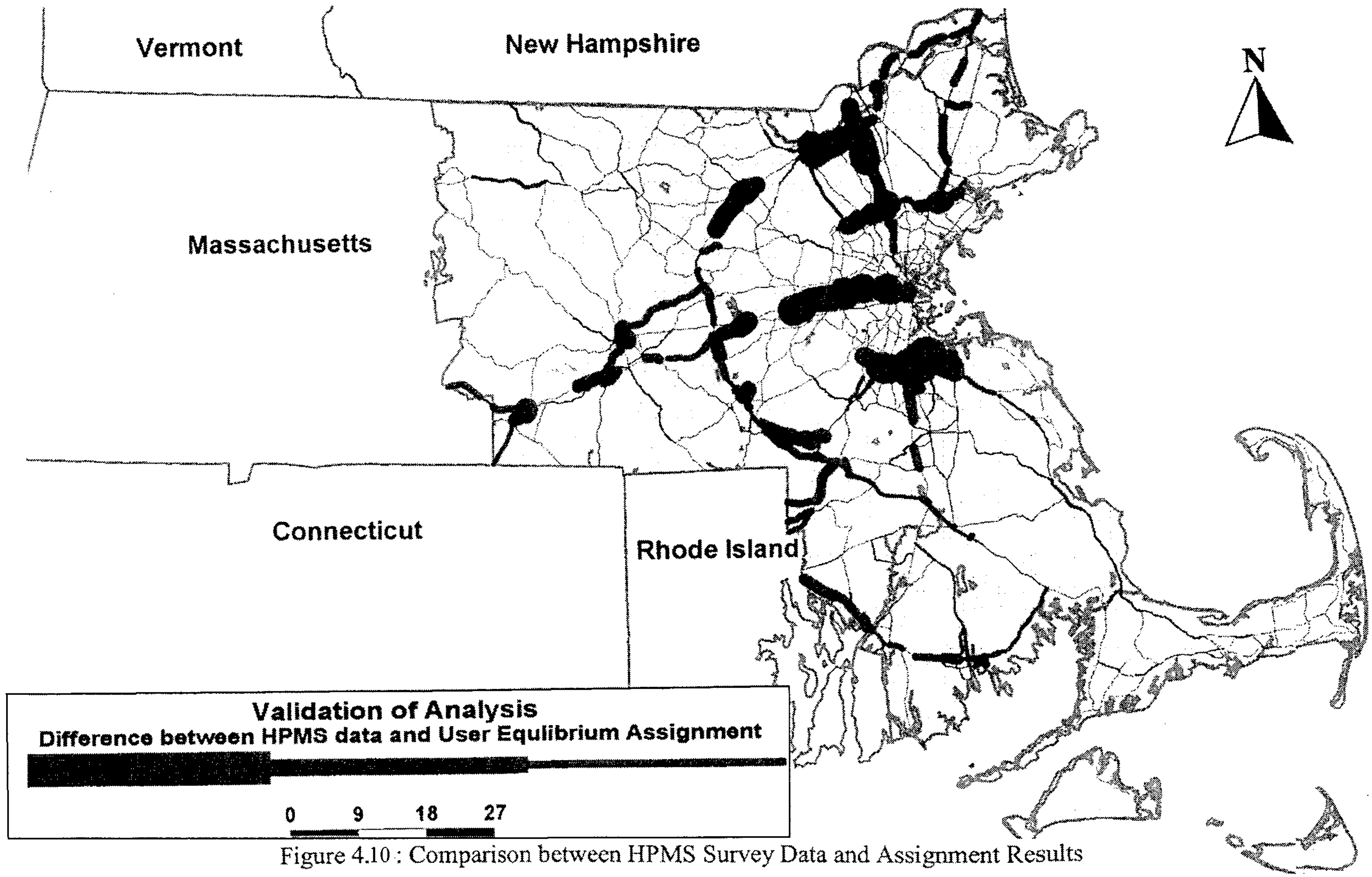

Figure 4.10 : Comparison between HPMS Survey Data and Assignment Results

In the second phase, the six OD matrices representing individual commodity groups were assigned individually over the network. Truck counts obtained on the different highway links after assignment were then summed up to represent total truck flow over the links. These values were then compared with the assignment values obtained in phase one to determine the effectiveness of performing the analysis by commodity type. However no significant differences were obtained. Truck counts obtained in Phase 1 were closer to the HPMS counts at approximately 7% of the HPMS survey sites, while truck counts obtained in Phase 2 were closer at approximately 6% of the sites, per figure 4.11. The limited correspondence could be again attributed to the fact that the Reebie data did not include all types of truck flows. Further research should be pursued in this area.

4.8 Summary

The approach appears to provide insight into predicting commercial vehicle movements by commodity type from aggregate freight data. Its partially successful application to this region shows that it has to be applied with more complete data, to provide reasonable results for freight forecasting in the region. However, the results provide a reasonable picture of how many vehicles are moving in the region. The next chapter summarizes the inferences gained from the application of the methodology, its limitations, and areas for future research.

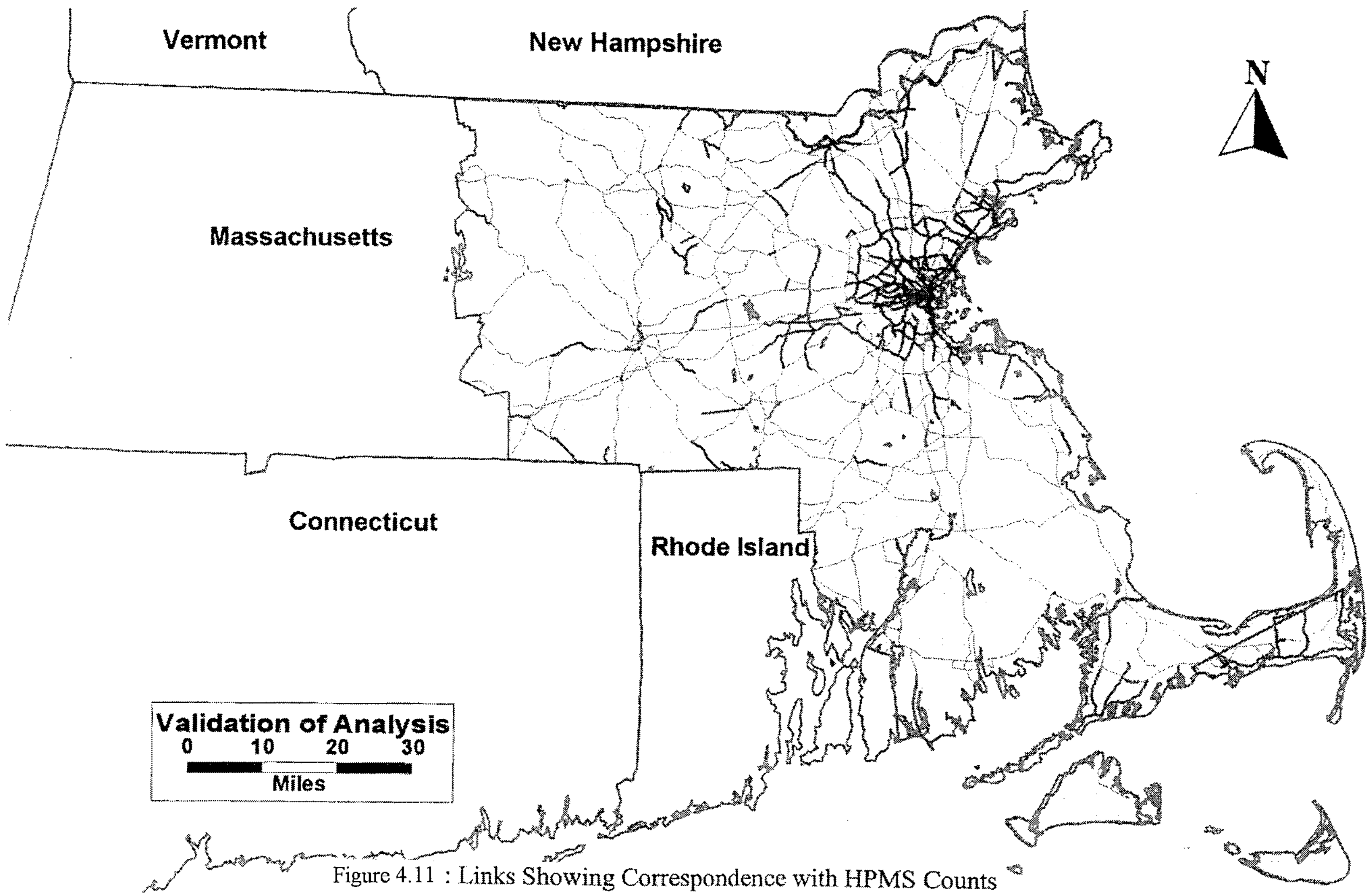

Figure 4.11 : Links Showing Correspondence with HPMS Counts

CHAPTER 5

CONCLUSION

5.1 Summary

A simple, straightforward and easily adaptable methodology for analyzing commodity movement for an area of analysis using GIS has been presented. The effectiveness of this approach has been tested using the Boston MPO as the case study. The following could be inferred from this research.

1) A reasonable rate of correspondence between calculated flows and observed counts suggests that it is possible to predict truck flows by commodity type from readily available aggregate movement data.
2) Commodity weight can be converted to truck volumes using empirical relationships that take into account the heterogeneity of freight and presence of dead-haul trucks.
3) Employment density is a good economic indicator variable for apportioning freight to regions.
4) Disaggregate analysis, i.e. analysis of freight by industry sectors, may be more effective and accurate for prediction of truck flows. Since significant difference in total vehicle flow were not obtained from the case study results, this area needs further research.

The proposed methodology is portable, since the data used can be established for any region. Though some amount of subjectivity was used for choosing entry/exit points, similar criteria can be applied to any region and the method can be applied in the same manner.

5.2 Limitations of the Methodology

1) The proposed approach provides for analyzing different categories of freight. The current trend is towards containerization and no direct method has been provided for better conversion between containers and commodity weight. This limitation may be addressed by assuming an average density for containers, and converting containers to equivalent commodity weight.

2) Average density of freight shipments is a critical issue in determining the number of trucks for a given commodity weight. Although commodities were classified

into six different classes, the vast amount of heterogeneity among commodities within a particular industrial sector has not been addressed.

3) The recommended cost function for assignment takes into account only link travel times and capacities. Ideally, this should be a function of other important factors such as cost of shipping, which is critical in the movement of trucks, and truck exclusion routes.

4) This methodology does not account for logistic criteria considered by private carrier companies to minimize total transportation costs. Route selection depends on logistic policies.

5.3 Future Research

1) The case study focused on analyzing freight movement on highways only. The railway network of the region should be added to this highway network, and intermodal transfer yards should be modeled as pseudo links connecting these networks. With an understanding of the spatial distribution of freight flows, suggestions for improving efficiency of the transportation system and reducing total shipment time could be studied.

2) The weight to truck number conversion formulae should be refined and recalibrated with current data.

3) Annual commodity flow has been converted to daily truck counts by using a factor of 260 (the average number of working days). Further research on the actual number of days that trucks travel should be performed.

4) At ports and other places of mass exchange of freight, additional socio-economic indicator variables should be introduced to represent intermodal activity. Trip chaining should be incorporated into the planning process.

5) More accurate data collection surveys need to be performed for obtaining counts of local delivery trucks, mail vans etc., which are not included in most data sets.

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APPENDIX A

FREIGHT PLANNING ACTIVITIES IN NEW ENGLAND

A.1 Central Massachusetts Regional Planning Commission, Worcester (CMRPC)

The CMRPC has undertaken significant work towards integration of freight movement into the urban transportation process. It participated in the nationwide truck survey conducted by the ATA[14] in 1991. During the development of the 1993 RTP, CMRPC contacted the New England ATA Foundation to inventory the existing freight operations, identify present concerns, and project the future characteristics of the region's trucking industry. The ATA conducted a survey of 85 trucking operations in the region resulted in the following :

- Locations and types of travel impediments, such as substandard ramps etc., were identified and mapped.
- An origin-destination matrix was constructed for regional commodity flows.
- An inventory of intermodal facilities was assembled and the usage patterns were reported.
- Travel patterns for trucks were identified.
- Expansion plans for various trucking agencies were identified.

The Intermodal Management System in the CMRPC region assists in the selection of improvements that enhance the efficient movement of freight. As a part of the IMS work, all of the region's major intermodal terminals have been identified, and all access routes indicated in the National Highway System (NHS) connections have been described.

For rail freight, existing operations of each freight railroad have been studied in detail. Current freight terminal and double stack issues in the region have been identified.

[4] ATA – American Trucking Association

Inventories of rail infrastructure improvements and regional at-grade rail crossings have been made, and plans for potential expansion or reductions in service have been developed. Abandoned and former rights-of-way within the region have been mapped to assist both in rail freight enhancement and rail to rail conversion efforts. Several recommendations have been proposed, and they include preparation of a terminal location map of the region's major trucking terminals using GIS, and also to conduct another survey with ATA

A.2 Franklin County Commission

To identify existing conditions, understand the concerns of freight industry in Franklin County, and identify needed infrastructure improvements to improve goods movement, freight and goods survey was conducted by the Franklin County Commission.

Industries within Franklin County and surrounding regions, which were considered to have major goods movements within the county, were identified, and were requested for informational assistance for developing the Regional Transportation Plan. The survey enabled the following:

- Identification of major trucking corridors,
- Identification of specific roads, highways and other infrastructure that needed improvements,
- Study of existing facilities and estimation of potential uses of rail yards and airports to determine which routes wide load transporters were using in the county, and also learning the reasons behind their choice.

A.3 Montachusetts Regional Planning Commission (MRPC)

The MRPC is involved in providing a more efficient means of transportation for movement of goods by attempting to bring into effect the following objectives:

- Promote the development and utilization of centralized terminal facilities for intermodal transfer and distribution of goods in the region.
- Encourage continued support for expanded use of the region's rail system for goods movement.
- Support provision of improved regional facilities for air cargo operations at the region's airports.

To achieve the above objectives, an inventory of goods movement in the Montachusetts region was made to determine if any problems existed. Further, a survey was mailed out to the shippers, trucking firms, and municipal officials, to collect data pertaining to the following considerations:

- Identify the roads used most often by carriers for local pick up and deliveries.
- Identify what truck operators believe to be the most serious truck movement problems and the best opportunities for alleviating those problems.
- Stimulate community interest in, and support for the goods movement project.

A region-wide shippers survey was conducted in February 1986, to develop basic data sets on the types of goods now moving within the region, transportation modes used, and other shipping characteristics that might help pinpoint future requirements.

To collect and organize data for the Intermodal Management System contract, IMS freight terminals and truck terminals within the MRPC area are also being identified. Many projects in the area of goods movement have also been listed for further work.

A.4 Old Colony Planning Council

Besides an inventory of the existing railroads, OPC conducted a truckers survey and prepared a trucking location map to be used in planning improvements designed to enhance the movement of highway freight within the region.

A.5 Merrimack Valley Metropolitan Planning Organization

The MVMPO made arrangements with the Rhode Island American Trucking Association (RIATA), to conduct a survey of truck haulers in the Merrimack Valley. This survey was performed to identify existing truck terminals in the Valley, as well as the pattern and magnitude of truck freight within the region and between the region and the rest of New England.

A.6 Massachusetts – State Level

At the state level, Louis Berger & Associates, Inc. is currently working towards collecting information, identifying and prioritizing state wide freight movement issues for the Massachusetts Freight Advisory Council (MFAC) and the Executive Office of Transportation and Construction (EOTC). According to a report published in February 1997, they had decided to carry out the following tasks:

- To conduct a background research into freight issues by reviewing the existing studies and to create a TRANSCAD database, by using tonnage information developed during research.
- To develop a list of region-wise freight issues such as choke points, infrastructure weaknesses, mode split by region and the rationale behind this, and policy issues affecting each mode.
- To conduct mode specific focus groups in order to identify mode specific issues whose anticipated solutions are both long term and short term.
- Depending on the results of the earlier task, to conduct a second round of interviews and focus groups to develop a process to prioritize issues.
- To facilitate two sessions of the MFAC to develop statewide long-term and short-term priority list of issues, by following the same process of prioritizing issues as developed in the regional focus groups.

APPENDIX B

CALCULATION OF PROPORTIONING RATIOS FOR ENTRY/EXIT POINTS

The calculation of proportioning ratios for the entry/exit points for the region of analysis was done by assigning relative values to the entry/exit points based on importance and proximity. It consisted of three steps as outlined below.

B.1 Assigning Proximity Measures

Proximity measures were calculated based on the distance between the centroids of external regions and the entry/exit points. The distances from the centroids of neighboring states/regions from the entry/exit points were first computed and then were assigned values based on the graph in figure B.1.

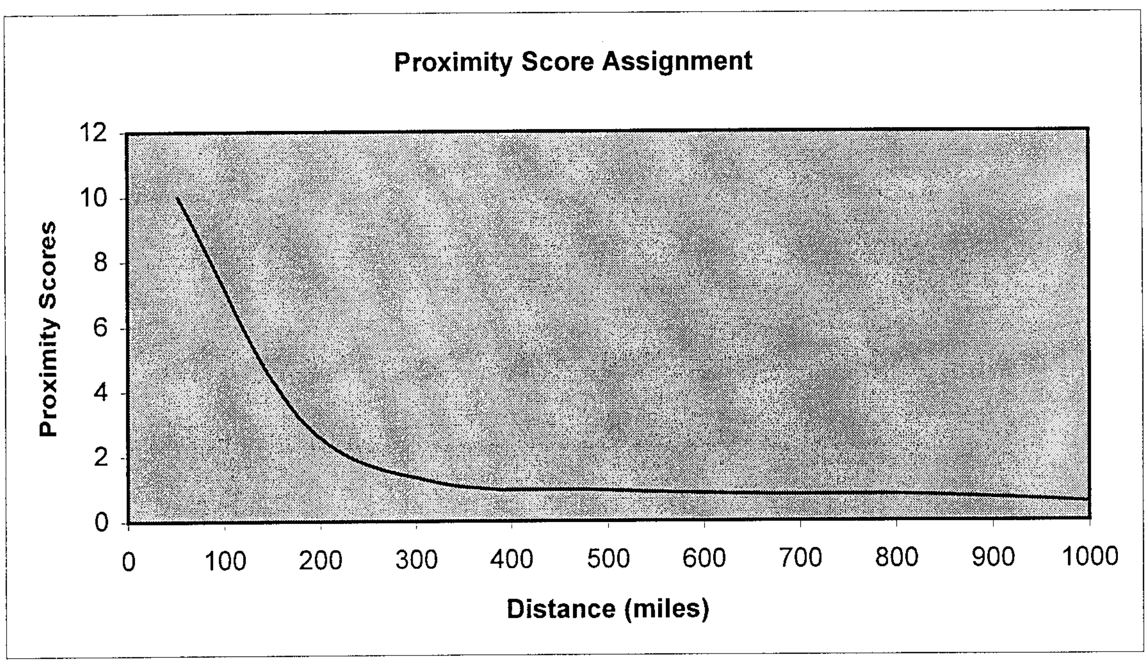

Figure B.1: Proximity Values for Different Distance Values (11)

Table B.1: Distance Calculation

Distances of entry/exit points from the centroids of regions (miles)–refer figure 4.18					
	Mid Atlantic	**Mid West**	**New England**	**Springfield**	**Rest of U.S.**
I-495	0[5]	0	194.65	0	0
I-93	0	0	85.32	0	0
US-3	0	0	141.28	0	0
SH-12	0	0	125.92	0	0
SH-2	124.69	124.69	143.03	0	124.69
SH-9	121.75	121.75	0	25.46	121.75
I-90	125.81	125.81	0	21.57	125.81
I-84	42.84	42.84	42.84	0	42.84
I-395	62.78	62.78	62.78	0	62.78
SH-146	84.07	84.07	84.07	0	84.07
I-95u	112.62	112.62	112.62	0	112.62
I-95d	135.35	135.35	135.35	0	135.35

The distances in table B.1 were entered for 'x' values in figure B.1 and the corresponding proximity values were determined which are shown in table B.2.

Table B.2: Proximity Score Assignment

Entry/Exit Points–refer figure 4.18					
	Mid Atlantic	**Mid West**	**New England**	**Springfield**	**Rest of U.S.**
I-495	0[6]	0	4.6	0	0
I-93	0	0	9.1	0	0
US-3	0	0	6.4	0	0
SH-12	0	0	7	0	0
SH-2	6.8	6.8	6.4	0	6.8
SH-9	7.2	7.2	0	13.8	7.2
I-90	7	7	0	14.6	7
I-84	14	14	14	0	14
I-395	11.2	11.2	11.2	0	11.2
SH-146	9	9	9	0	9
I-95u	8	8	8	0	8
I-95d	6.6	6.6	6.6	0	6.6

B.2 Assigning Level of Service Ratios

Level of service values were assigned based on the classification of the highways i.e. Interstate, State or U.S. Route, and their relative importance to the state. The values are shown in table B.3.

Table B.3: Level of Service Score Assignment

Level of Service Values for Entry/Exit Points – refer figure 4.18					
	Mid Atlantic	**Mid West**	**New England**	**Springfield**	**Rest of U.S.**
I-495	0	0	10	0	0
I-93	0	0	10	0	0
US-3	0	0	9	0	0
SH-12	0	0	7	0	0
SH-2	7	7	7	0	7
SH-9	5	5	0	5	5
I-90	10	10	0	10	10
I-84	7	9	10	0	9
I-395	10	10	10	0	10
SH-146	5	0	5	0	5
I-95u	10	10	10	0	10
I-95d	0	0	8	0	0

B.3 Calculation of Final Apportioning Ratios

The proximity scores were multiplied with the level of service values and then these products were aggregated across a row, i.e. for each region. The entry/exit point proportions for each region were determined by finding the fractions of the products with respect to the total for each column. These ratios are shown in Table 4.7.

[6] Not calculated as this entry/exit point is very unlikely to be used by the state.

APPENDIX C

TRUCK WEIGHT DISTRIBUTION[6]

Table C.1 Truck Weight Variations by Truck Type in Connecticut (1992)

Axle Load in Kips	Number of Trucks		
	Single Unit Truck 2 Axles to 6 Tires	Single Tractor Trailer 4 Axles or Less	Multiple Tractor Trailer 5 Axles or Less
3	69	45	7
4	340	74	2
5	242	44	7
6	105	21	11
7	238	78	35
8	175	229	57
9	177	313	96
10	126	228	161
11	115	133	177
12	105	83	115
13	73	75	120
14	60	76	131
15	33	84	179
16	35	79	176
17	24	76	132
18	12	52	87
19	10	42	40
20	14	27	32
21	10	16	28
22	6	16	17
23	4	8	8
24	0	1	4
25	2	1	0
26	2	1	0
27	1	1	0
28	0	0	0
29	0	0	0
30 and above	0	0	0

[6] Source: *New England Vehicle Classification and Truck Weight Program,* Technical Report No.2, New England Transportation Consortium, UMass Amherst (36), figure F.3, pp. 130.

APPENDIX D

CONVERSION OF COMMODITY WEIGHT TO TRUCK NUMBERS

Equation 3.3 was used to convert between gross commodity weight and truck numbers. Data from work at the University of Massachusetts (36) were used to estimate the various variables in the equation. These calculations are shown below.

$$N = \frac{W_i}{\rho_{i\,(avg)} \Sigma p_i v_i} \qquad \text{(D.1)}$$

where,

N = Total number of all types of trucks for a given commodity weight W.
W_i = Weight of commodity shipped annually between any two O-D pairs (kg).
$\rho_{i\,(avg)}$ = Average density of freight of commodity type i shipped
p_j = Average percentage of truck type j (as defined in figure 3.2)
v_j = Average volume of truck type i (m^3)
p_{ej} = Average percentage of empty vehicles of type i

'v_j' was calculated from average dimensions of truck type j. The calculation of 'p_j' and '$p_j v_j$' are shown in table D.2. The numbers in the last column were summed up and substituted in equation D.1 and simplified to result in the following.

Table D.1: Tonnage to Trucks Conversion Equations

Commodity	Conversion Equation
Agriculture, Fishing and Forestry	N = 0.0799 W
Mining	N = 0.0280 W
Manufacturing – Non-Durables	N = 0.0600 W
Manufacturing – Durables	N = 0.0689 W
Transportation	N = 0.1135 W
Wholesale	N = 0.1310 W

'W' (in tons) of each commodity type was substituted in the above equation and the number of trucks for different commodity weights were determined.

Table D.2: Calculation of $p_j v_j$

Truck Type (*i*)	**Number**	**Fraction (p_j)**	**Volume (v_j)**	$p_j v_j$
3	1503	0.192	300	57.6
5	1074	0.137	300	41.1
6	220	0.028	1439	40.29
7	6	0.001	1800	1.8
8	849	0.109	2150	234.35
9	3732	0.431	2150	926.65
10	43	0.006	2424	14.54
11	330	0.042	2878	120.87
12	56	0.007	3500	24.5
13	2	0.001	4300	4.3

APPENDIX E

ORIGIN DESTINATION METRIX FOR TOTAL COMMODITY FLOWS

Table E.1: Freight Flow Origin Destination Matrix (trucks/day)

	9477586	9493844	9508468	9531949	9539179	9550087	9584823	9590290	9590378	9601237	9683695	9702242	9735503	9739603	9799784	9799881	9799883	9799884	9799885	9799886	9799887	9799888	9799889
9477586	-	-	-	-	-	107	-	-	-	-	9	32	-	-	-	38	29	57	16	22	19	14	8
9493844	-	-	-	-	-	100	-	-	-	-	9	29	-	-	-	35	27	54	15	20	17	13	7
9508468	-	-	-	-	-	32	-	-	-	-	3	9	-	-	-	11	9	17	5	6	5	4	2
9531949	-	-	-	-	-	3	-	-	-	-	0	1	-	-	-	1	1	1	0	1	0	0	0
9539179	-	-	-	-	-	71	-	-	-	-	6	21	-	-	-	25	19	38	11	15	12	9	5
9550087	56	63	40	55	102	156	139	40	83	22	15	22	21	28	24	29	22	98	9	31	29	5	23
9584823	-	-	-	-	-	109	-	-	-	-	9	32	-	-	-	39	30	59	16	22	19	14	8
9590290	-	-	-	-	-	36	-	-	-	-	3	11	-	-	-	13	10	19	5	7	6	5	3
9590378	-	-	-	-	-	55	-	-	-	-	5	16	-	-	-	19	15	29	8	11	9	7	4
9601237	-	-	-	-	-	2	-	-	-	-	0	1	-	-	-	1	1	1	0	0	0	0	0
9683695	6	6	3	2	6	15	14	5	9	3	2	2	5	4	3	3	2	10	1	3	3	1	2
9702242	8	9	5	5	11	22	20	7	12	4	2	3	4	5	5	4	3	14	1	4	4	1	3
9735503	-	-	-	-	-	3	-	-	-	-	0	1	-	-	-	1	1	1	0	1	0	0	0
9739603	*	*	*	*	*	*	*	*	*	*	*	1	-	-	-	2	1	2	1	1	1	1	0
9799784	*	*	*	*	*	*	*	*	*	*	*	1	-	-	-	1	1	1	0	0	0	0	0
9799881	11	10	7	10	15	29	27	7	16	4	3	4	4	5	5	5	4	18	2	6	5	1	4
9799883	0	0	0	0	0	22	0	0	0	0	2	3	0	0	0	4	3	14	1	4	4	1	3
9799884	35	36	22	30	55	98	91	27	55	16	10	14	14	19	17	18	14	63	6	20	19	6	15
9799885	3	3	2	3	6	9	8	2	5	1	1	1	1	2	1	2	1	6	1	2	2	0	1
9799886	12	12	7	9	16	31	29	9	17	5	3	4	5	6	6	6	4	20	2	6	6	1	5
9799887	16	15	7	4	10	29	30	8	15	5	3	4	4	5	4	5	4	19	2	6	5	1	4
9799888	3	3	1	1	2	5	5	2	4	1	1	1	1	1	1	1	1	3	0	1	1	0	1
9799889	9	11	5	4	8	23	19	10	17	6	2	3	4	4	3	4	3	15	1	5	4	1	4
9799890	19	50	11	7	14	54	44	27	39	22	6	7	10	10	8	10	8	36	3	11	11	2	8
9799891	17	19	18	8	17	42	39	12	24	7	4	6	6	6	5	8	6	27	2	8	8	1	6
9799892	8	8	5	3	6	17	16	5	10	3	2	2	3	3	3	3	2	11	1	3	3	1	3
9799893	19	23	12	8	18	50	47	16	28	11	5	7	9	11	8	9	7	33	3	10	10	2	8
9799894	22	27	17	13	31	61	54	16	34	9	6	8	9	11	10	12	9	40	3	12	12	2	9
9799895	28	34	18	13	27	70	65	22	39	16	7	10	13	15	16	13	10	44	4	14	13	2	10
9799896	17	19	10	7	16	46	42	15	29	11	5	6	11	11	9	9	7	31	3	9	9	2	7
9799898	4	4	3	3	10	12	11	3	6	2	1	2	1	2	2	2	2	8	1	2	2	0	2
9799899	1	1	1	1	2	4	3	1	2	1	0	0	1	1	1	1	1	2	0	1	1	0	1
9799900	5	5	3	3	6	12	11	3	7	2	1	2	2	3	2	2	2	8	0	2	2	0	2
9799901	7	7	5	5	10	19	18	5	11	3	2	3	3	5	4	4	3	13	0	4	4	1	3
9799903	16	18	11	14	28	47	44	10	26	6	5	6	7	10	9	9	7	31	3	10	9	2	7
9799904	7	7	5	5	10	18	16	4	10	3	2	3	3	4	1	3	3	12	1	4	3	1	3
9799905	20	22	13	11	25	59	55	17	33	10	6	8	13	17	13	11	8	38	3	12	11	2	9
9799906	7	8	4	3	8	20	19	6	12	4	2	3	4	8	9	4	3	13	1	4	4	1	3
9799907	6	7	4	3	7	17	16	5	10	3	2	2	3	5	5	3	2	11	1	3	3	1	3
9799908	2	2	1	1	2	4	4	1	2	1	0	1	1	1	1	1	1	3	0	1	1	0	1
9799909	1	1	1	1	2	4	3	1	2	1	0	1	1	1	2	1	1	2	0	1	1	0	1
9799910	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0

Table E.1: Freight Flow Origin Destination Matrix (trucks/day), continued

	9799890	9799891	9799892	9799893	9799894	9799895	9799896	9799898	9799899	9799900	9799901	9799903	9799904	9799905	9799906	9799907	9799908	9799909	9799910
9477586	32	34	12	20	20	34	24	5	6	10	9	17	11	23	18	12	22	28	13
9493844	30	32	11	19	19	31	23	5	6	9	9	16	10	22	17	11	20	27	12
9508468	9	10	4	6	6	10	7	2	2	3	3	5	3	7	5	3	6	8	4
9531949	1	1	0	0	0	1	1	0	0	0	0	0	0	1	0	0	1	1	0
9539179	21	23	8	14	13	22	16	4	4	6	6	11	7	16	12	8	14	19	9
9550087	54	42	17	50	61	70	46	12	4	12	19	47	18	59	20	17	4	4	1
9584823	32	31	12	21	20	34	25	5	7	10	10	17	11	24	18	12	22	29	14
9590290	11	12	4	7	7	11	8	2	2	3	3	6	4	8	6	4	7	10	4
9590378	16	18	6	10	10	17	12	3	3	5	5	9	6	12	9	6	11	15	7
9601237	1	1	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	1	0
9683695	6	4	2	5	6	7	5	1	0	1	2	5	2	6	2	2	0	0	0
9702242	7	6	2	7	8	10	6	2	0	2	3	6	3	8	3	2	1	1	0
9735503	1	1	0	1	1	1	1	0	0	0	0	0	0	1	0	0	1	1	0
9739603	1	1	0	1	1	1	1	0	0	0	0	1	0	1	1	0	1	1	1
9799784	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0
9799881	10	8	3	9	12	13	9	2	1	2	1	9	3	11	4	3	1	1	0
9799883	8	6	2	7	9	10	7	2	1	2	3	7	3	8	3	2	1	1	0
9799884	36	27	11	33	40	44	31	8	2	8	13	31	12	38	13	11	3	2	0
9799885	3	2	1	3	3	4	3	1	0	1	1	3	1	3	1	1	0	0	0
9799886	11	8	3	10	12	14	9	2	1	2	4	10	4	12	4	3	1	1	0
9799887	11	8	3	10	12	13	9	2	1	2	4	9	3	11	4	3	1	1	0
9799888	2	1	1	2	2	2	2	0	0	0	1	2	1	2	1	1	0	0	0
9799889	8	6	3	8	9	10	7	2	1	2	3	7	3	9	3	3	1	1	0
9799890	20	15	6	18	23	24	18	4	1	4	7	18	7	22	8	6	2	1	0
9799891	15	12	5	14	17	19	3	3	1	3	5	14	5	17	6	5	1	1	0
9799892	6	5	2	6	7	7	5	1	0	1	2	5	2	7	2	2	0	0	0
9799893	18	14	6	17	21	22	16	4	1	4	6	16	6	20	7	6	1	1	0
9799894	23	17	7	21	26	27	20	5	1	5	8	20	7	25	8	7	2	1	0
9799895	24	19	7	22	27	31	21	5	2	5	9	21	8	26	9	8	2	2	0
9799896	18	13	5	16	20	21	15	4	1	4	6	16	6	19	7	5	1	1	0
9799898	4	3	1	4	5	5	4	1	0	1	2	4	1	5	2	1	0	0	0
9799899	1	1	0	1	1	2	1	0	0	0	0	1	0	1	0	0	0	0	0
9799900	4	3	1	4	5	5	4	1	0	1	2	4	1	5	2	1	0	0	0
9799901	7	5	2	6	8	9	6	2	0	2	2	6	2	8	3	2	1	0	0
9799903	18	14	5	16	20	21	16	4	1	4	6	16	6	19	7	6	1	1	0
9799904	7	5	2	6	7	8	6	1	0	1	2	6	2	7	2	2	1	0	0
9799905	32	17	7	20	25	26	19	5	1	5	8	19	7	23	8	7	2	1	0
9799906	8	6	2	7	8	9	7	2	0	2	3	7	2	8	3	2	1	0	0
9799907	6	5	2	6	7	8	5	1	0	1	2	6	2	7	2	2	0	0	0
9799908	2	1	0	1	2	2	1	0	0	0	1	1	1	2	1	0	0	0	0
9799909	1	1	0	1	1	2	1	0	0	0	0	1	0	1	0	0	0	0	0
9799910	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0