Modeling Regional Freight Flow Assignment Through Intermodal Terminals

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16. Abstract

An analytical model is developed to assign regional freight across a multimodal highway and railway network using geographic information systems. As part of the regional planning process, the model is an iterative procedure that assigns multimodal freight traffic to the network to achieve overall network optimum. The procedure integrates optimization programming with traffic assignment, considering the interactions between multimodal and single-mode traffic. The different modes included in the research are all highway, all rail, and rail-highway intermodal. The methodologies and algorithms are developed modularly and designed to be incorporated into any regional planning process and compatible modeling environment. A case study is presented for regional freight traffic assignment across Massachusetts.

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1. INTRODUCTION

Freight movement is an important aspect of the transportation system because of its direct link with economic viability. However, limited attention has been paid to the integration of freight demand modeling and assignment in regional planning efforts, which currently focus on moving people efficiently and safely. With increasingly high proportions of trucks in the traffic composition, and considering their distinct operating characteristics, the effects of truck traffic on road conditions and performance of the entire transportation network cannot be ignored. As a result, many states have initiated efforts to incorporate freight in both state and metropolitan planning *(FHWA 2003)*.

In recent years, the scope of the transportation planning process has emphasized strategies that promote more efficient use of existing transportation infrastructure, especially when intermodalism is involved. Comprehensive cooperation between companies and advanced data exchange technologies has enhanced intermodal freight transportation by making it more manageable and efficient. As a result, intermodalism has developed quickly and become a major factor in how freight moves across the transportation network. However, limited research has been performed on the effect of intermodalism on traffic impacts. Work performed by Guelat et al. *(1990)*, Cantarella *(1997)*, and Friesz et al. *(1986)*, etc., on modeling of multimodal freight flow assignment on a multiproduct or multiuser basis provides important background information for this research. In addition, geographic information systems (GIS) have been widely applied to the areas of transportation planning, engineering, and management. Use of GIS technologies in freight transportation planning can enhance conformity with recent efforts and methodologies in other areas of transportation planning and provides the flexibility for understanding the spatial effects of commodity flow. In this aspect, the research benefited directly from past work in the routing of freight over intermodal networks by Southworth and Peterson *(2000)*, from the development of highway freight flow assignment using GIS by Krishnan and Hancock *(1998)*, and from the regional intermodal freight assignment model developed by Xu et al. *(2003-1& 2)*.

As a critical part of intermodalism, intermodal terminals connect different single mode networks and establish the availability of facilities for intermodal transportation. The operating performance and physical characteristics of intermodal terminals directly influence the routing of intermodal freight traffic. Poor terminal performance or small handling capacity can greatly increase transportation costs and discourage intermodal transport of goods through the terminal, thus leading to a redirection of intermodal freight traffic. Evaluation of intermodal terminals' operating performances and improvement of operating efficiency have been considered by Jahren et al. *(1995)*, Kozan *(1997)*, Mazzucchelli et al. *(1995)*, Ferreira and Sigut *(1992)*, and Sarosky and Wilcox *(1994)*, etc. An intermodal terminal database that identifies terminals and describes their performance measures to facilitate the modeling of intermodal movement was developed by Oak Ridge National Laboratory (ORNL) *(Middendorf 1998)*. This database is a component of the National Transportation Atlas Database (NTAD), which is a multimodal transportation network that includes the geographical distribution of intermodal terminals connecting the various modal networks so that multimodal transportation analyses can be performed. However, this intermodal terminal database includes only the terminal's location, the modes being connected, types of cargo being handled, and the direction of transfer, with no details of the terminal's internal operating characteristics. For this project, a more detailed intermodal terminal database is constructed.

Currently many regional planning agencies or state departments of transportation are trying to integrate freight movement into their planning process. However, the scarcity of comprehensive data is the major obstacle to the analysis of regional freight traffic distribution. Information about goods movement generated from private industries is not easily accessible, which results in incomplete and inaccurate data. Moreover, the heterogeneity of goods leads to different transportation requirements and different transportation modes, especially for long-distance shipments. Large numbers of private shippers, carriers, third party transportation providers, and recipients make freight movement very complex. Each party has distinct decision-making processes and goals that may conflict with one another. Because intermodalism is used heavily in the transportation of freight, its inclusion in the planning process, more specifically, in the assignment of the multimodal freight traffic onto a broad network involving different modes, is challenging to regional planning agencies. These issues greatly increase the difficulty of modeling freight movement.

The primary objective of this work was to develop an analytical procedure to assign freight across a highway and railway network through intermodal terminals. A key feature of the research approach is the optimization of an intermodal freight traffic assignment to achieve an overall network optimum considering the interaction between multimodal and single mode traffic. Using available freight data, this research constructs a practical methodology to study regional multimodal traffic assignment, which can be used by both public and private planners. This optimized iterative methodology to assign freight movement onto an intermodal transportation network is described, including the construction of a GIS-based data structure, followed by the implementation of the methodology to a case study of an intermodal freight assignment in Massachusetts.

2. METHODOLOGY

The traffic assignment procedure is an iterative procedure that integrates optimization programming with traffic assignment, considering the interactions between single-modal and multimodal freight traffic. The modes include all highway, all railway, and railway-highway intermodal. This analytical method is developed modularly and can be incorporated into any regional planning process and compatible modeling environment. The result of this methodology is the freight traffic flow distribution pattern within the analysis area. Figure 1 shows the necessary components of the methodology.

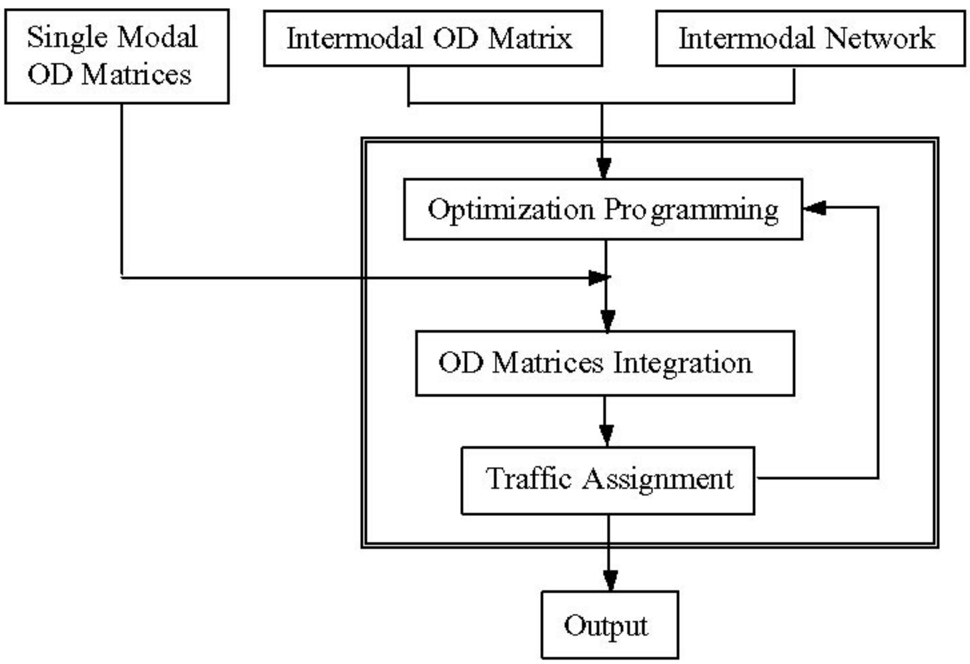


Figure 1. Representation of an optimized iterative assignment procedure.

2.1 Data Structure

To perform intermodal or multimodal analyses in current commercial GIS packages, all modes of transportation under consideration must be joined into a single network with careful consideration given to the intermodal facilities data structure.

2.1.1 Intermodal Network Construction

The intermodal network for an analysis area can be extracted from the CFS Intermodal Network developed by ORNL. The CFS Intermodal Network is designed to be used with GIS software packages to locate transportation features and provide a flowable framework for transportation network analysis. It integrates all individual mode networks and connects them through terminal links. The attributes of the links, such as the length and mode, are provided in the network.

2.1.2 Intermodal Terminal Data Structure

An intermodal terminal database is necessary for providing information required for analysis. However, the degree of completeness on terminal performance measures depends on the database. As indicated in the previous section, the intermodal database constructed by ORNL is on a macro level, providing general non-operational performance related information about the terminal without enough information to conduct this research. Conversely, construction of a database that includes all operational features in intermodal terminals is time-consuming and resource intensive. A balance must be established based on the requirements of the study being performed. For this research, a regional meso-level intermodal terminal data structure was developed. Types of meso-level data for intermodal terminals are identified in the literature *(Krishnan, 1998)*. Combining the previous study with the particular needs of this research, an intermodal terminal data structure is suggested in Table 1. The first five features are required for this study. The other three features are complementary attributes which describe the performance of intermodal terminals.

Table 1. Regional intermodal terminal data structure.

Characteristic of the Terminal	Attribute Category
Geographic coordinates of the terminal	Location
Average sitting time per unit of freight	Travel time
Average loading/unloading time per unit of freight	Handling time
Tariff for handling	Cost
Storage cost	Cost
Annual tonnage of freight transferred	Capacity
Daily weekday/weekend intermodal trains	Capacity
Daily weekday/weekend gate moves	Capacity

2.2. Analytical Procedure Development

The following tasks are required to model a freight movement on a multi-modal transportation system: (1) generation of transportation costs, (2) construction of OD matrices, and (3) assignment of traffic. Transportation cost is the basis used to assign freight volume onto the network. In an intermodal network, several individual transportation mode networks coexist with different operating characteristics, and intermodal terminals are the only locations where these individual modal networks interact with each other. To model intermodal freight movement, the modules for single modes and intermodal terminals have to be constructed first and then, based on the features of intermodal freight movement, the intermodal module is established. Figure 2 represents the relationships among these modules. Although highway, railway and intermodal terminal modules are basically independent of each other, some common features are still interrelated. For example, while the transportation cost is constructed for each module, the magnitude of these costs should reflect the difference among these modes when shippers determine the mode or modes to use. Data sources used in this research are also shown in Figure 2.

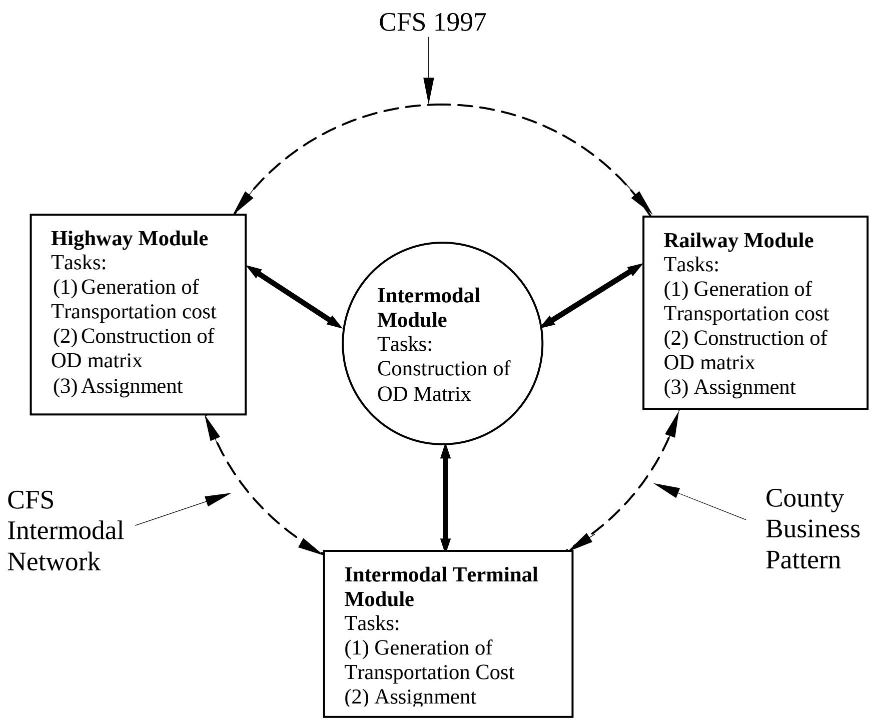


Figure 2. Intermodal traffic assignment structure.

In the freight industry, various roles in freight transportation exist: shippers, carriers, and third parties. Different roles require different cost compositions. In this project, the cost structure is set up from shippers' perspective.

Construction of the OD matrices is required to distribute the freight traffic volume from distinct origins to distinct destinations, based on certain socioeconomic characteristics of each region and a prescribed distribution rule. The aggregated data from the 1997 Commodity Flow Survey are disaggregated into OD matrices on vehicle volumes including the OD demand information for each single mode and intermodal movements *(Xu 2003-1).*

The multi-modal assignment procedure, used for this work, is a generalized cost assignment that lets the user assign trips by individual modes to the network simultaneously. Through this task, the freight traffic flow pattern is obtained within the analysis area.

2.2.1 Generation of Transportation Costs

Transportation cost is a fundamental data element that directly influences the decision-making process in freight traffic routing. In this methodology, the travel cost is constructed as an expected disutility function that incorporates cost related attributes, such as distance and travel time *(Xu 2003-1)*.

2.2.1.1 Highway cost

Highway link costs are composed of fixed and variable costs. Fixed costs can be viewed as (1) the operational cost, including fuel consumption and the depreciation of the wear and tear of vehicles along the link, or (2) the tariffs or tolls paid which are directly related to the physical distance of the link. Variable costs area closely associated with the actual travel time on the link, which depends on the current volume on the road *(Sarosky 1994)*. As a result, the link cost is formulated as follows:

$$LC^h_{mnp} = c^h_{np} \cdot D^h_m + v^h_{np} \cdot T^h_m + \delta^h_m \qquad (1)$$

where:

LC^h_{mnp}: Transportation cost for cargo type *n* and vehicle type *p* on highway link *m*;

c^h_{np}: Unit fixed cost for cargo type *n* and vehicle type *p*;

D^h_m: Physical distance of highway link *m*;

v^h_{np}: Value of travel time for cargo type *n* and vehicle type *p*;

T^h_m: Travel time on highway link *m*;

δ^h_m: Calibration variable, representing other expenses not included in this function.

The calibration variable facilitates the calibration of the model and makes the function more flexible. One thing worth mentioning here is that the variable cost of highway links dominates the process in congested environments, which may result in freight traffic moving to other routes or modes.

2.2.1.2 Railway Cost

The railway network consists of line-haul links and interlines which have totally different cost structures due to their different functions. The cost function is constructed from the shippers' perspective. For line-haul links, travel time (or speed) and transportation tariff are the major parts of the transportation cost as indicated in equation 2.

$$LC^r_{mnp} = v^r_{np} \cdot T^r_m + R^r_{np} \cdot W^r_{np} \cdot D^r_m + \delta^r_m \quad (2)$$

where:

LC^r_{mnp}: Transportation cost for cargo type *n* and vehicle type *p* on line-haul link *m*;

v^r_{np}: Value of travel time for cargo type *n* and vehicle type *p* transported by railway;

T^r_m: Average travel time on railway link *m*;

R^r_{np}: Transportation rate for cargo type *n* and vehicle type *p*; it can be obtained from the different rail companies operating on a link.

W^r_{np}: Weight of cargo of type *n* in vehicle type *p*;

D^r_m: Physical distance on railway link *m*;

δ^r_m: Calibration variable, representing other expenses not included in this function.

Unlike other types of links, railway interlines are not on-the-ground traffic ways. The use of an interline link is limited and depends on the agreements among railway companies. If an agreement exists between companies, the link cost is the average of interline fees. Otherwise, entry to the link is prohibited. The cost of an interline is:

$$LC^r_{mnp} = \begin{cases} IC^r_{mnp}, & if\ an\ agreement\ exits \\ +\infty, & Otherwise \end{cases} \quad (3)$$

where:

LC^r_{mnp}: Cost of interline *m* for cargo type *n* and vehicle type *p*;

IC^r_{mnp}: Average interline fee for using interline *m* for cargo type n and vehicle type *p*.

The interline cost is constant, and sensitive to the railway companies involved.

2.2.1.3 Intermodal Terminal Cost

An intermodal terminal is represented by a set of terminal links that connect different modes. If certain mode(s) involved in a transfer cannot be handled by a terminal, the entry to the terminal link is prohibited for such transfer. The status of goods in a terminal can be (1) waiting for operations, (2) being handled, or (3) in storage. Therefore, the terminal cost consists of a sitting time penalty (including waiting, handling, and storage time), handling (such as loading and unloading), and storage cost. The sitting time, defined as the total time that goods spend in the terminal, is a comprehensive performance measure that reflects the level of service of the terminal. It is highly dependent on the operation characteristics of the terminals, such as facility capacity, the efficiency of operations and the arrival distribution of freight traffic. As a result, the cost function for a terminal link is:

$$LC_{mn}^{t} = \begin{cases} \omega_{mn}^{t} \cdot T_{mn}^{t} + h_{mn}^{t} \cdot W_{mn}^{t} + s_{mn}^{t} \cdot W_{1,mn}^{t} + \delta_{m}^{t}, & \text{if transfer can occur} \\ +\infty, & \text{Otherwise} \end{cases} \quad (4)$$

where:

LC_{mn}^{t} : Transportation cost for cargo type *n* on terminal link *m*;

ω_{mn}^{t} : Unit sitting time penalty for cargo type *n* on terminal link *m*;

T_{mn}^{t} : Average sitting time for cargo type *n* on terminal link *m*;

h_{mn}^{t} : Unit handling cost for cargo type *n* on terminal link *m*;

W_{mn}^{t} : Weight of cargo of type *n* or number of containers handled on terminal link *m*;

s_{mn}^{t} : Unit storage cost for cargo type *n* on terminal link *m*;

$W_{1,mn}^{t}$: Weight of cargo of type *n* or number of containers stored on terminal link *m*;

δ_{m}^{t} : Calibration variable, representing other expenses not included in this function.

The variables involved in the formulation are usually the performance measures of a terminal and can be obtained directly from the terminal itself. If the data are available, the sitting time penalty can be further disaggregated into waiting, handling, and storage time penalties, as the values of these times are different from the transportation perspective.

2.2.2 Construction of OD Matrices

Three groups of OD matrices are generated during this task. The first group of OD matrices is the most aggregated one, i.e., state-to-state OD flows by mode(s) extracted from an available freight flow data source (e.g., Commodity Flow Survey). This statewide OD flow needs to be further disaggregated into more detailed ones based on the following procedures.

2.2.2.1 Single Mode OD Matrices

Step 1: Identification of Origin and Destination Points in the Analysis Area

Because an analysis area is a comparatively diverse area, it is divided into several smaller regions generally based on certain socioeconomic standards to study traffic flows. The centroid of each region is a notional point representing the internal origin or destination of freight shipments from or to the corresponding region within the analysis area.

As freight enters and leaves the analysis area, entry and exit points are required to study the external shipments. These points are located as nodes of the intermodal network that lie on the borders of the analysis area that correspond to external origins and destinations. For the highway network, the entry and exit points are defined as the nodes where the major highways (e.g. interstate highways) intersect the boundary of the analysis area; while for the rail network, these points are the locations where higher-classified railway links cross the border of the analysis area.

Step 2: Apportioning Flows between Regions

The Commodity Flow Survey (CFS) is a comprehensive database that broadly records freight movements by mode and commodity type between states. Based on these aggregated statewide commodity flow data, the freight volume originating from, destined to, and going through the analysis area can be extracted.

Apportioning flows coming in from regions external to the analysis area to highway and railway entry/exit points may be done by estimating (1) the proximity of these points to the centroid of the external area and (2) the importance and level of service for the transportation facility. A simple way to deal with this problem is to calculate the shortest distance between the centroid of the external area and the entry/exit point. Probability of using one entry/exit point highly depends on the distance between that point and the centroid of the external area. Priority is given to higher road and rail classification types.

Freight flows originating from or destined to the regions inside the analysis area have to be further disaggregated into the internal regions. The distribution ratio can be calculated from a socio-demographic characteristic, such as employment or employment density, which is available from County Business Pattern database. The distribution ratio can be obtained from the following function:

$$d_n = \frac{e_n}{\sum_{n=1}^{N} e_n} \qquad (5)$$

where,

d_n : Distribution ratio for region n;

e_n : Total Employment (all sectors) for region n;

N : Total number of regions in the analysis area.

Step 3: Conversion to Freight Traffic OD Matrices

To this point, the OD matrices representing the freight movement have been obtained in tons. However, to study freight traffic flow, a traffic volume OD matrix should be developed. Hancock et al. *(2001)* and

Karthakayan *(2000)* present methodologies for converting freight volume to the number of trucks and rail cars, respectively, resulting in payload matrices by vehicle type and commodity classification. Using the values provided by these payload matrices, freight volume in each OD pair could be converted to traffic volume. Following these procedures, the second group of OD matrices representing the freight traffic volume using centroids and entry/exit points as origins and destinations can be obtained.

2.2.2.2 Intermodal OD Matrices

Step 4: Identification of Intermodal Origin and Destination Points

Intermodal freight in this research refers to the freight requiring transshipment from one mode to another within the analysis area. Following the procedures for generating single mode OD matrices, an intermodal freight OD matrix can be obtained with origin and destination points being the entry/exit points and centroids in the analysis area. Due to the different operating features in highway and railway transportation, the intermodal freight movement may follow different assignment rules on both single mode networks. Therefore, this OD matrix needs to be further split into the corresponding highway and railway OD sub-matrices, with intermodal terminals being the break points.

Step 5: Finding Transshipment Point for each OD Pair

As part of the regional planning process, traffic assignment targets the minimum overall transportation cost in the network. When assigning intermodal facilities to shipments of each OD pair, the pattern of least overall transportation cost provides the solution, subject to demand, capacity, and flow conservation constraints. The formulation of the optimization programming follows:

$$
\begin{aligned}
\min \quad & \sum_i \sum_j P_{1,ij} x_{ij} + \sum_j \sum_k P_{2,jk} x_{jk} \\
s.t. \quad & \sum_j x_{ij} = \sum_k d_{ik} \\
& \sum_j x_{jk} = \sum_i d_{ik} \\
& \sum_i x_{ij} = \sum_k x_{jk} \\
& \sum_i x_{ij} \le C_j \\
& \forall i, j, k, \quad x_{ij}, x_{jk} \ge 0
\end{aligned}
$$

where:

i, k: The origin and destination of freight within the analysis area respectively, including railway or highway entry/exit points along the boundary, and county centroids;

j: Intermodal facility within the analysis area;

x_{ij}: Freight intermodal traffic volume shipped from i to j;

x_{jk}: Freight intermodal traffic volume shipped from j to k;
$P_{1,ij}$: Penalty from i to j;
$P_{2,jk}$: Penalty from j to k;
d_{ik}: Freight intermodal OD volume from i to k;
C_j: Capacity of j.

Using the transportation cost functions formulated in the previous section, the lowest cost route is found for each OD. Therefore, the penalties, $P_{1,ij}$ and $P_{2,jk}$, can be obtained by adding the transportation costs of all the links along the route from entry point or county centroid i to intermodal facility j, and from intermodal facility j to county centroid or exit point k in the highway and railway sub- networks, respectively. The penalty for each OD pair can be different due to different traffic volumes assigned on the links along the route. An iterative procedure is designed to reduce this discrepancy. Link capacities are calculated based on the physical characteristics of the links or obtained from existing data sources, which are stored in the multimodal network. The objective of this formulation is to find an intermodal freight traffic flow pattern with the least overall transportation cost. By solving this problem, the volumes of intermodal traffic going from origins through intermodal facilities to destinations for all OD pairs are obtained.

2.2.3 Matrices Integration

Step 6: Integration of single-mode and intermodal OD matrices

The original intermodal OD demand has been disaggregated into OD demand from the origin to intermodal facility or from intermodal facility to destination based on the results from the optimization programming step. Because both the single mode freight traffic and the corresponding intermodal freight traffic (e.g., all highway freight traffic and the highway part of intermodal freight traffic) are assigned to the same network simultaneously, they need to be integrated as unified highway and railway OD matrices. The final OD matrices are obtained using the structure shown in Figure 3. Among the parts identified in the structure, part IX represents the highway-railway-highway or railway-highway-railway intermodal freight traffic in the analysis area, which is not within the scope of this research.

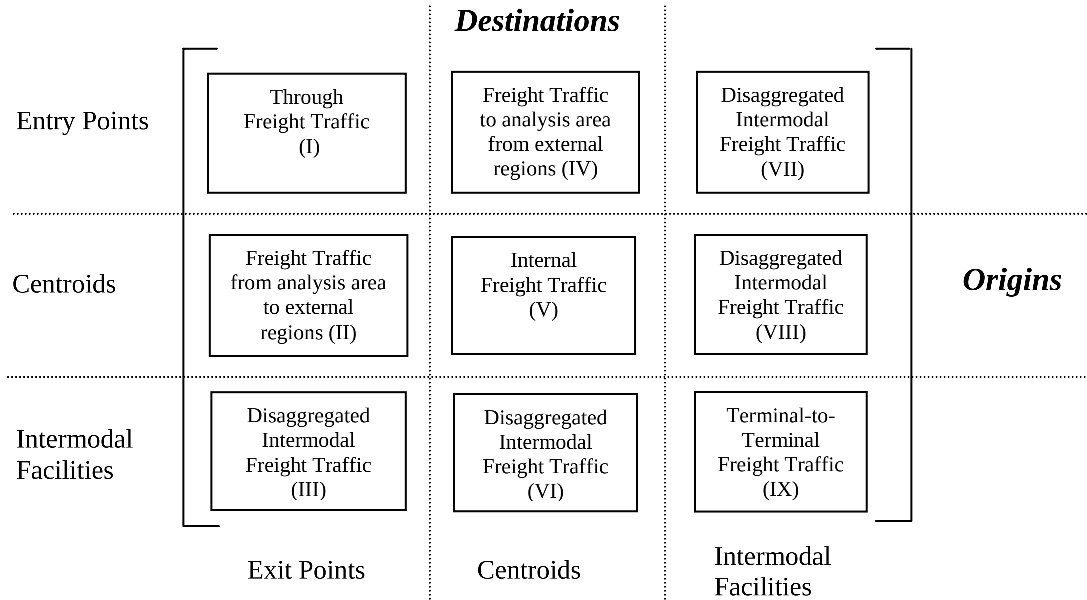


Figure 3. Structure of integrated origin-destination matrix.

2.2.4 Traffic Assignment

Step 7: Traffic assignment

The assignment techniques for each mode should be different due to their distinct operating characteristics. For example, optimizing vehicle operation to reduce operating costs is the goal of users for highway transportation, and therefore, user equilibrium seems appropriate for highway freight traffic assignment. For railway transportation, trains generally follow a timetable so that the average travel time varies within a small range, and the tariff for transport is nearly fixed. In this case, all-or-nothing can be used for assigning rail car traffic onto the network for simplicity *(Xu 2003-1)*. The procedure used in this research is highly adaptive to the different scenarios for different modes. Planning agencies can choose from existing traffic assignment methods and apply them based on specific regional conditions. The assignment techniques can also be easily expanded to the multiclass assignment, e.g., containerized freight vs. bulk cargo, when needed.

2.2.5 Iterations

Step 8: Iterative Procedure

After each assignment of traffic, the freight traffic volume on each link may change. Different volume on a link can result in different transportation cost on that link, and as a result, the overall penalty can be different. In this case, the discrepancy exists between the penalties used in the former optimization programming step and those acquired after the traffic assignment. To make results consistent, the following iterative procedure is applied: (1) calculate the transportation cost of each link after each assignment, (2) find the route of lowest cost for each OD pair (the total cost of the route is the penalty), (3) if the difference between the newly generated penalty and the corresponding previous one is within a given tolerance, then the procedure stops; otherwise, repeat the procedure using the new penalties until they converge as shown in Figure 4.

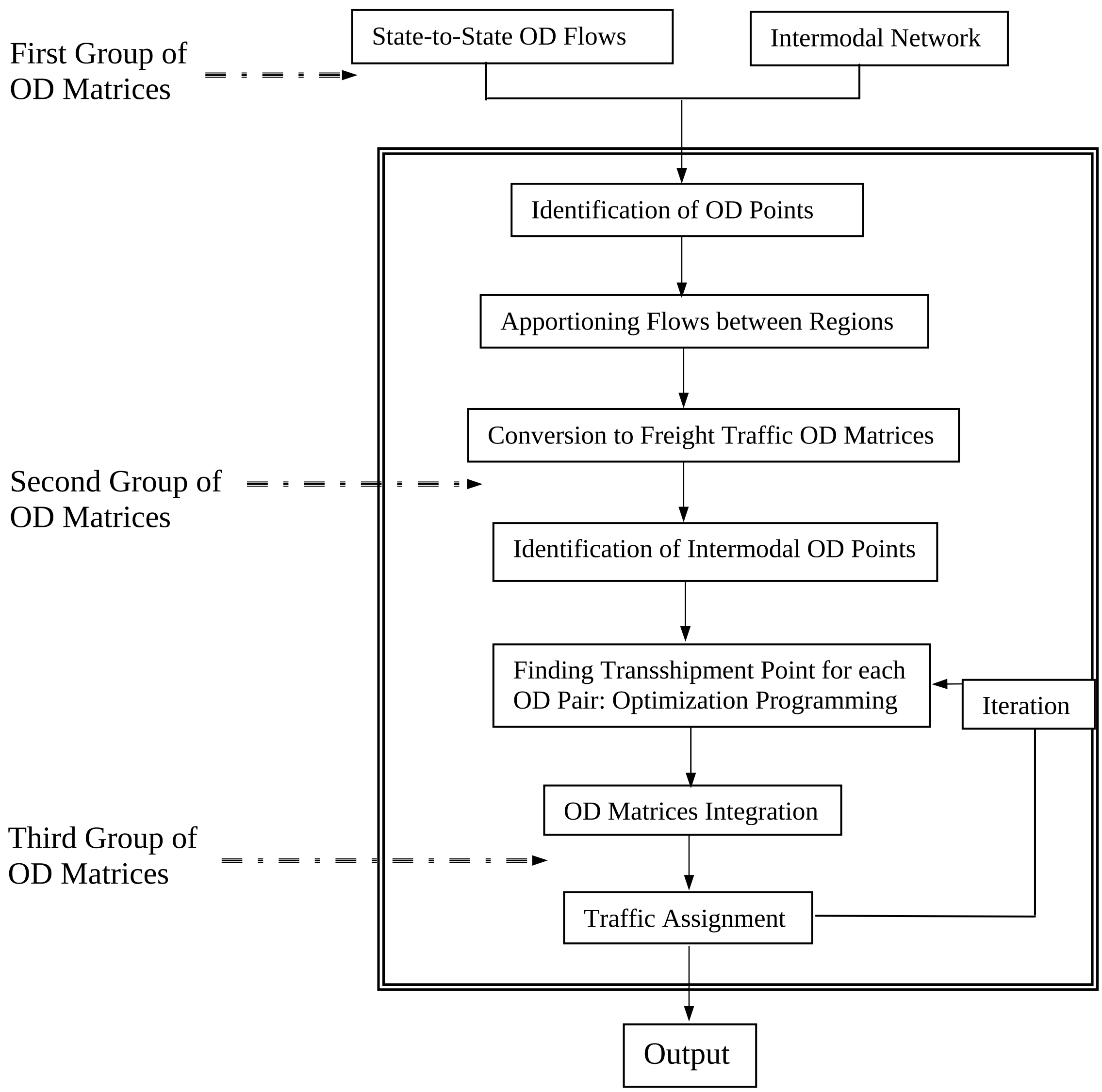


Figure 4. Representation of an optimized iterative assignment procedure.

3. CASE STUDY

To demonstrate the implementation of the proposed methodology, the optimized iterative assignment procedure is applied to Massachusetts. Massachusetts has a reasonably dense highway network, with the major Interstates being the Massachusetts Turnpike (I-90), I-91, I-95, and I-495. Massachusetts contributes about 40% of New England area's truck traffic. A significant imbalance exists between inbound and outbound freight movements in the region due to its location at one end of the national transportation infrastructure and the fact that it is a "consumer" state rather than a "production" state.

The total miles of railroad operated in Massachusetts is approximately 265 miles, mainly owned and/or operated by CSX Transportation, Guilford Rail System, Providence and Worcester Railroad (P&W), Bay Colony Railroad, and New England Central Railroad. Among the ten railroads currently in Massachusetts, CSX is the only Class 1 Railroad and Guilford and P&W are the two regional railroads. The remaining operators consist of six local railroads and one switching and terminal railroad. Intermodal terminals for rail-truck transfer of containers are located in Boston, Springfield, and Worcester. The intermodal terminal database was constructed following the structure identified in Table 1.

3.1 Network Construction

The intermodal network for Massachusetts was extracted from the CFS Intermodal Network developed by Oak Ridge National Laboratory. The network includes highway and railway network integrated and connected by terminal links and is shown in Figure 5.

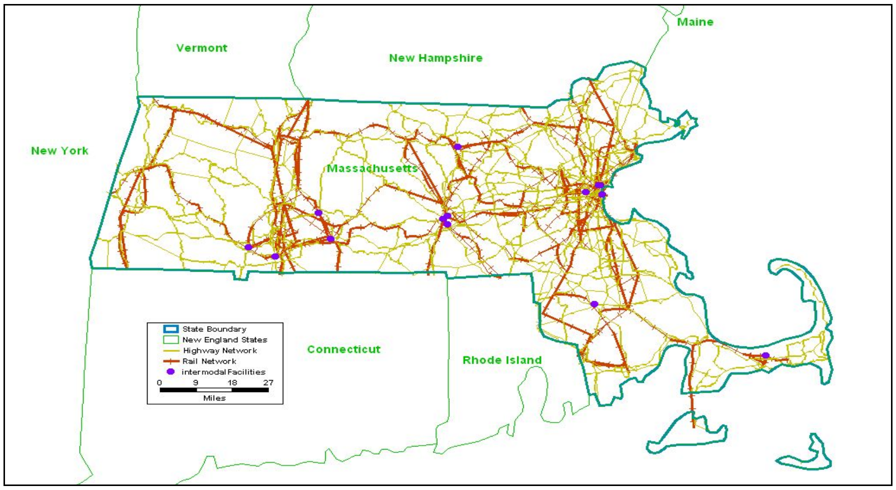


Figure 5. Intermodal network in Massachusetts.

3.2 Identification of Origin and Destination Points

Counties are defined as the smallest region to study freight traffic flow. The centroid of each county is set as the internal origin or destination of freight shipments from or to that county. As freight enters and leaves Massachusetts, the entries or exits in the intermodal network that lie on the borders of Massachusetts are defined as external origins and destinations as shown in Figure 6.

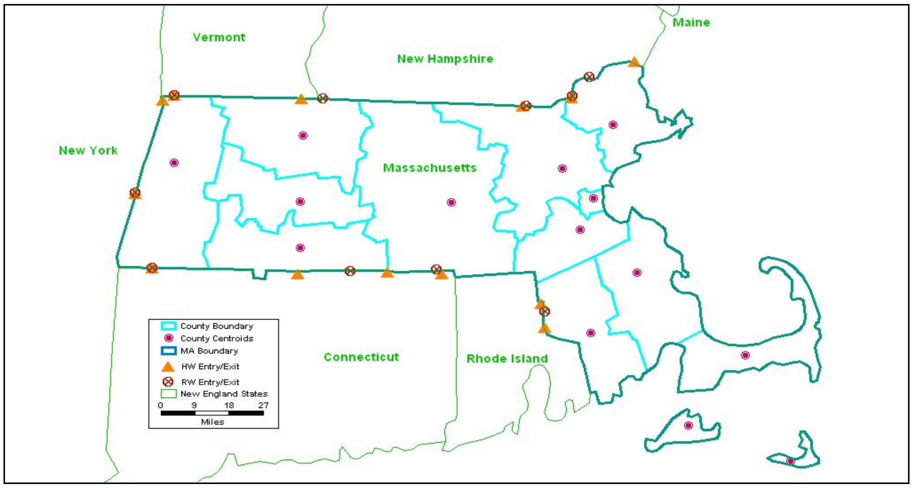


Figure 6. Entry/exit points in Massachusetts.

3.3 Construction of OD Matrices

The statewide freight flow data were extracted from the 1997 CFS and are shown in Table 2 as tons (in thousands) of commodity shipped by truck, rail, and truck-rail among the New England states, New York, and the rest of the United States.

Table 2. Multimodal Commodity Flow in New England, New York and the Rest of US.

Origins		Destinations							
		CT	ME	MA	NH	RI	VT	NY	Rest of US
CT	Truck	--[a]	165	2190	200	--	n.a.	--	--
	Rail	--	n.a.[b]	n.a.	n.a.	--	n.a.	--	--
	Truck-Rail	--	n.a.	n.a.	n.a.	--	n.a.	--	--
ME	Truck	178	--	1201	--	130	--	n.a.	40165
	Rail	57	--	74	--	n.a.	--	162	1973
	Truck-Rail	n.a.	--	n.a.	--	n.a.	--	n.a.	120
MA	Truck	3495	733	63562	4133	2225	747	2004	6214
	Rail	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	Truck-Rail	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	81
NH	Truck	863	--	6391	--	100	--	729	31002
	Rail	n.a.	--	n.a.	--	n.a.	--	n.a.	n.a.
	Truck-Rail	n.a.	--	n.a.	--	n.a.	--	n.a.	24
RI	Truck	--	97	3382	n.a.	--	40	--	--
	Rail	--	n.a.	n.a.	n.a.	--	n.a.	--	--
	Truck-Rail	--	n.a.	n.a.	n.a.	--	n.a.	--	--
VT	Truck	129	--	889	--	137	--	652	8060
	Rail	n.a.	--	n.a.	--	n.a.	--	n.a.	n.a.
	Truck-Rail	n.a.	--	n.a.	--	n.a.	--	n.a.	54
NY	Truck	--	581	4227	404	--	1380	--	--
	Rail	--	n.a.	156	n.a.	--	n.a.	--	--
	Truck-Rail	--	n.a.	n.a.	n.a.	--	n.a.	--	--
Rest of US	Truck	--	44896	12686	23739	--	10806	--	--
	Rail	--	2300	4391	1404	--	2381	--	--
	Truck-Rail	--	n.a.	518	21	--	60	--	--

Note: Figures in thousands of tons.
[a] Not required for this analysis. Hence the data are not extracted from the source.
[b] Not provided by the source.
Source: Commodity Flow Survey 1997.

These state-to-state OD matrices were disaggregated into the origin and destination points following the corresponding procedures described in the previous section. The internal flow was apportioned by county centroid through Equation (5) using the data obtained from the County Business Pattern. For external flow, the flow apportioned to a given entry/exit point is proportional to the distance between the point and the external centroid. The longer the distance, the lower the probability of using that point. Interstate highways or major railroads were given a higher priority than state and US highways or lower-level railroads. After conversion of freight volume in tons to vehicle numbers, the second group of OD matrices representing freight traffic using centroids and entry/exit points as origins and destinations was set up.

Intermodal facilities were identified for each OD pair to pass through in the optimization-programming step. The intermodal OD matrix was then disaggregated into two sub-matrices corresponding to highway and railway modes, respectively. Combining single mode matrices and the corresponding intermodal sub-matrices, the integrated multimodal OD matrices was obtained with the structure shown in Figure 2.

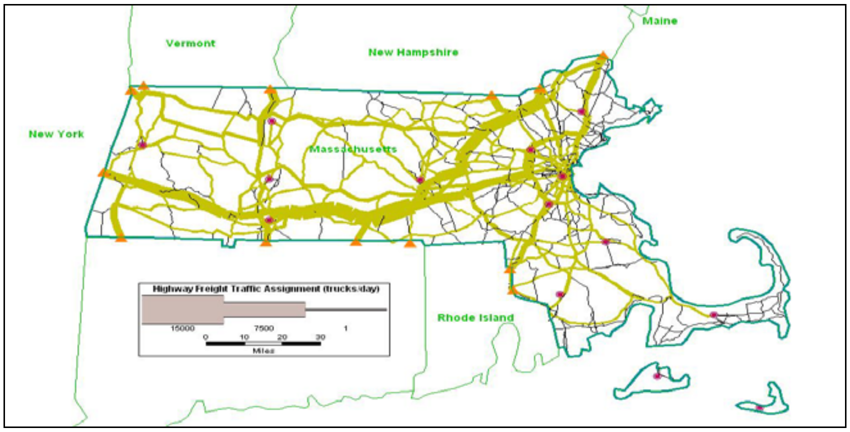
3.4 Cost Data Calculations

In this case study, the highway cost data were estimated from the average fuel consumption and average value of travel time over the studying area. The railway cost data were obtained from the publication of the shipping rates from different railway companies. Due to the difficulty of obtaining interline costs and for simplicity, a large number was given to suppress interlining in a regional freight shipment. Terminal costs were directly collected from terminals.

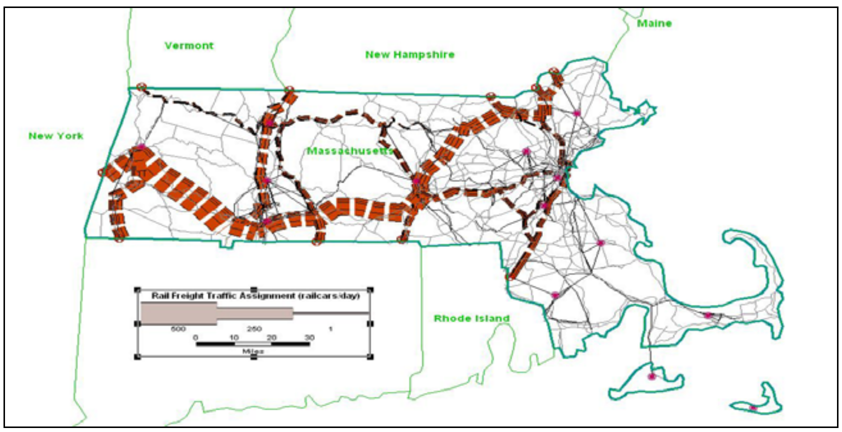
3.5 Traffic Assignment

The OD matrices were assigned to the multimodal network within Massachusetts using TransCAD. After the assignment, the penalty matrices between OD pairs were updated from the previous one, and the iteration step was activated. After three iterations, the penalty matrices converged with a threshold value of 0.005.

The final overall multimodal freight traffic flow patterns are shown in Figure 7. From this figure, we can see trucks are relatively evenly distributed among the highway system because of the user equilibrium traffic assignment and the efficient assignment of intermodal facilities to each OD pair. On the other hand, the majority of the rail cars are assigned to the high-classified railroads due to the all-or-nothing traffic assignment procedure. However, due to lack of available validation data, the assignment procedures have not been validated, which forms a part of the future research effort.



(a) Highway Freight Traffic Assignment



(b) Rail Freight Traffic Assignment

Figure 7. Regional freight traffic assignment results.

4. CONCLUSION

An analytical model that focuses on assigning regional intermodal freight across a highway and railway network has been developed. This iterative procedure integrates optimization programming with traffic assignment to assign intermodal freight traffic to achieve the overall network optimum, considering the interaction between intermodal and single-mode traffic. As part of the regional planning process, this analytical method can promote more efficient use of the existing intermodal transportation infrastructure to increase overall network performance. However, as this model is on a much higher aggregated level, additional research is necessary.

(1) The assignment procedures should be further differentiated for bulk goods and containerized freight, as these types of cargoes generally have distinct handling facilities, and their transportation cost and operating features are different. For example, some intermodal facilities can only serve certain types of goods, such as trailer-on-flatcar (TOFC) and container-on-flatcar (COFC) terminals. In addition, the conversion ratios to vehicle are not the same for these types of freight.

(2) The assignment technique applied to rail and intermodal terminals in this report is all-or-nothing, which could be improved. This technique is applicable only when the rail or intermodal volume is relatively low and rarely over the capacity of the facilities. However, in a general case, capacity is a critical issue for traffic assignment. Capacity of intermodal terminals and railway links will be calculated and new assignment techniques will be considered.

(3) This model needs to be calibrated and validated using data from other sources.

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APPENDIX A

Poster presented at
The 2004 Transportation Research Board Annual Meeting

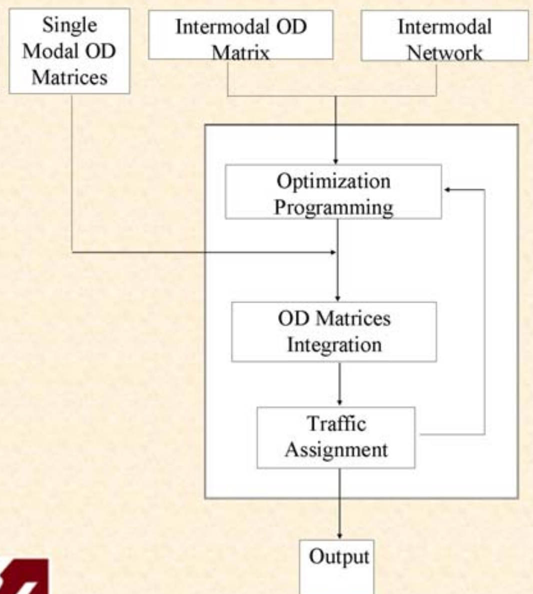
Abstract

An analytical model is developed to assign regional freight traffic across a multimodal highway and railway network using geographic information systems. As part of a regional planning process, the proposed model is an iterative procedure to assign multimodal freight traffic to the transportation network to achieve overall network optimum. The procedure integrates optimization programming with traffic assignment, considering the interactions between multimodal and single-modal traffic. The different modes involved in this paper consist of all highway, all railway, and railway-highway intermodal. This analytical model is developed modularly and can be incorporated into any regional planning process and compatible modeling environment. A case study is presented for regional freight traffic assignment across Massachusetts, using the model developed in this research.

Objectives of the Research

- Development of an analytical procedure to assign freight traffic across a highway and railway network through intermodal terminals, which can be used by both public and private planners.
- A key feature of the proposed approach is the optimization of intermodal freight traffic assignment to achieve an overall network optimum considering the interaction between multimodal and single-modal traffic.

Representation of an Optimized Iterative Assignment Procedure



Optimization Programming

$$\min \quad \sum_i \sum_j P_{1,ij} x_{ij} + \sum_j \sum_k P_{2,jk} x_{jk}$$

$$s.t. \quad \sum_j x_{ij} = \sum_k d_{ik}$$

$$\sum_j x_{jk} = \sum_i d_{ik}$$

$$\sum_i x_{ij} = \sum_k x_{jk}$$

$$\sum_i x_{ij} \le C_j$$

$$\forall i, j, k, \quad x_{ij}, x_{jk} \ge 0$$

where:

i, k: The origin and destination of freight within the analysis area respectively, including railway or highway entry/exit points along the boundary, and county centroids;

j: Intermodal facility within the analysis area;

x_{ij}: Freight intermodal traffic volume shipped from i to j;

x_{jk}: Freight intermodal traffic volume shipped from j to k;

$P_{1,ij}$: Penalty from i to j;

$P_{2,jk}$: Penalty from j to k;

d_{ik}: Freight intermodal OD volume from i to k;

C_j: Capacity of j.

UMASS

Prepared for TRB 2004 Annual Meeting

An Optimized Iterative Procedure for Regional Intermodal Freight Assignment

By Jinghua Xu and Kathleen L. Hancock
Civil and Environmental Engineering, University of Massachusetts, Amherst

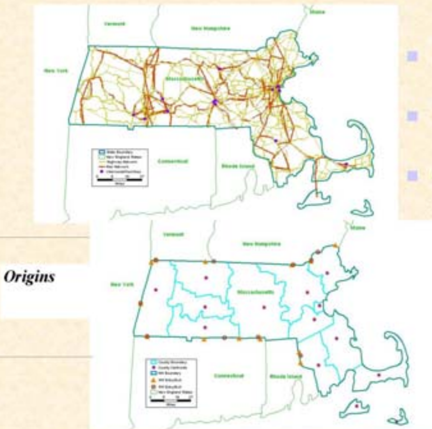
Structure of Integrated Origin-Destination Matrix

Destinations (columns) / *Origins* (rows)

	Exit Points	Centroids	Intermodal Facilities
Entry Points	Through Freight Traffic (I)	Freight Traffic to analysis area from external regions (IV)	Disaggregated Intermodal Freight Traffic (VII)
Centroids	Freight Traffic from analysis area to external regions (II)	Internal Freight Traffic (V)	Disaggregated Intermodal Freight Traffic (VIII)
Intermodal Facilities	Disaggregated Intermodal Freight Traffic (III)	Disaggregated Intermodal Freight Traffic (VI)	Terminal-to-Terminal Freight Traffic (IX)

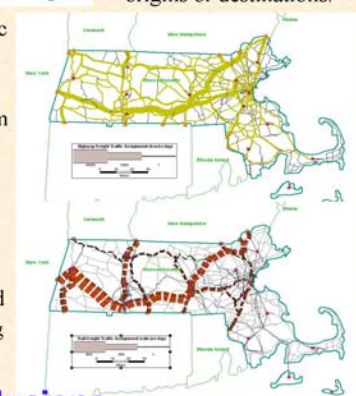
Iterative Procedure

- Step 1: Assign intermodal facilities to shipments of each OD pair using optimization programming, and integrate the facilities into the OD matrix as origins and destinations.
- Step 2: Assign the integrated OD matrix onto the railway and highway networks.
- Step 3: Calculate the transportation cost of each link after each assignment.
- Step 4: Find the route of lowest cost for each OD pair (the total cost of the route is the penalty).
- Step 5: If the difference between the newly generated penalty and the corresponding previous one is within a given tolerance, then the procedure stops; otherwise, repeat the whole procedure using the new penalties until they converge.



Case Study

- Study Area
  - Massachusetts
- Modes
  - Highway, railway
- Counties are the smallest region to study freight flow.
  - The centroids of counties are set as internal origins or destinations.
  - The entries or exits that lie on the borders of MA are defined as external origins or destinations.
- Results: Multimodal freight traffic flow patterns
  - Trucks are relatively evenly distributed on the highway system because of the use of UE method and the optimized assignment of intermodal facilities to shipments of each OD pair.
  - The majority of the rail cars are assigned to the high-classified railroads due to the all-or-nothing traffic assignment procedure.



Conclusions

- As part of the regional planning process, this analytical method can promote more efficient use of the existing intermodal transportation infrastructure to increase the overall network performance.
- More detailed research needs to be done in the future, e.g., disaggregation of freight category for the assignment, calibration of the model, etc.