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Freight Demand Forecasting Considering Economic Growth Factors

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ABSTRACT

This work proposes a methodology to project future freight demand for all commodity types that begin and end in each geographical region and the amount of freight that moves between all origin and destination pairs. Following the traditional four-step demand forecasting framework, the procedure corresponds to trip generation and trip distribution analysis for interregional freight demand. Using future economic growth factors from macroeconomic and input-output models, the amounts of freight production and attraction in each analysis zone are forecasted and taken as given. Subsequently, an iterative matrix balancing method is applied to determine the estimated freight shipment demand for all origin and destination zone pairs. The proposed algorithm is applied to generate predicted future freight demand within the United States from 2010-2050 in five-year increments based on the national freight demand data from 2007. Four different scenarios are proposed that consider variations in both global economic growth and environmental regulation. This study will assist transportation planners and decision makers in public and private sectors to assess how future freight delivery demand on the national scale considering various future global economic growth and environmental policy scenarios will affect various issues such as air quality and human health problems.

1. Introduction

Demand for freight transport has been continuously increasing since global industrialization began, and growth rates have become more rapid in recent decades. According to Cambridge Systematics, Inc. et al. (2008), the amount of freight movement within the U.S. has grown dramatically in the past three decades. For example, the total U.S. freight shipment in ton-miles increased more than 70% between 1970 and 2000 (Bureau of Transportation Statistics, 2012). Globalization and the corresponding changes in transportation and logistics systems affected the growth in freight shipment (Hesse and Rodrigue, 2006). Concurrently, the sharp increase in freight activities has generated great amount of emissions from various freight shipment modes (ICF Consulting, 2005), which has degraded air quality and affected human health and welfare significantly. Although there have been various efforts to improve energy efficiency in order to reduce total energy consumption in freight transportation and the corresponding emissions, emissions from freight shipment modes are still expected to increase further (Schipper et al., 1997).

As such, freight transportation modes have been producing a large share of various air pollutants and greenhouse gases, and this problem has motivated our study to develop a comprehensive freight demand forecasting model. The primary purpose of this work is to forecast future freight demand for all commodity types that begin and end in each freight demand zone. Also, the amount of freight that moves between all pairs of zones under various combinations of potential global economic growth and environmental policy scenarios will be estimated. These procedures correspond to trip generation and trip distribution steps in the traditional four-step transportation demand forecasting framework

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(Cambridge Systematics, Inc. et al., 2008) as denoted by the grey boxes in Figure 1.

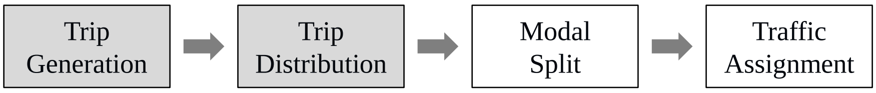

Figure 1. Trip generation and trip distribution in the four-step transportation demand forecasting model

Previous studies related to trip generation analysis typically have estimated freight production and attraction in a region using simple linear regression in which total employment by different industry types or population size are often used as dependent variables (Fischer and Han, 2001; Cambridge Systematics, Inc. et al. 2008). However, since future input-output (I-O) commodity value growth at all freight demand zones for all commodity types under various global economic development and environmental policy scenarios are exogenously given from the Phoenix model (Fisher-Vanden et al., 2012) and a pseudo-multiregional I-O model (Cascetta, 2009), the amount of freight movements that begin and end in each zone can be directly forecasted by scaling the base-year freight production and attraction. Therefore, the estimated freight production and attraction for each zone can be distributed on all shipment origin-destination (O-D) pairs using an RAS algorithm, a two-dimensional matrix balancing approach.

The estimated freight shipment activity at the national and regional levels will help decision makers and analysts in the freight industries, as well as government agencies, assess atmospheric impacts of freight shipment activities in various future economic growth and climate policy scenarios. Eventually, development and dissemination of such results will be useful to enhance human health and social welfare.

2. Literature review

There have been a number of previous studies concerning trip generation and trip distribution steps of the freight demand modeling. In the case of trip generation modeling for freight movement, Fischer and Han (2001) identified a set of truck trip generation data available for transportation engineers and travel demand modelers and reviewed the current state of data applications in various research fields. This report classified trip purposes and trip generating activities associated with appropriate categories of land use and showed how these factors affect the truck trip generation data and truck trip rates. Transportation Engineering and Planning, Inc. et al. (2003) studied truck trip generation in Fontana, California. This research investigated a total of nine land use categories that generate heavy truck traffic volume and suggested a set of equations which can be used for predicting truck trip generation rates in response to the land use categories. However, results might not be appropriate for national level studies since the analysis utilizes locally collected data. Also, this study is confined to the freight trip production side and does not consider freight trip attraction. Tolliver et al. (2006) developed trip generation equations for grain elevators in North Dakota using various databases including land use and highway traffic data. In this study, a trip attraction equation was applied to analyze how elevator storage capacity and side track capacity affect elevator throughout. As such, trip generation analyses in freight demand modeling side are usually very similar to those in passenger travel demand modeling side; the former produces annual or daily freight trip generation rate by commodity type, which is a function of employment by industry type or total population in a geographic region.

Regarding trip distribution analysis in freight demand modeling, Rawling and DuBoe (1991) used employment distribution to estimate the truck trip distribution in the Chicago area. The gravity model, commonly used in passenger travel demand analysis, has been adopted and widely used to determine the distribution of freight shipment demand in many studies (Cambridge Systematics, Inc. et al., 2008). Mao and Demetsky (2002) utilized a commodity-based gravity model for the freight flow distribution of truck mode. The authors defined four freight flow scenarios within Virginia as well as between Virginia and other regions. In addition, friction factors which represent difficulties associated with moving freight among zones were considered. The Fratar method was also adopted from conventional passenger travel planning for the freight demand distribution process. For example, Cambridge Systematics, Inc. et al. (1996) introduced the Fratar method to estimate future freight flow at the statewide level.

In this study, freight trip generation and trip distribution are investigated. In general, previous studies concerning trip generation have estimated freight production and attraction using simple linear regression models involving total employment by industry type or population. However, in this study, I-O commodity value growth forecasts for all freight analysis zones and all commodity types are given exogenously; i.e., a general equilibrium Phoenix model (Fisher-Vanden et al., 2012) provides initial projections of national economic factors, which serve as inputs to a pseudo-multiregional I-O model (Cascetta, 2009). Then, the amount of freight movements that begin and end in each zone for ten typical commodity types can be directly estimated by scaling the base-year freight production and attraction data. For freight trip distribution analysis, Cambridge Systematics, Inc. et al. (2008) reported that the gravity model has been commonly used in statewide trip distribution research. However, it may not be suitable for our nationwide freight shipment analysis for the following reasons. First, for national scale freight movements, shipping cost per unit weight can be a more important friction factor than vehicle travel time or distance. For example, the bulk of heavy and time-insensitive goods can be transported over a further distance using a transportation mode that provides the lowest shipment cost per unit weight. Second, socioeconomic adjustment factors in the gravity model are hard to predict for future years under multiple global economic growth and environmental policy scenarios. Thus, a two-dimensional iterative matrix-balancing method is used to determine the estimated future freight production and attraction among all pairs of freight shipment O-D zones. This approach utilizes a base-year freight demand distribution matrix which accounts for existing factors associated with freight movements such as unit shipment cost, and shipment distance or time among all shipment O-D pairs for various commodity types. In addition, this approach requires neither socioeconomic adjustment factors nor a travel time matrix between all shipment O-D pairs.

3. Freight demand forecasting model

This section presents the procedure employed for forecasting freight shipment and its distribution throughout all shipment O-D pairs. The RAS algorithm is adopted to iteratively allocate future freight production and attraction on all freight demand O-D zone pairs proportionally to the base-year freight demand distribution. Since its introduction in Deming and Stephan (1940) and further development by Csiszár (1975) and Bishop et al. (1975), the RAS algorithm has been widely used in various research fields, including economics and statistics.

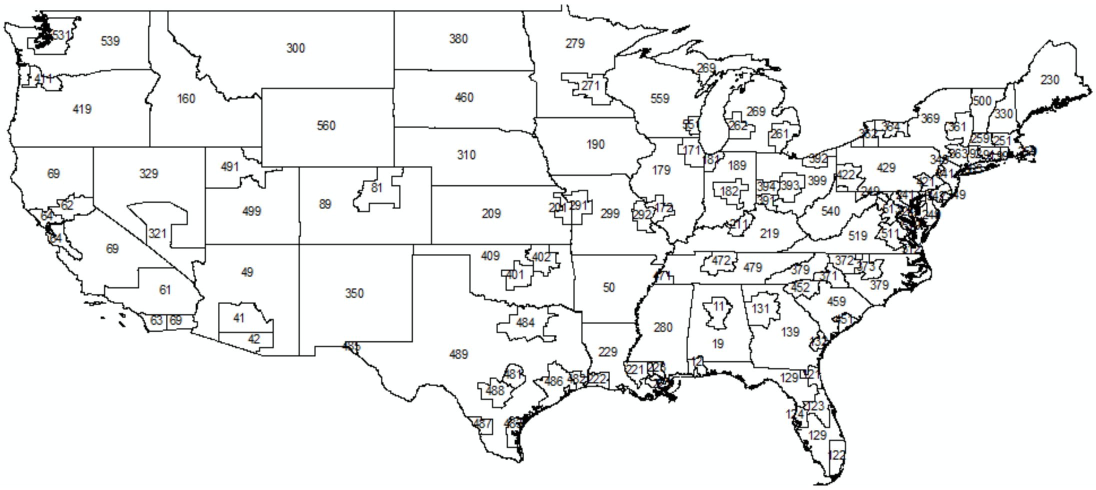

Figure 2. Domestic Freight Analysis Zones in the United States

In order to develop the freight demand model for forecasting freight shipments between geographical regions in the United States, Freight Analysis Zones (FAZs) in the Freight Analysis Framework data version 3 (FAF3) is adopted as shown in Figure 2 (Federal Highway Administration, 2011). Therefore, excluding Hawaii and Alaska, 123 domestic geographical regions are selected for both origin and destination zones of freight shipment in this study.

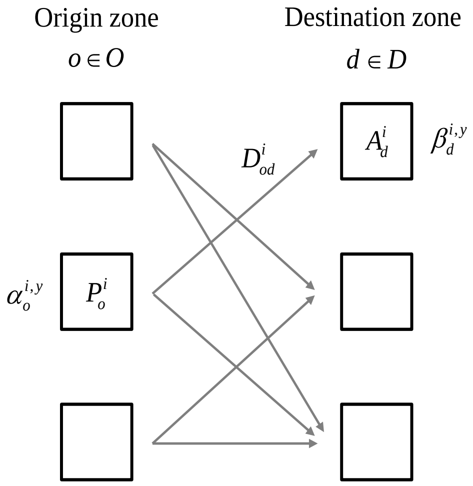

Figure 3. Base-year freight demand distribution data structure

To apply the RAS algorithm, several assumptions are made as follows: (i) forecast of economic growth factors are exogenously given for all commodity types and FAZs, (ii) current FAZ structures do not change (i.e., neither new zones will be created nor existing zones will be eliminated), and (iii) distribution of future freight demand is proportional to that of the base-year freight demand between all FAZ O-D zone pairs.

Let Q denote a set of commodity types, which is assumed to be composed of N different types, i.e., $Q=\{1,2,...,N\}$. Figure 3 describes the structure of the base-year freight demand distribution data by commodity type $i \in Q$. All squares on the left show origin zones denoted by set O, and those on the right represent destination zones denoted by set D. Since each FAZ can be both origin and destination of a freight shipment, the origin zone set O and the destination zone set D are generally composed of the same elements indexed from 1 to Z, i.e., $O=D=\{1,2,...,Z\}$. The set of arrows connecting all FAZ O-D zone pairs describe freight movements. Also, we define the variables such that P_o^i represents the base-year total production of commodity $i \in Q$ in an origin zone $o \in O$, A_d^i describes the base-year total attraction of commodity $i \in Q$ in a destination zone $d \in D$, D_{od}^i represents freight volume of commodity $i \in Q$ moving from an origin zone $o \in O$ to a destination zone $d \in D$.. We use $\alpha_o^{i,y}$ to denote growth rate of commodity $i \in Q$ production in an origin zone $o \in O$ for future year y. Similarly, $\beta_d^{i,y}$ is used to represent growth rate of commodity $i \in Q$ attraction in a destination zone $d \in D$ for future year y. Then, the detailed procedures can be described as follows:

Step 0: Generate a base-year freight demand O-D matrix for a commodity type i, $\forall i \in Q$, as shown in Figure 4. Each row describes each origin and each column represents each destination spanning from 1 to Z. The freight movement for each O-D pair is described as D_{od}^i in the figure. All elements in the diagonal represent the freight demand produced and consumed within the same zones (i.e., the origin and the destination are the same). The last two columns describe the given production (G/P) and future production (F/P) for each origin zone, and current information related to only the given production is available from the base-year data such that the sum of D_{od}^i in a row direction is P_o^i. Similarly, the last two rows represent the given attraction (G/A) and future attraction (F/A) for each destination zone, and the cells with given attraction can be filled with the base-year data such that sum of D_{od}^i in a column direction becomes A_d^i.

D O	1	2	$\cdots$	d	$\cdots$	Z	G/P	F/P
1								
2								
$\vdots$								
o				D_{od}^i			P_o^i	
$\vdots$								
Z								
G/A				A_d^i				
F/A								

Figure 4. Base-year freight demand distribution matrix

Step 1: Estimate future production, V_o^i, and future attraction, W_d^i, represented by the grey column and row in Figure 5 for all FAZs such that each P_o^i and A_d^i is multiplied by $\alpha_o^{i,y}$ and $\beta_d^{i,y}$ respectively, i.e., $V_o^i=\alpha_o^{i,y}\cdot P_o^i$, $W_d^i=\beta_d^{i,y}\cdot A_d^i$, $\forall o \in O,\ d \in D,\ i \in Q$, where y is a target future year.

Step 2: Since the estimates of future input and output commodity value growth are modeled separately, the total future production summed across all origin zones (i.e., $\sum_{\forall o \in O} V_o^i$) could be different from the total future attraction summed across all destination zones (i.e., $\sum_{\forall d \in D} W_d^i$), although theoretically the sum of production and attraction should be the same. Therefore, assuming freight commodity production is derived from attraction, we multiply the future production of all origin zones by the same factor such that the total sum of the modified future production is balanced with the total sum of future attraction: Update $V_o^i \leftarrow V_o^i \cdot \left(\sum_{\forall d \in D} W_d^i \big/ \sum_{\forall o \in O} V_o^i \right)$, $\forall o \in O, i \in Q.$

D O	1	2	$\cdots$	d	$\cdots$	Z	G/P	F/P
1								
2								
⋮								
o				D_{od}^i			P_o^i	V_o^i
⋮								
Z								
G/A				A_d^i				
F/A				W_d^i				

Figure 5. Freight demand distribution matrix with future production and attraction

Step 3: The RAS algorithm is applied. In this procedure, we first define a growth factor R_o^i, $\forall o \in O,$ to adjust each entry D_{od}^i in a row direction to match with the future production V_o^i, $\forall o \in O$ for all commodities $i \in Q$. Also, we define a growth factor C_d^i, $\forall d \in D$, to adjust each entry D_{od}^i in a column direction to match with the future attraction W_d^i, $\forall d \in D$ for all commodities $i \in Q$. Then, we modify the matrix in a row first and then by column, and we do so iteratively until the sum of each row and each column converge to both future production and future attraction respectively. The distribution of future freight demand obtained from the suggested RAS algorithm will be proportional to that of the base-year freight demand for all commodity types $i \in Q$. The detailed algorithm is described as follows:

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Define tolerance $\varepsilon \ll 1$, and let $L$ = large positive integer and $n = 1$.
Also define $R_o^i = V_o^i \big/ \sum_{d \in D} D_{od}^i$, $\forall o \in O$ and $C_d^i = W_d^i \big/ \sum_{o \in O} D_{od}^i$, $\forall d \in D.$
While {( $n \le L$ ) and ( $|R_o^i - 1| > \varepsilon$ for some $o \in O$ or $|C_d^i - 1| > \varepsilon$ for some $d \in D$ )}
{
    Set $D_{od}^i \leftarrow R_o^i D_{od}^i$, $\forall o \in O, d \in D$,
    Update $C_d^i \leftarrow W_d^i \big/ \sum_{o \in O} D_{od}^i$, $\forall d \in D$,
    Set $D_{od}^i \leftarrow C_d^i D_{od}^i$, $\forall o \in O, d \in D$,
    Update $R_o^i \leftarrow V_o^i \big/ \sum_{d \in D} D_{od}^i$, $\forall o \in O$,
    Update $n \leftarrow n + 1,$
}
End
```

In this way, the future freight demand generation for all commodity types and for all FAZs can be forecasted, and the results can be distributed across all shipment O-D zone pairs proportionally to the base-year freight demand distribution.

4. Case study

4.1 Data source

The proposed algorithm is applied to forecasting future freight demand distribution within the U.S. from 2010-2050 in five-year increments. We investigate four scenarios proposed by the general equilibrium Phoenix model (Fisher-Vanden et al., 2012) to consider variations in both global economic growth and environmental regulation. To capture uncertainty in the global economy, “low GDP growth” and “high GDP growth” scenarios are considered. For each hypothetical economic development scenario, two different environmental regulations are addressed including “business as usual” and “climate policy” scenarios. The former assumes global emission projections will follow historical trends, while the latter assumes cumulative constraints in energy-related CO_2 emissions, such as the introduction of carbon taxes (Kim et al., 2010) will be implemented.

The base-year freight demand distribution matrix and the future I-O commodity value growth estimates for all scenarios are inputs in this analysis. The base-year freight demand distribution was collected from the FAF3 database (Federal Highway Administration, 2011). The FAF3 database contains information regarding the freight shipment activities including the amount of freight flow both in tonnage and value in 2007. From FAF3 records, data related to two major freight transport modes in the U.S., truck and rail, were extracted. Note that intermodal transport has been excluded due to the lack of data available. We focus on freight shipments within the continental U.S. and data related to Hawaii and Alaska were excluded. In total, 128,562 data records were obtained for constructing the base-year freight demand matrix, which includes origin, destination, commodity type, and freight demand in tons. The commodity production and attraction growth estimates for all FAZs and future years under different scenarios are obtained exogenously from the pseudo-multiregional I-O models (Cascetta, 2009). Data includes commodity production and attraction in dollars for all FAZs and for 10 typical commodity types from 2005-2050 in five-year increments for four macroeconomic scenarios; those monetary values are applied to obtain the growth rates of future freight demand in Step 1 of the proposed algorithm. The base-year is set to 2007, and the data for this year was obtained using liner interpolation between 2005 and 2010 data.

4.2 Forecasting results

The proposed algorithm is coded and tested on a personal computer with a 3.4 GHz CPU and 8 GB memory. The algorithm converged in a short time (i.e., within a few minutes) and the future freight demand from 2010-2050 in five-year increments was generated for each scenario. The results are presented in three hundred and sixty 120-by-120 matrices, each of which estimates the total freight demand among all FAZ O-D zone pairs for a specific future year, commodity type, and scenario. Table 1 summarizes the total freight demand forecast for the four given scenarios, summed across all commodity types and all FAZ O-D zone pairs.

Row (a) in Table 1 shows the four global economic growth and environmental policy scenarios. Column (b) represents the future years from 2010 as well as the base-year (2007). Columns (c)-(f) describe the total freight demand in thousand tons, and columns (g)-(j) calculate percentage changes of the total freight demand from the base-year data. The freight demand in 2007 is the benchmark used in all scenarios.

Table 1. Computational results for forecasting freight demand

(a) Scenario	Scenario 1: High GDP growth with business as usual		Scenario 2: High GDP growth with climate policy		Scenario 3: Low GDP growth with business as usual		Scenario 4: Low GDP growth with climate policy	
(b) Year	(c) Total freight demand forecasted (thousand ton)	(g) % change	(d) Total freight demand forecasted (thousand ton)	(h) % change	(e) Total freight demand forecasted (thousand ton)	(i) % change	(f) Total freight demand forecasted (thousand ton)	(j) % change
2007	15,059,745	0.00	15,059,745	0.00	15,059,745	0.00	15,059,745	0.00
2010	15,703,789	4.28	15,648,288	3.91	15,528,787	3.11	15,494,244	2.89
2015	17,501,995	16.22	17,438,001	15.79	16,929,857	12.42	16,890,825	12.16
2020	19,431,308	29.03	18,780,540	24.71	18,355,956	21.89	17,742,894	17.82
2025	21,438,103	42.35	20,650,764	37.13	19,755,145	31.18	19,023,791	26.32
2030	23,693,953	57.33	22,780,286	51.27	21,271,576	41.25	20,435,507	35.70
2035	26,034,285	72.87	24,945,108	65.64	22,725,696	50.90	21,747,683	44.41
2040	28,697,929	90.56	27,356,813	81.66	24,523,312	62.84	23,339,737	54.98
2045	31,574,234	109.66	29,893,810	98.50	26,377,074	75.15	24,903,553	65.37
2050	34,673,664	130.24	32,621,827	116.62	28,351,364	88.26	26,573,564	76.45

Table 1 shows the estimates of the total future freight demand increase for all global economic growth and environmental regulation scenarios. Around year 2030 in scenarios 1 and 2, year 2035 in scenario 3, and year 2040 in scenario 4, future freight demand increases more than 50% compared to the base-year freight demand. Note that the total freight demand for truck and rail in the U.S., in fact, decreased by 9% from 2007-2011 (Federal Highway Administration 2011) due to the recession that began in late 2007. This discrepancy was caused by the fact that the global economic forecast models which provide initial projections of various economic factors are not able to capture unexpected short-term economic fluctuations.

5. Conclusions

Due to the globalization and worldwide industrialization, demand for freight transport has increased in recent decades. The objective of this study is to estimate future freight demand that will be produced in and attracted to each freight zone and distribute the estimated freight shipment demand among all O-D zone pairs. Given future I-O economic value growth factors, the total production and attraction for all commodity types and all FAZs were generated. Then, the RAS algorithm was applied to distribute the future freight demand on all FAZ O-D zone pairs assuming future freight demand distribution is proportional to the base-year freight demand distribution.

The proposed methodology was applied to generate future freight demand distribution from 2010-2050 in five-year increments considering four economic growth and environmental regulation scenarios. The FAF3 database was selected to construct the base-year freight demand matrices and the commodity production and attraction growth estimates were generated from the global economic forecast models and I-O models. As a result, the algorithm converged and the future freight demand distribution was obtained.

In future studies, the gravity model could be applied, as in Lim (2011), once the values for the parameters in the model become available; the results can be compared with the current study to improve forecast accuracy. Second, extension and application of the proposed methodology to other transportation studies is possible. Final results from our freight demand forecasting model includes practical information such as the predicted freight flow distribution and possible congestion locations in freight transport networks in a specific future year. Such information could be used to address many related problems such as transportation network capacity expansion, maintenance scheduling, as well as traffic safety. Lastly, the environmental impacts from the estimated freight demand could be investigated. For example, Kim et al. (2016) examined various truck delivery policies and their impacts on both transport cost and emission cost, in which initial freight demand data could be provided with the method in this paper. The emissions from freight transport activities affect climate change on the global scale and deteriorate air quality and human health in regional and urban areas. Thus, the proposed freight delivery demand forecasting model will be useful to investigate its impacts on the environment.

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