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FREIGHT DEMAND ESTIMATION FROM SECONDARY SOURCES. CASE STUDY: MANHATTAN

ESTIMACIÓN DE DEMANDA DE TRANSPORTE DE CARGA A PARTIR DE FUENTES SECUNDARIAS. CASO DE ESTUDIO: MANHATTAN

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ABSTRACT: The proposed freight Origin-Destination Synthesis formulation uses a gravity model to estimate trip flows in Manhattan based on traffic counts. The resulting total truck trips are assigned to the network to obtain a set of estimated truck traffic volumes, which are compared to the observed truck traffic. At this stage, the parameters of the model are then recomputed to improve the agreement between estimated and observed truck traffic. The process ends once no further improvement is possible.

KEYWORDS: Freight Transportation, Travel Demand Modeling, Origin-Destination Synthesis.

RESUMEN: La formulación propuesta para sintetizar matrices Origen-Destino de carga se basa en un modelo gravitatorio que permite estimar los flujos de viajes de carga en Manhattan basado en conteos vehiculares. Estos flujos de viajes se asignan a la red para obtener una serie de volúmenes de tráfico de camiones en determinados arcos viales. Estos volúmenes estimados se comparan con el número de camiones observados, para luego calcular iterativamente los parámetros del modelo que permitan disminuir las diferencias entre volúmenes estimados y volúmenes calculados. El proceso termina cuando no se puede lograr mejores resultados por medio de ajustes en los parámetros del modelo.

PALABRAS CLAVE: Transporte de Carga, Modelación de la Demanda de Viajes, Síntesis de Matrices Origen-Destino.

1. INTRODUCTION

The estimation of future freight transportation requires the use of network and freight demand models. When characterizing freight demand, basic data are sought to appropriately model the decision processes associated with freight generation, distribution and consumption. In this context, freight origin-destination (OD) matrices are one of the most important data elements a planner could have, which is why a significant amount of time, effort and money is spent on their estimation. The estimation of OD matrices can be done by: (a) direct sampling methods; and, (b) using secondary data sources such as traffic counts. The latter techniques are referred to here as origin-destination synthesis (ODS). Direct sample estimation includes all methodologies in which the OD data are obtained by interviewing the participants in the transportation activity. These approaches have some well-known limitations: roadside interviews tend to double count trips; on-board interviews may lead to bias in the parameters of random utility models; mail interviews are often biased because the rate of response varies across the population; and home interviews, though able to provide statistically sound estimates of OD, require a great deal of planning, time, effort and money [2].

ODS overcomes these limitations by bypassing the need for surveys. This type of demand-modeling may therefore play a significant role in reducing the need for the direct collection of freight data, which entails the use of significant economic resources. In ODS, the traffic counts—which are a function of the OD flows—are used to estimate the OD matrices. Since the number of unknowns (OD pairs) exceeds the number of independent traffic counts, the estimation problem is under-specified. Therefore, this requires the use of analytical techniques to estimate the most likely OD matrix that fits the observed traffic counts. The research on ODS has concluded that, though not a replacement for actual data, it could produce fairly realistic estimates of freight OD matrices. This, in turn, could play a significant role boosting the dissemination of freight demand models as data collection cost is the main constraint for the implementation of such models.

2. ORIGIN-DESTINATION SYNTHESIS

Two approaches have been used to conduct ODS: Structured and Unstructured approaches. The former approach imposes a model structure on the estimation, reducing it to a parameter estimation problem. The latter approach uses general principles, e.g., maximum likelihood, to reduce the feasible space so that the problem has a unique solution [2].

In general terms, ODS models can be classified on the basis of the time-dimension of the estimation process and the characteristics of the underlying traffic assignment model. The former could be subdivided into: a) *static estimation* –in which the OD matrix is time-invariant; and b) *dynamic estimation*–in which the resulting OD matrices are time-varying. The techniques can be further classified, depending on the traffic assignment process in: 1) *not requiring route choice*, i.e., problems in which the route choice process can be disregarded (e.g., when estimating turning movements at intersections); 2) *proportional route choice methods*, i.e., problems in which the probability of using a given route does not depend upon the OD flows – which implies disconnection between the route choice and the OD estimation problems; and 3) *non-proportional route choice methods*, i.e., problems in which route choice and OD estimation are interdependent, thus requiring a joint estimation process involving equilibrium models.

Although there is a vast amount of literature on the subject of passenger ODS, the same cannot be said about freight ODS. The literature review revealed that freight ODS has received relatively little attention from researchers and transportation professionals. After a comprehensive search, only seven formulations were found [3-9]. Tamin and Willumsen [8] developed a formulation to obtain the parameters of the Gravity Opportunity model that best reproduce a given set of traffic counts. Their approach, an example of a structured formulation, requires the observed link volumes and the estimates of freight generation for each zone as model inputs. The formulation developed by Gedeon et al. [4] is aimed at obtaining optimal multi-commodity flows in multimodal networks. Since this formulation does not model demand behavior, it will not be further discussed. List and Turnquist [7] developed a formulation to estimate the OD matrix using optimization principles. They formulated the problem as a large-scale linear programming problem in which the decision variables are the OD flows and the objective function is a weighted combination of the deviations of the estimated volumes with respect to the target values. Their formulation was extended to estimate U.S.-Mexico travel patterns using the dollar values of each commodity group and port of entry as the control variables [10]. Tavasszy, et al. [9] used partial techniques to estimate unobserved elements of the OD matrix, for estimation of interregional freight transport flow. Al-Battaineh and Kaysi [3] uses an input-output methodology to estimate productions and attractions and a Genetic Algorithm to compute the OD matrix. This formulation uses the value of the goods transported.

3. ORIGIN-DESTINATION SYNTHESIS IN MANHATTAN

New York City (NYC) is one of the most economically vibrant cities in the world. The city is comprised of five boroughs: The Bronx, Brooklyn, Staten Island, Queens and Manhattan. Manhattan, with over 1.5 million inhabitants, covers around 23 square miles. There are over 40,000 freight-related business establishments with more than 650,000 employees and over 60,000 establishments with 1.4 million employees that are not related to freight [11]. Holguín-Veras and Ban [11] estimate that about 180,000 truck trips are attracted daily by Manhattan's freight-related business establishments, which shows the importance of the target area for this study and its potential for implementing an ODS model. For the study, each of the 41 geographic ZIP codes in Manhattan is used as an internal Transportation Analysis Zone (TAZ). In addition to this, four external zones are considered to account for the interactions between Manhattan and the surrounding region. The external zones considered are: NY East, New Jersey South West, New Jersey North West and Upstate NY. In terms of the network, 180 of Manhattan's 590 miles of roadway—the designated truck routes—were included as a test network. This truck route system, which includes 2,615 links and 1,781 nodes, is one of the most complex in the USA.

The secondary data sources consist of truck-traffic counts (collected in 2009) from 97 intersections in Midtown Manhattan provided by the NYC Department of Transportation. A prior processing of the data had to be done because these traffic counts did not cover the entire day. The traffic volumes were available for three time periods: *am*, *midday* and *pm*. The *am* period covers the vehicle flows from 6:00 am to 10:00 am. The *md* period covers the period from 11:00 am to 2:00 pm, while the *pm* period accounts for vehicles from 4:00 pm to 8:00 pm. In essence, traffic counts were available only for 11 hours so that an expansion factor must be applied to convert these flows into daily ones.

The expansion factor was determined based on the daily counts of bridges and tunnels connecting Manhattan to the external zones. The traffic volumes on the bridges and tunnels were obtained from NYC Bridge Traffic Volumes 2009 [12] which presents the data for the same year that the truck-traffic data were collected, and from a dataset collected from automatic vehicle recorders at eight different bridge toll locations for different week days in 2002 and 2003 (Table 1 and Table 2 respectively). For matters of consistency, both traffic volumes consider small and large trucks, which correspond to classes 5 to 13 of the Federal Highway Administration Vehicle Classification [13]. The expansion factor estimation procedure is summarized in Table 1 and Table 2. As shown, the link data set has counts for a time interval *t*. Therefore, growth factors are computed as the total volume divided by the total volume in *t* at the aforementioned tunnels and bridges (major flows entering Manhattan where data are available for the whole day). The overall growth factor to be applied to the intersections in Midtown Manhattan was computed as the weighted average of the growth factors computed before. The results show that the percentage of traffic in time *t* varies around 60%, and ranges from 32% to 75% depending on the tunnel/bridge considered and the sample considered.

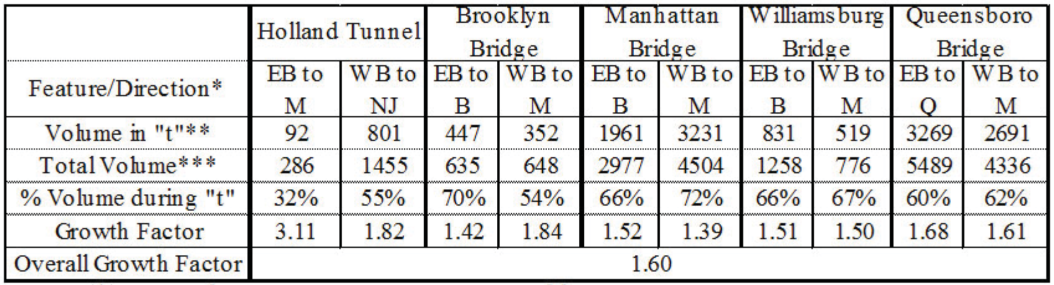
As an outcome of this analysis 1.83 was selected as the factor to expand the sample, meaning that each link flow in the study area should be multiplied by 1.83 to obtain daily volumes. In essence, this indicates that the volumes provided for Midtown Manhattan represent 56% of the daily traffic. The factor found was subsequently applied to the traffic counts for the 97 intersections in the city. The expanded traffic volumes were then assigned onto 154 links in Midtown Manhattan. As all the counts were not on the truck routes, an expanded network that includes all the traffic counts available was used.

Figure 1 shows the links where traffic counts were available (circled) on the new traffic network. As shown, all the traffic counts available correspond to Midtown Manhattan. This lack of dispersion of the traffic counts represents the main limitation of this application in NYC. In ODS, traffic counts are used to estimate trip distribution. However, a previous step is necessary to compute trip generation data for each TAZ.

3.1. Manhattan Trip Generation

The ODS approach proposed in this research requires the number of freight trips produced and attracted by each TAZ as inputs. As Freight Trip Generation (FTG) primary data for Manhattan is not available, trip rates and regression models developed by the authors were applied to estimate FTG [14]. In previous research, Freight Generation (FG) and FTG patterns of firms were found to be related to the industry sector to which they belong and the number of employees [15]. In fact, the Standard Industrial Classification (SIC) code assigned to an establishment is a strong predictor for FG and FTG because it classifies establishments in a way that is closely related to the economic and logistic process of firms [16].

Table 1. Flow Expansion Factor for Midtown Manhattan



	Holland Tunnel		Brooklyn Bridge		Manhattan Bridge		Williamsburg Bridge		Queensboro Bridge	
Feature/Direction*	EB to M	WB to NJ	EB to B	WB to M	EB to B	WB to M	EB to B	WB to M	EB to Q	WB to M
Volume in "t"**	92	801	447	352	1961	3231	831	519	3269	2691
Total Volume***	286	1455	635	648	2977	4504	1258	776	5489	4336
% Volume during "t"	32%	55%	70%	54%	66%	72%	66%	67%	60%	62%
Growth Factor	3.11	1.82	1.42	1.84	1.52	1.39	1.51	1.50	1.68	1.61
Overall Growth Factor	1.60									

Notes: (*) M: Manhattan, NJ: New Jersey, B: Brooklyn, Q: Queens
(**) "t" is the time interval for which volumes in Midtown are available
(***) Counts include every vehicle with two axles, six tires and larger

Table 2. Flow Expansion Factor using data from Bridge Tolls

	BB Tunnel	GB	GWBL	GWBP	GWBU	Holland Tunnel	Lincoln Tunnel	OBX
Volume in "t"*	560	1948	379	108	4844	749	5315	914
Flow from 6am to 7pm	719	2500	473	129	6157	904	6298	1160
Total Volume**	860	3493	941	143	9988	1141	7583	2077
% Volume during "t"	65%	56%	40%	75%	49%	66%	70%	44%
Growth Factor	1.54	1.79	2.48	1.33	2.06	1.52	1.43	2.27
Overall GF for "t"	1.83							

Notes: (*) "t" is the time interval for which volumes in Middle Town are available
(**) Counts include every vehicle with two axles, six tires and larger

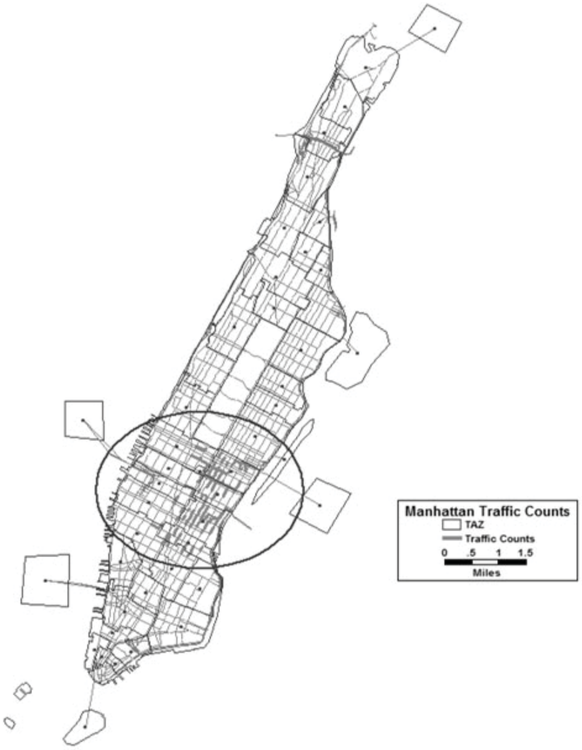


Figure 1. Manhattan Road Network and Traffic-Counts Location

The models used to estimate FTG in Manhattan were calibrated using data collected in 2005; the sample is comprised of 339 carriers and 362 receivers in Manhattan, Brooklyn and New Jersey. The data contain elements such as the number of deliveries received or number of trips made in a typical day, SIC category and number of employees. SICs were grouped into eleven categories according to their sector descriptions. Eight of the eleven categories were defined as freight-related: agriculture, forestry and fisheries; mineral industries; construction industries; manufacturing; transportation, communication and utilities; wholesale trade; retail trade; and food. After classifying the establishments by freight-related SIC, statistical models were estimated for the ones having more than five observations. Depending on the industry sector, FTG per establishment is estimated using a constant number of deliveries, an employment-dependent rate, or an ordinary least squares regression model combining constant generation and an employment-dependent term [16]. The criterion used to choose the specification of the model is the Root Mean Square Error (RMSE). Table 3 shows the FTG rates used to calculate both attraction and production per establishment by SIC.

As shown in Table 3, attraction models estimate the number of deliveries received by the establishments, while production models estimate the number of trips produced by them. In this study, a delivery is assumed to generate 2 trips because the truck does not stay permanently in the establishment.

As shown in Figure 2, each delivery attracts one trip (with cargo) and produces one trip (which can be loaded or empty). Similarly, each cargo pick-up generates 2 trips (inbound and outbound trips). From the analysis it follows that trip origins (O_s) and trip destinations (D_s) match exactly for each internal zone.

An alternative approach used in the past by the authors is to consider commodity flows and use a sub-model to account for empty trips. However, this is only possible when FG is available (this is not the case in Manhattan).

The unit expressing FTG in this study is truck trips; a truck is defined as any vehicle used in the transportation of cargo. Although the truck definition is not exactly the same as the one used for the traffic counts, this difference is not expected to have a big impact on the accuracy of the results because few automobiles are used to transport cargo.

Table 3. Daily Trip Generation by SIC

Gr	SIC	Description	Deliveries received		Truck Trips Produced	
			del/est	del/emp	trip/est	trip/emp
1	Agriculture, forestry & fish.	1,2,7,8,9	2.160		2.160	
2	Mineral Industries	10,12,13,14	2.160		2.160	
3	Construction	15, 16, 17	2.467		1.081	0.037
	15	General contractors & operative builders		0.132	2.160	
	17	Special trade contractors	2.508		2.067	
4	Manufacturing	21-39	3.156		1.611	
	23	Apparel & other finished products	3.778		1.611	
	24	Lumber & wood products, except furniture		0.067	1.611	
	25	Furniture & fixtures	1.434	0.207	1.611	
	34	Fabricated metal products	2.875		1.611	
	39	Miscellaneous manufacturing industries	3.377		1.611	
5	Transp. Comm. & Utilities	40-49	1.000		2.216	0.072
6	Wholesale Trade	50, 51	2.272	0.069	1.594	0.057
	50	Wholesale trade - durable goods	3.071	0.054	1.554	0.040
	51	Wholesale trade - nondurable goods	1.813	0.074	1.992	0.065
7	Retail Trade	52, 53, 55, 56, 57, 59	3.371		1.720	
	52	Building materials & mobile home dealers		0.353	1.720	
	56	Apparel and accessory stores	1.314	0.032	1.720	
	57	Home furniture, equipt. stores	3.714		1.720	
	59	Miscellaneous retail	2.902		1.720	
8	Food	20, 54, 58	1.826	0.090	1.444	
	20	Food and kindred products	1.609	0.01	1.500	
	54	Food stores	2.764	0.011	1.440	
	58	Eating and drinking places	2.017	0.034	1.440	

Notes: (*) For Groups 1 and 2 these values were assumed from the models estimated for Group 3.

(**) For Group 5 the deliveries received were assumed.

(***) Some SICs contained in each group have more specific models which may depend or not on business size, or can differ from the group estimate.

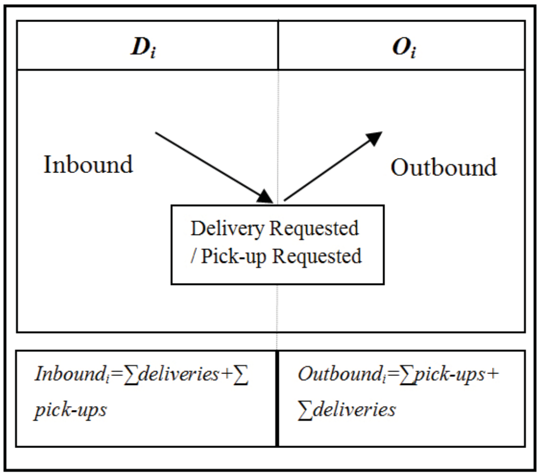


Figure 2. Trip Generation at the Establishment level. Source: [1]

As discussed in the previous section, the zoning system for the ODS application corresponds to the ZIP codes in Manhattan for the internal zones. Therefore, the authors applied the models presented in Table 3 to the 2007 County Business Patterns data from the U.S. Census Bureau [17], and aggregated the FTG by SIC and per ZIP code according to the methodology described in Holguín-Veras et al. [16]. Table 4 shows the daily FTG estimates by industry segment (SIC at the 2-digits-level),. As shown in Table 4, wholesale sector represents 41% of the establishments and generates about 40% of the total trips in Manhattan. The food-related sectors represent 25% of the establishments and generate 23% of total trips.

For the external zones FTG, the process followed a different logic. As not all the trips terminating in the external zones are interacting with Manhattan, the external trips were estimated using the volumes on the bridges and tunnels that connect Manhattan to these zones. However, the authors assumed, based on previous studies, that only 25% of the bridge and tunnel traffic is actually destined for Manhattan and the remaining 75% is through traffic.

Table 5 shows the groups of bridges and tunnels connecting each external zone to Manhattan as well as the daily truck volumes before the through traffic adjustment in both directions. The resulting FTG estimates for the external zones are presented in the bottom of Table 6, while the top of the table presents the FTG estimates for each internal zone. According to the geographical aggregation process, Manhattan produces and attracts 182,354 truck trips every day. If the traffic generated at external zones is considered, the total sums up to 218,480 truck trips per day.

3.2. Methodology

The starting point for this research is the multi-commodity ODS formulation developed by Holguin-Veras and Patil [5]. For this reason this section provides a succinct description of the methodology.

The model proposed assumes that: (1) estimates of the freight trip productions and freight trip attractions for each of the origin and destination zones are available; (2) the formulation implemented considers trucks transporting a generic commodity; (3) the underlying demand process that determines the freight-related traffic flows could be approximated by a doubly constrained gravity model; and, (4) the flow of empty trips is already considered in the freight generation estimation step. In all cases, the (unknown) parameters of the models are determined during the estimation process.

Define:

z_{ij} = Total number of trips from *i* to *j*

Assuming that z_{ij} follows a doubly constrained gravity model, as in equation (1):

$$z_{ij} = O_i \, D_j \, A_i \, B_j \, f_{ij} \tag{1}$$

Where:

O_i= Production at origin *i*

D_j = Consumption at destination *j*

A_i , B_j = Balancing factors to ensure satisfaction of origin and attraction constraints

$f_{ij} = e^{\beta \, c_{ij}}$ =Impedance function (negative exponential deterrence function)

c_{ij} = Travel cost between *i* and *j*

β = Impedance parameter

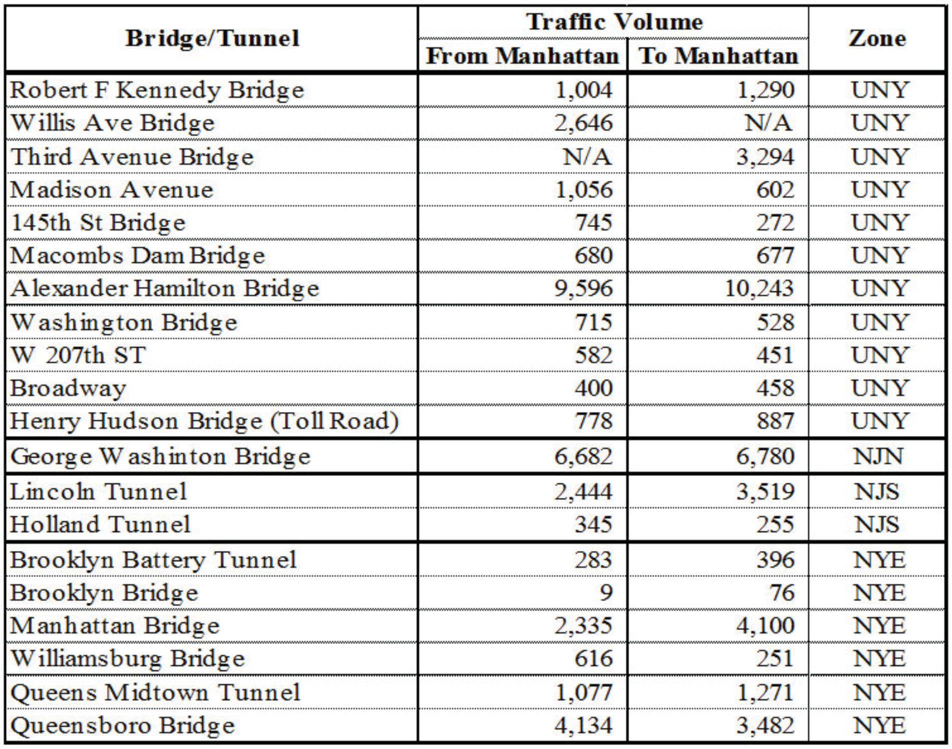
Table 4. FTG by Industry Segment in Manhattan

Industry Segment	SICs	Number of Establishments	Trip Production	Trip Attraction
Agricult., forestry, and fisheries	1,2,7,8,9	467	2.161	2.161
Mineral	10,11,13,14	6	28	28
Construction	15,16,17	1.969	8.594	8.594
Manufacturing	21-39	3.881	19.161	19.161
Transport., Comm., and Utilities	40-49	4.009	22.174	22.174
Wholesale Trade	50,51	15.714	74.063	74.063
Retail Trade	52,53,55,56,57,5	3.122	14.864	14.864
Food	20,54,58	9.877	41.310	41.310
Total		**39.045**	**182.354**	**182.354**

The impetus for using a gravity model is a pragmatic one because it provides a relatively easy and to a certain extent flexible, way to estimate OD matrices accounting for spatial interactions [5]. Holguín-Veras and Patil [5] implemented the model described in Equation (1) to a case study for which the actual commodity OD matrix, the loaded trips OD matrix, the empty trips OD matrix and traffic counts were known. They found that the model produced reasonable estimates of the true parameters of the underlying models. This research proposes a trip-based formulation, in which freight trip generation (FTG) considers the total flow between an origin *i* and a destination *j* as the summation of the corresponding loaded trips and the empty trips.

As in most previous freight ODS formulations, traffic counts are used to obtain estimates of the freight OD matrices. In this context, the problem reduces to the estimation of the parameters of the demand model so that the resulting traffic flows resemble the observed traffic in the network. In terms of the traffic assignment model needed in the ODS procedure, the authors decided to use techniques that are based on route choice that do not change with traffic flows (proportional route choice).

Table 5. Bridges/Tunnels Connecting Manhattan to External Zones



Bridge/Tunnel	Traffic Volume		Zone
	From Manhattan	To Manhattan	
Robert F Kennedy Bridge	1,004	1,290	UNY
Willis Ave Bridge	2,646	N/A	UNY
Third Avenue Bridge	N/A	3,294	UNY
Madison Avenue	1,056	602	UNY
145th St Bridge	745	272	UNY
Macombs Dam Bridge	680	677	UNY
Alexander Hamilton Bridge	9,596	10,243	UNY
Washington Bridge	715	528	UNY
W 207th ST	582	451	UNY
Broadway	400	458	UNY
Henry Hudson Bridge (Toll Road)	778	887	UNY
George Washinton Bridge	6,682	6,780	NJN
Lincoln Tunnel	2,444	3,519	NJS
Holland Tunnel	345	255	NJS
Brooklyn Battery Tunnel	283	396	NYE
Brooklyn Bridge	9	76	NYE
Manhattan Bridge	2,335	4,100	NYE
Williamsburg Bridge	616	251	NYE
Queens Midtown Tunnel	1,077	1,271	NYE
Queensboro Bridge	4,134	3,482	NYE

In terms of the gravity and the empty trip models, the estimated traffic on link l can be observed in equation (2):

$$V_l^e = \sum_i \sum_j z_j \, \overline{p}_j^l \qquad (2)$$

Denoting:

$\overline{p}_{ij}^l$ = Fraction of traffic traveling from i to j using link l

V_l^e = stimated truck-traffic on link l

The value of fraction $\overline{p}_{ij}^l$ can be estimated using any route choice model including all or nothing assignment, which is used in this study. Distance in miles is used to represent travel cost c_{ij} .

The objective function used to compute the optimal parameters considers the summation of the squared differences in the observed and estimated total (loaded plus empty) truck-traffic in the links, as shown in equation (3).

$$\arg\min(\hat{\mathbf{a}}, p) \quad F_V = \sum_l \left(V_l^o - V_l^e\right)^2 \qquad (3)$$

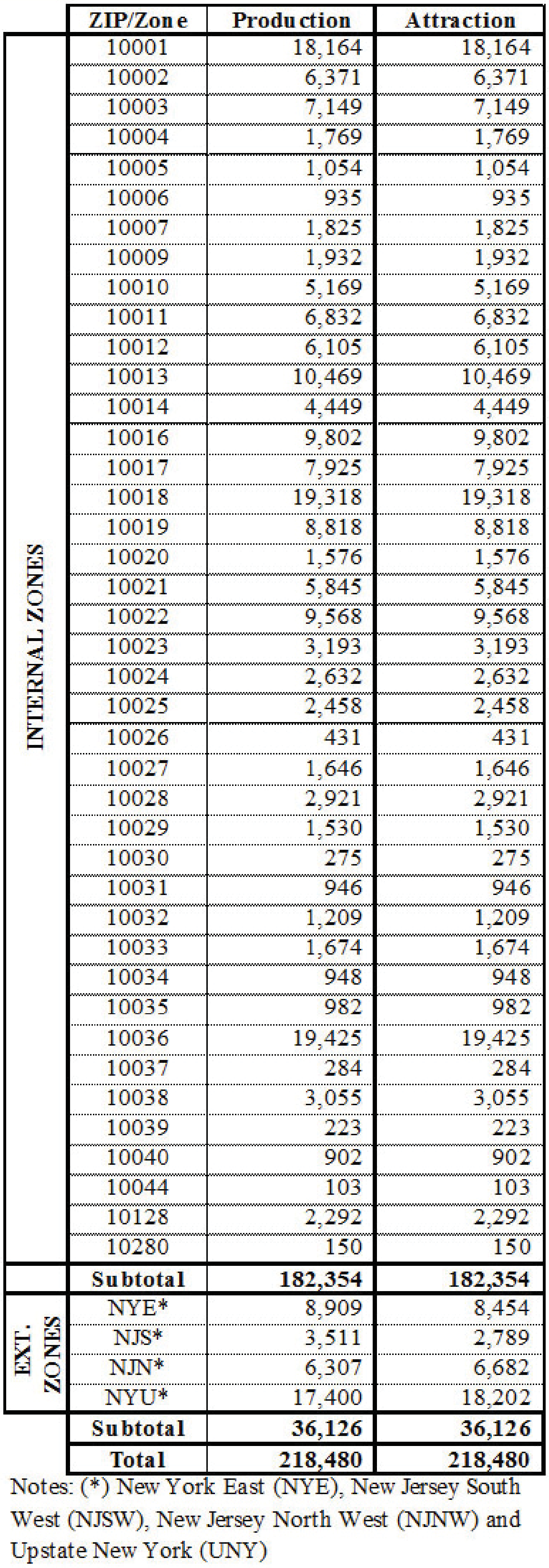
Where:

V_l^o = observed total traffic volume on link l

V_l^e = estimated total traffic volume on link l

The objective is to minimize the total traffic error, i.e., equation (3). The parameter β is estimated iteratively using a golden search procedure. The procedure is systematically repeated until convergence is reached. The performance of the model was assessed in terms of its ability to replicate the observed traffic counts.

Table 6: Freight Trip Generation by Zones in New York City



	ZIP/Zone	Production	Attraction
INTERNAL ZONES	10001	18,164	18,164
	10002	6,371	6,371
	10003	7,149	7,149
	10004	1,769	1,769
	10005	1,054	1,054
	10006	935	935
	10007	1,825	1,825
	10009	1,932	1,932
	10010	5,169	5,169
	10011	6,832	6,832
	10012	6,105	6,105
	10013	10,469	10,469
	10014	4,449	4,449
	10016	9,802	9,802
	10017	7,925	7,925
	10018	19,318	19,318
	10019	8,818	8,818
	10020	1,576	1,576
	10021	5,845	5,845
	10022	9,568	9,568
	10023	3,193	3,193
	10024	2,632	2,632
	10025	2,458	2,458
	10026	431	431
	10027	1,646	1,646
	10028	2,921	2,921
	10029	1,530	1,530
	10030	275	275
	10031	946	946
	10032	1,209	1,209
	10033	1,674	1,674
	10034	948	948
	10035	982	982
	10036	19,425	19,425
	10037	284	284
	10038	3,055	3,055
	10039	223	223
	10040	902	902
	10044	103	103
	10128	2,292	2,292
	10280	150	150
	Subtotal	**182,354**	**182,354**
EXT. ZONES	NYE*	8,909	8,454
	NJS*	3,511	2,789
	NJN*	6,307	6,682
	NYU*	17,400	18,202
	Subtotal	**36,126**	**36,126**
	Total	**218,480**	**218,480**

Notes: (*) New York East (NYE), New Jersey South West (NJSW), New Jersey North West (NJNW) and Upstate New York (UNY)

3.3. Results

As mentioned in the methodology, the parameter β is estimated iteratively using a golden section search procedure. For doing this, a computer program was written to perform the calculations. The inputs for the code are the total freight trip productions and freight trip attractions of the TAZs, the impedance between zones (given as a distance) and the list of the links including the connecting nodes, centroids of the TAZs, direction of the links and traffic counts. The optimization routine only considered internal zones. For external zones, the FTG inferred from the bridges' traffic volumes was assigned onto the network using a stochastic traffic assignment. These truck volumes generated by external zones were subtracted from the observed truck volumes and the result was used as input for the ODS model. The optimization procedure was systematically repeated until convergence was reached. The process included the optimization of the impedance parameter of the gravity model β, the proportion of empty trips *p*, and the Sum of Square Errors (SSE) between the observed and estimated total traffic volume in the links.

After running the code several times (about 100 iterations), it was found that β = 1.82.The parameter β is closely related to the average distance travelled. The greater the β, the less is the average distance travelled. In the Manhattan case, the average distance between zones is short (about 4 miles); therefore a large value for β was expected.

The plot of the parameter optimization is shown in Figure 3. The SSE is plotted as a function of the proportion of empty trips and the parameter β of the impedance function of the gravity model. It can be observed that for a value of β = 1.82, *p* = 0 and the SSE value is minimal. The link flows estimated by the ODS procedure were compared to the observed flows on the network. For most of the links the flow is overestimated.

The authors did not considered a statistical test analysis (such as chi-squared test) to compare observed and estimated link flows because it would be biased due to relatively few traffic counts spread throughout all the traffic network and the proportional assignment implemented. The total volume estimated for these links is 350,006 trucks while the observed volume is 100,179 trucks. In terms of accuracy, the SSE is 1.865E+9, that is the minimum of the function obtained using the golden search procedure.

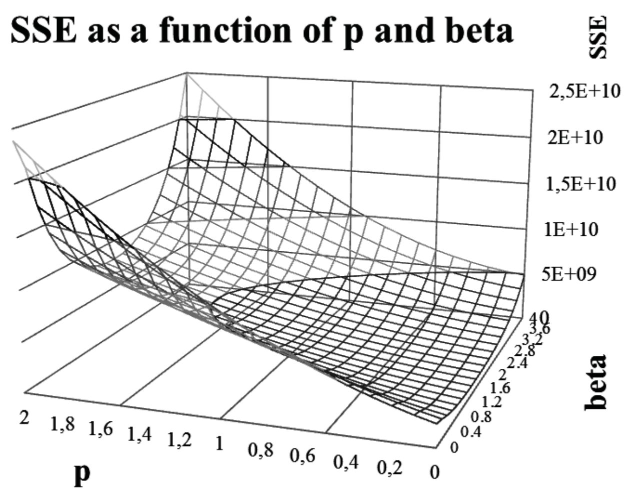


Figure 3. Plot of Sum of Squared Errors

It was found that for only 15% of the links the difference between the estimated flow and the observed flow is less than 50%. For another 22% of the links, the flows estimation error is between 50 and 100%. Another interesting finding is that 23% of the links studied had no traffic assigned, and about 40% of the links have an estimation error of more than 100%. These large errors reveal some limitations for implementing ODS. The main source of errors is the limited availability of traffic counts that were only available for midtown Manhattan. Hence, an opportunity for further research is to implement the model using new traffic counts spread over the network. Additionally, the authors consider that the implementation of a multi-path algorithm could significantly improve the ODS model performance.

4. CONCLUSIONS

The proposed ODS procedure permits the estimation of freight OD matrices using secondary sources in a region. The framework developed here will enable transportation management agencies to estimate freight OD matrices from traffic counts at a much reduced cost and with relative good accuracy. The framework will also make it possible to seamlessly integrate freight planning into agencies' transportation system planning. The theoretical approach works properly. However, when applying the model to a study case, it is necessary to consider the following lessons learned to obtain more accurate ODS results: 1. Having more traffic counts spread over the study area may improve the quality of the flow estimates; 2. The use of a commodity based approach instead of a trip based approach may improve results (the gravity model does not reflect the reality of the trips); 3. It is important to reduce the error in the traffic counts expansion (i.e., computation of growth factors) and through trips; and 4. The implementation of a multi-path algorithm to assign traffic and more traffic counts could significantly improve the ODS model's performance.

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