University Transportation Research Center - Region 2

Final Report

Freight Demand Estimation from Secondary Sources

Performing Organization: Rensselaer Polytechnic Institute

Rensselaer

January 2012

Sponsor:
Research and Innovative Technology Administration / USDOT

University Transportation Research Center - Region 2

The Region 2 University Transportation Research Center (UTRC) is one of ten original University Transportation Centers established in 1987 by the U.S. Congress. These Centers were established with the recognition that transportation plays a key role in the nation's economy and the quality of life of its citizens. University faculty members provide a critical link in resolving our national and regional transportation problems while training the professionals who address our transportation systems and their customers on a daily basis.

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Final Report

Freight Demand Estimation from Secondary Sources

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16. Abstract

This report explains how to estimate freight demand using secondary source of data such as traffic counts. Freight origin-destination (OD) matrices are one of the most important data elements a planner could have, which is why a significant amount of effort, time 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).

OD data are obtained by interviewing the participants in the transportation activity and 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 (Ortúzar and Willumsen, 2001).

The proposed ODS procedure permits the estimation of freight OD matrices using secondary sources in Manhattan. The secondary data sources consist of truck traffic counts from 97 intersections in Midtown Manhattan provided by the NYSDOT. The framework developed here will enable NYSDOT, NYMTC and other 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. 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. 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 in boosting demand modeling efforts as collecting freight data is extremely time consuming and expensive.

The results of the proposed ODS model could be improved by implementing a multi-path algorithm to assign traffic. The implementation of a multi-path algorithm increases the consistency between observed traffic counts and estimated traffic flows.

The lack of data (relatively few traffic counts, spread throughout the traffic network) severely constrains the ability to obtain accurate results. The research team suggests gathering more traffic counts in Downtown and Uptown Manhattan to obtain more accurate O-D flows estimations. In essence, using data that cover a broader geographic area enables a better representation of different travel characteristics and patterns in the city. Freight industry sectors vary from zone to zone, which affects the distribution of freight trips. In fact, data from only one sector of Midtown Manhattan cannot be used to explain goods movements across the whole city.

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Origin-destination, origin-destination synthesis, matrices, freight demand, freight data

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I. SUMMARY

The proposed freight ODS formulation uses a gravity model to estimate trip flows in Manhattan. 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.

II. 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 effort, time 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 (Ortúzar and Willumsen, 2001).

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 is extremely time-consuming and expensive. 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. 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 in boosting demand modeling efforts as collecting freight data is extremely time consuming and expensive.

III. 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 (Ortúzar and Willumsen, 2001).

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 separability 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 conducted revealed that freight ODS has received relatively little attention from researchers and transportation professionals. After a comprehensive search, only seven formulations were found (Tamin and Willumsen, 1988; Gedeon et al., 1993; List and Turnquist, 1994; Tavasszy et al., 1994; Al-Battaineh and Kaysi, 2005; Holguín-Veras and Patil, 2007; 2008). Tamin and Willumsen, using the gravity-opportunity model (GO), developed a formulation to obtain the parameters of the GO model that best reproduce a given set of traffic counts (Tamin and Willumsen, 1988). Their approach, an example of a structured formulation, requires link volumes and estimates of total tons produced and attracted at each zone. The formulation developed by Gedeon et al. is aimed at obtaining optimal multi-commodity flows in multimodal networks (Gedeon et al., 1993). Since this formulation does not model demand behavior, it will not be further discussed. List and Turnquist developed a formulation to estimate the OD matrix using optimization principles (List and Turnquist, 1994). 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 (Nozick et al., 1996). Tavasszy et al. used partial techniques to estimate unobserved elements of the OD matrix, for estimation of interregional freight transport flow (Tavasszy et al., 1994). The formulation by Al-Battaineh and Kaysi uses an input-output formulation to estimate productions and attractions and a Genetic Algorithm to compute the OD matrix (Al-Battaineh and Kaysi, 2005). As in input-output formulations, this formulation uses the value of the goods transported.

IV. ORIGIN-DESTINATION SYNTHESIS IN MANHATTAN

3.1 Manhattan Zoning System and Network

New York City 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(Holguín-Veras and Ban, 2010).Holguín-Veras and Ban (2010)estimate that about180,000truck 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:

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

In terms of the network, one hundred eighty of Manhattan's 590 miles of roadway—the designated truck routes--were included in the test network. This truck route system, which includes 2,615 lines and 1,781 nodes, is one of the most complex in the nation. Both the truck routes and TAZs are depicted in Figure 1.

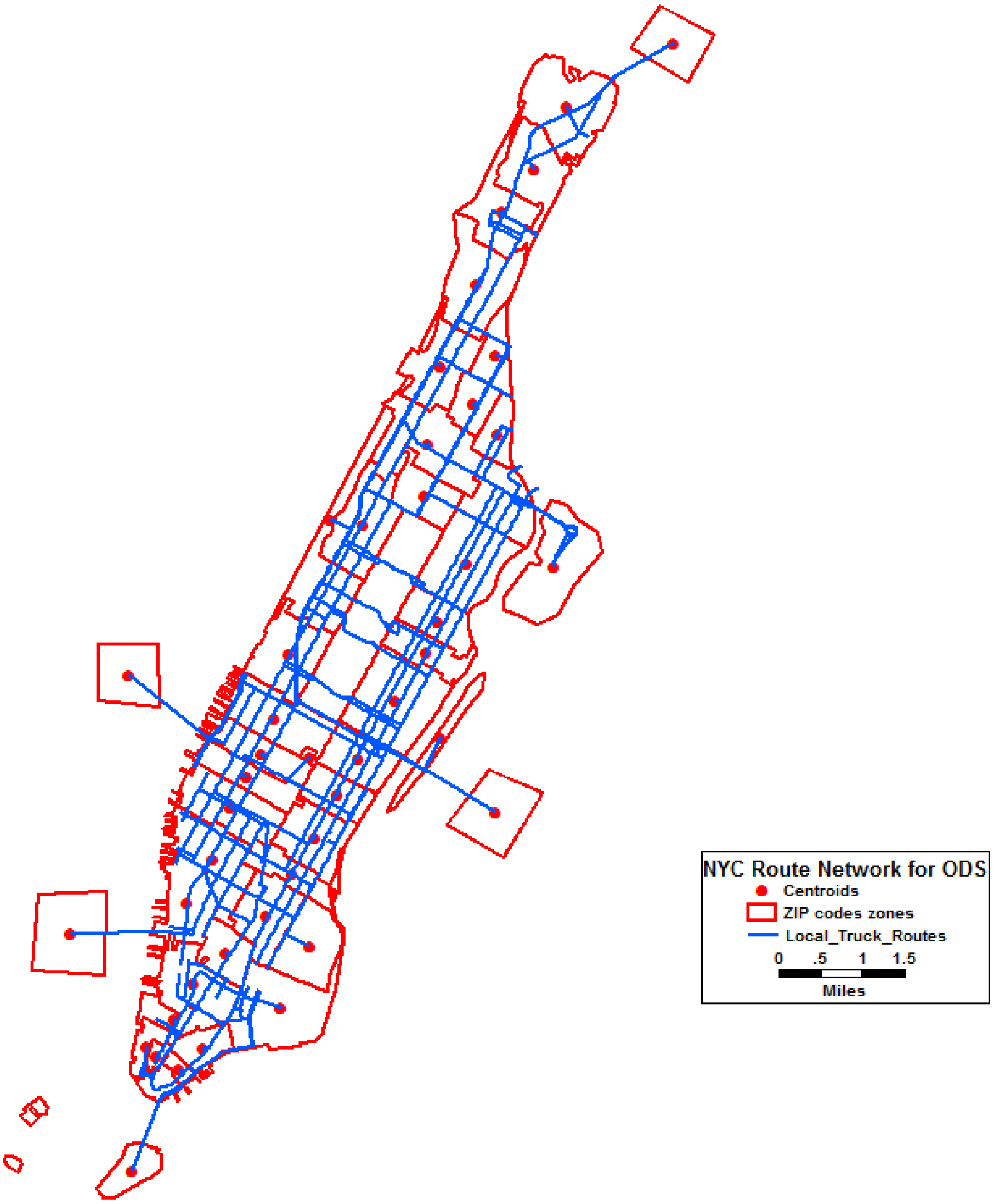


Figure 1: Manhattan Route Network for ODS

The secondary data sources consist of truck-traffic counts (collected in 2009) from 97 intersections in Midtown Manhattan provided by the NYCDOT.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(NYC Department of Transportation, 2011) which presents the data for the same year than the truck-traffic data was collected. For matters of consistency both traffic volumes consider small and large trucks, which correspond to classes 4, 5, 6 ,7, 8 , 9, 10, 11, 12 and 13 of the Federal Highway Administration - FHWA Vehicle Classification (FHWA, 2001). The expansion factor estimation procedure is summarized in Table 1. 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 is 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.

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									

* 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							

* "t" is the time interval for which volumes in Middle Town are available

**Counts include every vehicle with two axles, six tires and larger

As presented in Table 1, the expansion factor found was 1.60. However, the authors underwent a further step and analyzed data collected at eight different bridge toll locations for different week days in two different years (2002 and 2003). This further step confirmed that the percentage of traffic in time "t" varies around 60%. The results from this analysis are presented in Table 2. As the results in Table 2, was based on a more complete dataset for different days of the week, eight bridges/tunnels and for different years, the expansion factor used was 1.83, meaning that each link flow in the study area should be multiplied by 1.83 to expand the volume to a daily one. 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. All the counts were not on the truck routes. For that reason, an expanded network was used as test network including all the traffic counts available. Figure 2 shows the links where traffic counts were available (circled) on the new traffic network.

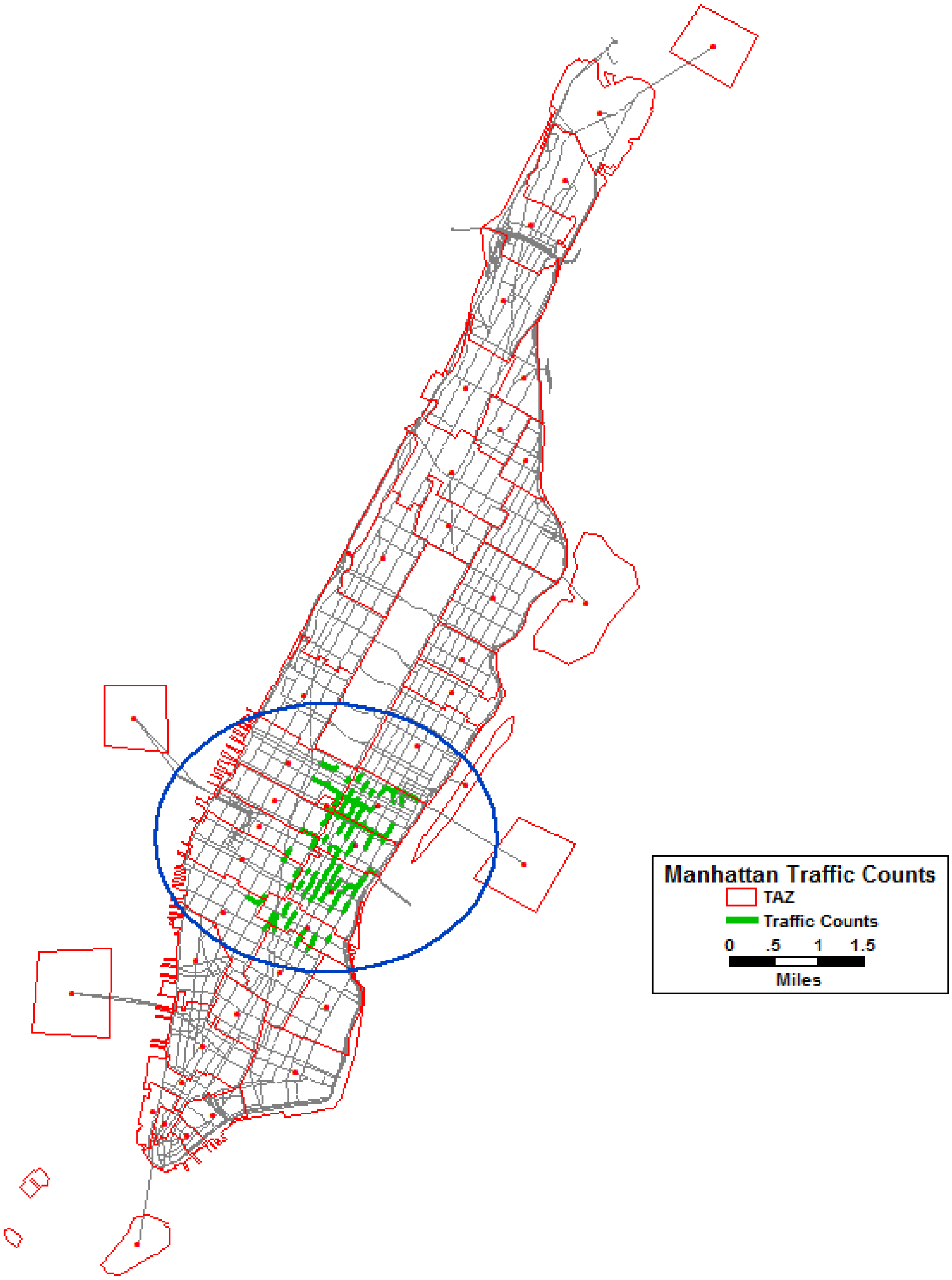


Figure 2: Manhattan Traffic-Counts Location

As shown in Figure 2, all the traffic counts available correspond to Midtown Manhattan. The OD synthesis process makes use of the counts to estimate OD matrices taking into account the productions and attractions of the TAZs as explained below.

3.2 Manhattan Trip Generation

This section describes the methodology followed to estimate freight trip generation for the study case. The Origin–Destination Synthesis (ODS) approach proposed in this research requires the number of freight trips produced and attracted by each zone 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(Campbell et al., 2011). 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 (Bastida and Holguín-Veras, 2009). In fact, the Standard Industrial Classification (SIC) code assigned to a 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 (Holguín-Veras et al., 2011).

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. Due to a lack of data, FTG models could not be estimated for non-freight-related SICs (finance, insurance, real estate; service industries; and public administration); FTG for establishments in these industry sectors will be the subject of further research.

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 (Holguín-Veras et al., 2011). 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. In essence, 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). This idea is illustrated in Figure 3a. 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 only, using a sub-model to account for empty trips. However, this is only possible when FG is available for the studied zones (which is not the case in Manhattan).Future research on the relation between deliveries and trips might result in more accurate ODS results. Figure 3b shows a possible modeling approach that takes into account the fact that some businesses have their own trucks (private carriers). In these cases one trip inbound and one trip outbound can account for one trip produced (O_i) and one delivery (D_i) in zone *i*. Moreover, implementing a tour-based sub-model for trip distribution based on freight generation would enhance the performance of this model.

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, and fisheries	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	Transportation, Communication and 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	

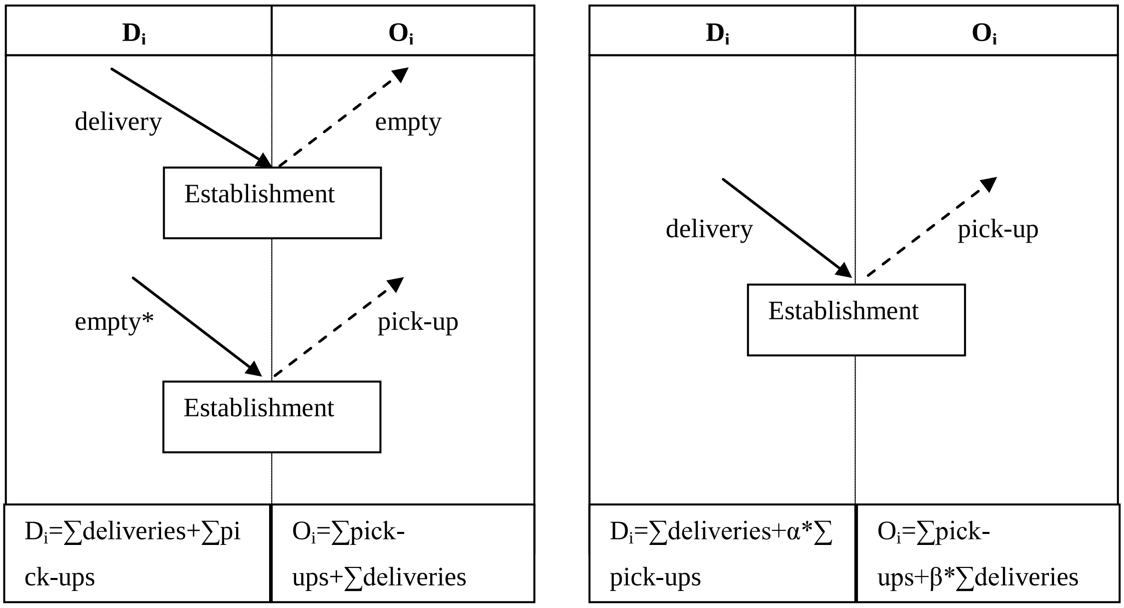
Notes: (*) For Groups 1 and 2 these values were assumed from the models estimated for Group 3.

(**) 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.

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

As discussed in the previous section, the zoning system for the ODS application corresponds to the ZIP codes in Manhattan for the internal zones. To estimate the FTG per zone, the authors used the 2007 County Business Patterns data from the U.S. Census Bureau(U.S. Census Bureau, 2007). The FTG aggregation process is based on the number of establishments and employment level per ZIP code and per SIC according to the methodology proposed by Holguín-Veras et al. (2011).



a. Deliveries and trips produced are independent (different trucks)

b. Some deliveries and some trips are coordinated (same truck)

Notes: (*) Not necessarily empty trip. If delivery is part of a tour the truck, it will still be loaded

Figure 3: Trip Generation at the Establishment Level

For the external zones, the process followed a different logic. As not all the trips originating from or destined for 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. Moreover, it was assumed that only 25% of the bridge and tunnel traffic is actually destined for Manhattan and the remaining 75% just use the bridges or tunnels to go across the island. The FTG study includes the vehicles classified as trucks or classified in the classes 5 to 13 in the Bridge Traffic Report 2009 (NYCDOT, 2011). In the cases where traffic counts are not available for the whole day an expansion factor is applied; this expansion factor is calculated based on other bridges. Table 4 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.

Table 5 shows daily FTG estimates aggregated by industry segment. The total number of trips attracted and produced by SIC was computed using a dataset that includes the total number of establishments (as well as the number of employees) by SIC in Manhattan, and the models presented in Table 3.The aggregation process was made according to the type of model for each SIC at the 2-digits-level.The 37,045 number of freight-related establishments in Manhattan generate 182,354 trips. As shown in Table 5, 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.

Table 4: 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

Table 5: FTG by Industry Segment in Manhattan

Industry Segment	SICs	Number of Establishments	Trip Production	Trip Attraction
Agriculture, 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	21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39	3,881	19,161	19,161
Transport., Comm., and Utilities	40,41,42,43,44,45,46,47,48,49	4,009	22,174	22,174
Wholesale Trade	50,51	15,714	74,063	74,063
Retail Trade	52,53,55,56,57,59	3,122	14,864	14,864
Food	20,54,58	9,877	41,310	41,310
Total		**39,045**	**182,354**	**182,354**

From the work of Holguín-Veras et al. (2011) were calculated the FTG totals for internal and external zones. The FTG totals are presented in Table 6. According to the geographical aggregation process, Manhattan produces and attracts 182,354 truck trips every day. Similarly, the total generation for Manhattan and its external zones is 218,480 truck trips every day.

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

	ZIP/Zone	Trip Production	Trip 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**
	Grand Total	**218,480**	**218,480**

3.3 Methodology

The starting point for this research is the multi-commodity ODS formulation developed by team members Holguin-Veras and Patil (2007). However, the data available as input and the geographical context differ from the one used previously(Holguín-Veras and Patil, 2007; 2008). 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):

$$z_{ij} = O_i \, D_j \, A_i \, B_j \, f_{ij} \qquad (1)$$

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*

$\beta =$ Impedance parameter

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. Although the authors acknowledge the shortcomings of the gravity model, which were discussed elsewhere (Holguín-Veras and Patil, 2007), it is used as part of the proposed ODS because of its relative computational efficiency. Furthermore, Holguín-Veras and Patil(2007) applied the above formulation (Eq. (1)) to a case study (Guatemala City) for which both the actual OD matrix and traffic counts were known. They found that the model produced reasonable estimates of the true parameters of the underlying models.

In the proposed formulation, 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 does not change with traffic flows (proportional route choice).

Denoting:

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

V_l^e = Estimated 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, which is used in this study. Distance in miles is used to represent travel cost c_{ij}. In terms of the gravity and the empty trip models, the estimated traffic on link *l* can be observed in equation (2):

$$V_l^e = \sum_i \sum_j z_{ij} \overline{p}_{ij}^{l} \tag{2}$$

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).

$$\arg\min(\boldsymbol{\beta}, p) \quad F_V = \sum_l \left(V_l^o - V_l^e\right)^2 \tag{3}$$

Where:

V_l^o = observed total traffic volume on link *l*

V_l^e = estimated total traffic volume on link *l*

The accuracy of the formulation was assessed in terms of its ability to replicate the observed traffic counts and OD matrices. 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.

3.4 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. Appendix I shows a description of the used code. The inputs for the code are the total freight trip productions and freight trip attractions of the TAZs, the impedance between zones (given as 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 to 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 Sum of Square Errors (SSE) between the observed and estimated total traffic volume in all links. After running the code several times, it was found that β = 1.82.The parameter β is closely related to the average distance travelled. The greater β, the less is the average distance travelled. In the Manhattan case, the distance between zones is not so big; therefore a big value for βwas expected. The plot of the parameter optimization is showed in Figure 4. The Sum of Square Errors (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 in Figure 4 that for a value of β = 1.82, p = 0 and the SSE value is minimal.

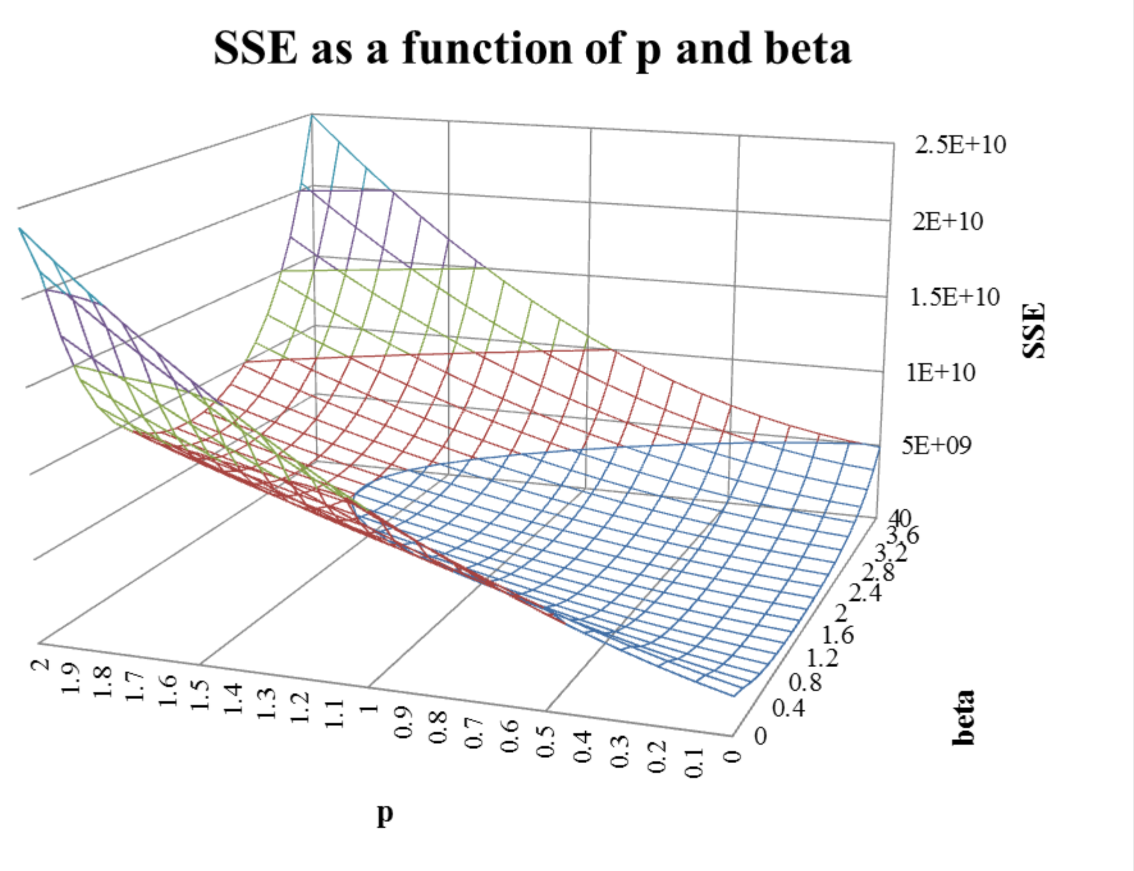


Figure 4: Plot of the Parameter Optimization

Table 7 shows the link flows estimated by the ODS procedure as well as the observed flows on the network. For most of the links the flow is overestimated. It was not considered a statistical test analysis (such as chi-squared test) to compare both 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 Sum of Squared Errors (SSE) is 1.865E+9, that is the minimum of the function obtained using the golden search procedure.

Table 8 summarizes the trucks volume estimation errors by link flows. The links are classified according to the magnitude of the estimation error.

As shown in Table 8, only for 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%. This can be explained by the type of proportional assignment implemented (all-or-nothing), where all the users are assumed to use the shortest path. Another reason is the sparse nature of the traffic counts that were only available for midtown Manhattan. It is then evident that implementing a multi-path algorithm to assign traffic and more traffic counts could significantly improve the ODS model performance.

Table 7: Link Flows Observed (in trucks) on the Network and Volumes Estimated by the ODS Procedure

Link	Observed	Estimated	Link	Observed	Estimated	Link	Observed	Estimated
732	77	1355	1202	601	3843	1337	248	37
739	1062	1620	1203	611	7682	1338	883	4067
1068	193	2444	1204	508	748	1339	236	881
1071	560	607	1205	550	7682	1341	421	892
1072	779	1883	1206	610	4590	1343	278	881
1073	837	1883	1208	656	7682	1346	544	0
1074	411	607	1209	553	3897	1356	461	752
1077	339	904	1210	487	53	1358	593	567
1078	417	1757	1252	61	1513	1383	192	3673
1089	231	748	1254	156	183	1385	2212	10576
1093	901	2694	1256	809	6169	1386	152	102
1094	720	3241	1257	519	2530	1393	2299	7005
1096	383	3398	1265	1145	39	1395	566	119
1098	399	5063	1268	408	2899	1396	672	188
1099	485	7562	1271	139	2617	1398	367	119
1108	138	183	1272	552	2899	1400	374	885
1110	569	747	1273	615	2796	1401	815	4067
1117	1151	1608	1274	324	2617	1402	174	4295
1125	1634	1149	1280	332	5918	1403	1793	7661
1126	547	211	1281	552	3963	1409	988	657
1127	512	447	1285	1528	12842	1414	1870	7661
1128	1095	16	1296	230	37	1428	665	0
1129	500	198	1298	1720	19272	1436	1019	718
1152	1863	3542	1299	865	39	1437	588	398
1156	1663	6455	1300	217	5983	1438	16	167
1157	1934	6455	1302	514	3963	1441	1725	693
1158	2490	1608	1312	1824	0	1442	93	656
1159	312	6198	1313	817	2854	1463	5308	5248
1160	442	4128	1314	202	2606	1512	2849	8112
1161	2159	12842	1315	681	0	1518	2915	2
1162	491	10241	1319	370	643	1519	7672	8112
1166	1174	16	1321	972	494	1762	896	1244
1169	2728	3542	1326	112	37	3509	1520	12842
1171	174	419	1327	581	5613	3639	780	2155
1172	255	291	1329	619	4784	3643	1711	15592
1176	1084	168	1330	315	1714	3658	532	467
1186	561	3149	1333	350	37	3659	616	3095

Table 8: Model Estimation Errors for Link Flows

Estimation Error	Number of cases	Percentage of cases
<10%	6	4%
11%-50%	17	11%
50%-100%	34	22%
>100%	61	40%
Links with no traffic assigned	36	23%
Total	154	100%

V. CONCLUSIONS

The proposed ODS procedure permitsthe estimation offreight OD matrices using secondary sources in Manhattan. The framework developed here will enable NYSDOT, NYMTC and other 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 parameter β of the impedance function of the gravity model was estimated iteratively using a golden search procedure. The obtained value of $\beta=1.82$ shows that the framework is producing good estimates. The parameter β is closely related to the average distance travelled. The greater β, the less is the average distance travelled, which is what is observed in this study.

The results of the proposed ODS model could be improved by implementing a multi-path algorithm to assign traffic. The implementation of a multi-path algorithm increases the consistency between observed traffic counts and estimated traffic flows.

The lack of data (relatively few traffic counts, spread throughout the traffic network) severely constrains the ability to obtain accurate results. The research team suggests gathering more traffic counts in Downtown and Uptown Manhattan to obtain more accurate O-D flows estimations. In essence, using data that cover a broader geographic area enables a better representation of different travel characteristics and patterns in the city. Freight industry sectors vary from zone to zone, which affects the distribution of freight trips. In fact, data from only one sector of Midtown Manhattan cannot be used to explain goods movements across the whole city.

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VII. APPENDIX

DESCRIPTION OF THE CODE

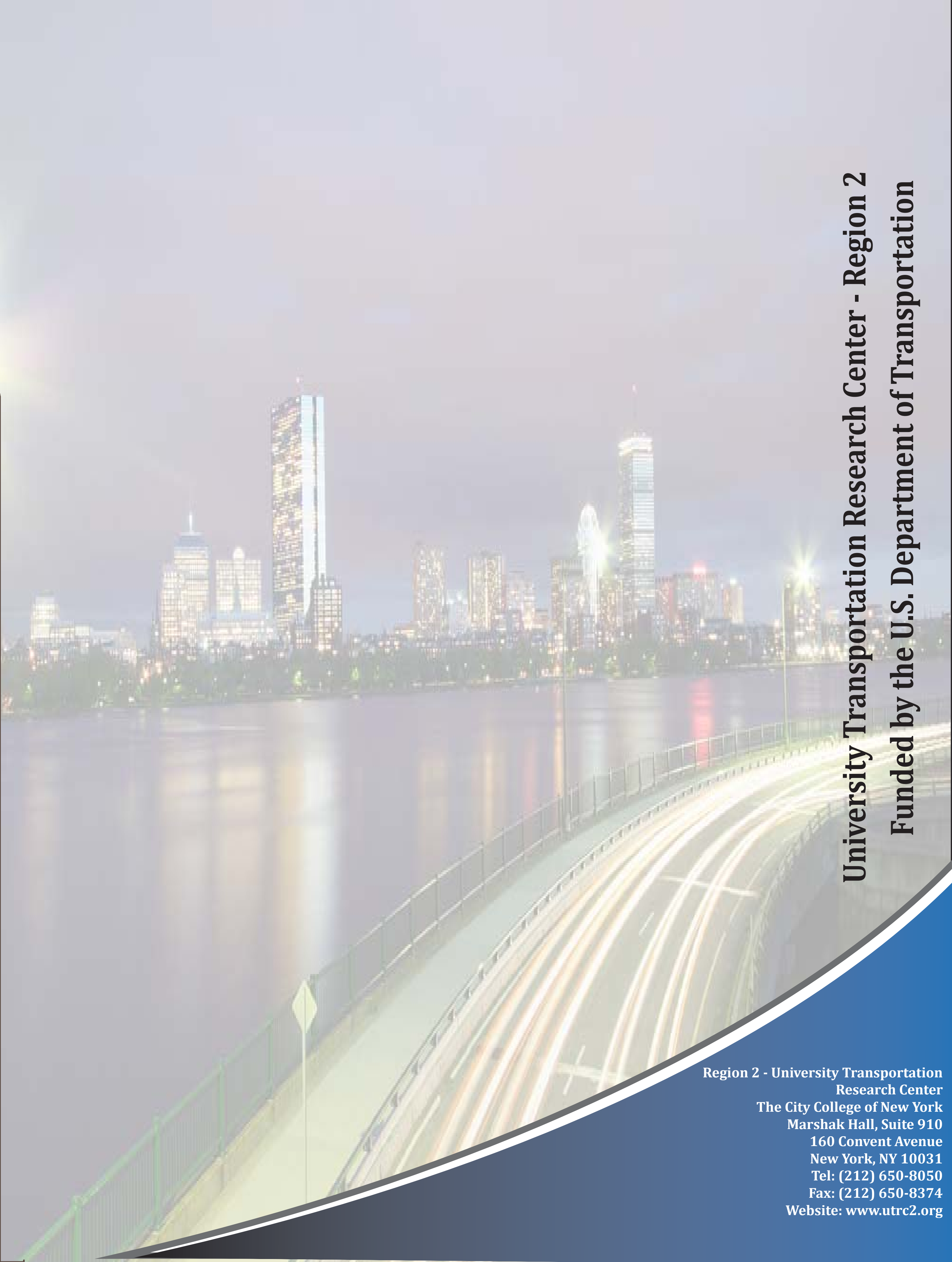
The code requires two input files: 1) a ‘TRIP’ file containing the model parameters such as average payload and the estimated production and attraction levels for each zone in the analysis region and 2) a ‘NETWORK’ file containing the link data such as length and observed vehicle counts.

```
'Typical TRIPS input file
'------------------------
'1               'Link flow rule regarding the sampling procedure
'0               'Binary variable indicating whether or not to include the empty trip sub-model
'19.5            'Assumed average payload (1 if trips are used rather than commodity amounts)
'0.491  'Assumed initial empty trip proportion 'p'
'0.6             'Assumed initial value of beta 'beta' for the gravity model
'1   780   629 'Zone inputs: Zone, Productions, Attractions
'2   659   478
'-9999  'Indicates the end of the data

'Typical NETWORK input file
'---------------------------------------
'1   2   3    4    3.77   -9999
'2   3   3    2    4.56   -9999

'3   4   6    7    2.25   -9999

'-9999                     'Indicates the end of the data
Each row contains: Serial#, Link ID, Start Node, End Node, Length, Observed Flow
```

Using the inputted data, the cost matrix is created for the network using the shortest path algorithm. A Doubly Constrained Gravity Model (DCGM) and the initial value of ‘beta’ are utilized to create the initial trip distribution matrix.

Traffic is assigned to the network using an All -or-Nothing (AON) assignment utilizing the initial values of ‘beta’ and ‘p’. The resulting link flows and observed link flows are used to calculate the initial sum of squared errors (SSE). If empty trips are included, the traffic assignment and SSE are determined for total traffic, loaded traffic and empty traffic individually.

The model then performs an iteritive process where one of the two parameters (‘p’ and ‘beta’) is fixed and the other goes through an iteritive process using a Golden Search algorithm to minimize the objective function. The other parameter is then fixed and the process repeats. The new link flows and the resulting SSE are determined and then the entire process is repeated. This continues until the changes in the parameter values between iterations is within a set tolerance level.



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