An empirical investigation on the impacts of spatial and temporal aggregation on empty trips models

Investigación empírica sobre los impactos de agregación espacial y temporal en los modelos de viajes vacíos

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Abstract

This paper analyzes the impacts of spatial and temporal aggregation of empty trips models. The authors analyze five models of empty trips (Noortman and van Es, and four Holguin-Veras and Thorson empty trips models) for different aggregation levels of six national freight origin-destination (OD) matrices. They were collected by Colombia's Ministry of Transportation during the 2000 to 2005 time period. The research includes an assessment of the spatial aggregation and time-dependency of the parameters for the different models. Furthermore, three aggregation levels are examined to study the performance of the different empty trips models specifications and the spatial and temporal stability of the parameters for these models.

---------- *Keywords:* Freight transportation, empty trip models, stability of parameters

Resumen

Este artículo analiza los impactos de agregación espacial y temporal en los modelos de viajes vacíos. Los autores analizan 5 modelos de viajes vacíos (Noortman and van Es, y cuatro modelos de Holguín-Veras y Thorson) para diferentes niveles de agregación de seis matrices origen-destino. Las matrices fueron obtenidas por el Ministerio de Transporte de Colombia en los

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años 2000 a 2005. La investigación incluye una evaluación de la agregación espacial y la dependencia en el tiempo de los parámetros de los modelos. Adicionalmente, se examinaron tres niveles de agregación para estudiar el desempeño de las especificaciones en los diferentes modelos de viajes vacíos y la estabilidad temporal de sus parámetros.

---------- *Palabras clave:* Transporte de carga, modelos de viajes vacíos, estabilidad de parámetros

Introduction

During the modeling process, freight demand can be measured either by the weight of commodities or the number of vehicle trips. From here, two approaches arise: vehicle-trip-based and commodity-based approaches [1-4]. The commodity-based models capture the economic aspects of freight demand, but fail to model empty trips. Conversely, trip-based models consider both loaded and empty trips but fail to capture the economic aspects of freight movements. Truck trips models should take into account empty trips which are a consequence of underlying logistical decisions. Those trips may represent between 15% to 40% of the number of trips in specific corridors [2]. Empty trips are frequently overlooked, but the reality is that they account for 56% of the miles traveled by straight trucks not pulling a trailer; 58% of the miles traveled by straight trucks pulling a trailer; and 33% of the miles traveled by truck-tractors (power-unit) pulling trailer(s) [5]. Moreover, empty travel typically accounts for about 20% of truck traffic in urban areas [6], and about 30-40% in intercity freight [3].

The analysis of the paper is based on different aggregation levels of six national freight origin-destination (OD) matrices. They were collected by Colombia's Ministry of Transportation during the 2000 to 2005 time period. For a more detailed description of the data, refer to Holguin-Veras et al. [7]. The analyses in this paper for empty trips are based on three different levels of aggregation: 28, 36 and 69 zones. The reason for choosing these zoning systems is the data available (electronic versions of the original files at a finer level of detail are only accessible for five years). The zoning system used includes internal zones (departments) and external zones (Ecuador, Venezuela, Peru, and Panama).

Finally, the objective of the paper is to analyze five models of empty trips (Noortman and van Es, and four from Holguin-Veras and Thorson) for different spatial aggregation levels. In doing so, the authors intend to show that empty trips models' parameters and specifications depend on the level of aggregation where data is available. In addition to this, the authors assess time-dependency of the parameters for the different models and aggregation levels.

This paper is composed by an introduction; a description of the empty trips used in the paper; an assessment of the empty trips models in Colombia for the 2000-2005 time period; and the key findings from the research.

Empty trips models

As discussed above, empty trips make up a substantial proportion of freight transportation, both in terms of miles traveled and trips made, so they need to be included when modeling freight transportation. Also, the correct estimation of commercial vehicle empty trips is very important for transportation planning purposes because if not done correctly, it will lead to severe directional errors in commercial vehicle traffic estimation, as shown in Holguín-Veras and Thorson [8].

A suitable approach for taking empty trips into account is to use complementary models which estimate empty trips from a commodity flow matrix [3, 8-11]. In essence, an accurate estimation of empty trips increases the chance of the demand model producing meaningful results.

A summary of the most representative empty trips models is presented in Holguín-Veras et al. [9].

The notation used for the models in the paper follows Holguín-Veras and Thorson [3]:

m_{ij} = commodity flow (tons) between origin i and destination j

a_{ij} = average payload (tons/trip) for loaded trips between i and j

$x_{ij} = \frac{m_{ij}}{a_{ij}}$ = estimated number of loaded trips between i and j

y_{ij} = estimated number of empty trips between i and j

$z_{ij} = x_{ij} + y_{ij}$ = estimated total number of trips (loaded + empty) between i and j

p = probability of a zero order trip chain

γ, β = parameters to be determined empirically

d_{ij} = distance (miles) between origin i and destination j

x_{hi} = number of loaded trips from h to i which is calculated as: $x_{hi} = m_{hi}/a$

$P^h(j)$ = probability that a vehicle that came from h to i chooses j as the next destination

$P^h(E/j)$ = probability that a vehicle following the tour h-i-j does not get cargo to j

$P^h(j)\,P^h(E/j)$ = probability that a vehicle traveling in h-i-j goes empty to j

$P^h(j)$ is a function of the attractiveness of zone j as a destination, which can be assumed to be a function of the commodity flow from j to i, m_{ij} and the trip impedance between i and j.

This paper uses the Noortman and van Es and Holguin-Veras and Thorson empty trips models that are summarized below.

Noortman and van Es (NVE)

Hautzinger [10] describes the model developed by Noortman and van Es which postulates that empty trips are a function of the commodity flow in the opposite direction. The model was included as part of the Dutch Freight Transport Model. A fraction, p, of the loaded trips in the opposite direction is expected to return empty to their origin. Therefore the number of empty trips in direction i-j can be estimated as the total number of loaded trips in the opposite direction multiplied by this constant p, see Eq. (1) below.

$$Z_{ij} = x_{ij} + y_{ij} = \frac{m_{ij}}{a_{ij}} + p\frac{m_{ji}}{a_{ji}} \quad (1)$$

Holguín-Veras and Thorson (HVT)

Holguín-Veras and Thorson [3] introduce a new set of models for commercial vehicle empty trips based on a first order model of trip chains. The models are based on the concept of order of a trip chain, defined as the number of additional stops with respect to the primary trip. In general, the models developed by the authors depict empty trips as the summation of a zero order trip chain term and a first order trip chain term, expanded to take into account higher order terms. For more information about HVT empty trips models refer to Holguín-Veras et al. [9]

The general formulation for the empty trips models shown below in Eq. (2) is from Holguín-Veras and Thorson [3], and will be used in this paper.

$$E(z_{ij}) = \frac{m_{ij}}{a_{ij}} + p\frac{m_{ji}}{a_{ji}} + \gamma\sum_{h\neq j} x_{hi}\left(P^h(j)P^h(E/j)\right) \quad (2)$$

Different formulations could be obtained depending on the assumption made regarding the function of the attractiveness of zone j as a destination $P^h(j)$. Special forms for $P^h(j)$ are presented below in Equations (3-6):

$$P(j) = \frac{m_{ij}}{\sum_l m_{il}} \quad (3)$$

$$P(j) = \frac{m_{ij}e^{-\beta d_{ij}}}{\sum_l m_{il}e^{-\beta d_{il}}} \quad (4)$$

$$P(j)=\frac{m_{ij}(d_{ij})^{-\beta}}{\sum_{l} m_{il}(d_{il})^{-\beta}} \tag{5}$$

$$P^{h}(j)=\frac{m_{ij}(d_{ij}+d_{hi})^{-\beta}}{\sum_{l} m_{il}(d_{il}+d_{hi})^{-\beta}} \tag{6}$$

Equation (3) is considered if the choice probabilities are understood as a function of the commodity flows from i to the connecting zones. If the choice probabilities are a function of both commodity flows and the corresponding trip impedances, equation (4) is used. equation (5) is considered if the choice probabilities are a function of the corresponding trip impedances, and finally, equation (6) is used if the probability of selecting j as the destination has a direct relationship with the commodity flow from i to j, and an inverse relationship with the summation of trip lengths of the previous trip (h to i) and the next trip (i to j). Substituting each of these expressions into the general formulation given by equation (2), result in five different empty trips models, which are shown in table 1. Equations (7-11) show the models used in the paper. Note that the Noortman and Van Es' model is obtained by setting γ equal to zero in equation (2).

Table 1 Formulations considered in this paper

Noortman and van Es' model - NVE: $E(z_{ij})=\frac{m_{ij}}{a_{ij}}+px_{ji}$ (7)

HVT Model 1: $E(z_{ij})=\frac{m_{ij}}{a_{ij}}+p\frac{m_{ji}}{a_{ji}}+\gamma\sum_{h\neq j}x_{hi}\frac{m_{ij}}{\sum_{l}m_{il}}P(E/j)$ (8)

HVT Model 2: $E(z_{ij})=\frac{m_{ij}}{a_{ij}}+p\frac{m_{ji}}{a_{ji}}+\gamma\sum_{h\neq j}x_{hi}\frac{m_{ij}e^{-\beta(d_{ij})}}{\sum_{l}m_{il}e^{-\beta(d_{il})}}P(E/j)$ (9)

HVT Model 3: $E(z_{ij})=\frac{m_{ij}}{a_{ij}}+p\frac{m_{ji}}{a_{ji}}+\gamma\sum_{h\neq j}x_{hi}\frac{m_{ij}(d_{ij})^{-\beta}}{\sum_{l}m_{il}(d_{il})^{-\beta}}P(E/j)$ (10)

HVT Model 4: $E(z_{ij})=\frac{m_{ij}}{a_{ij}}+p\frac{m_{ji}}{a_{ji}}+\gamma\sum_{h\neq j}x_{hi}\frac{m_{ij}(d_{ij}+d_{hi})^{-\beta}}{\sum_{l}m_{il}(d_{il}+d_{hi})^{-\beta}}P(E/j)$ (11)

Holguín-Veras et al. [9] highlighted the potential benefits of using variable p functions. The authors consider logistic functions of the kind shown in equations (12 - 17). In this paper, all models were evaluated using different p functions presented in table 2, and will be discussed later. In table 2, expression (a) maintains the parameter p as a constant; expression (b) assumes p is a function of the commodity flow; expression (c) assumes p is a function of the trip length; expression (d) assumes p as a function of the commodity flow using a modified naïve proportionality model; expression (e) assumes p as a function of trip length modified using a naïve proportionality model that considers distance instead of commodity flow, and finally expression (f) assumes p as a function that combines both distance and the opposing commodity flow. In the logistics functions, $p0$ captures the relationship between empty trips and opposing commodity flows; while $p1$ capture the contribution of vehicle-miles to empty trips.

Table 2 Logistic functions used in empty trips models

(12)	a) Constant
(13)	b) $\exp(p0 + p1 * m_{ji}) / (1 + \exp(p0 + p1 * m_{ji})$
(14)	c) $\exp(p0 + p1 * d_{ij}) / (1 + \exp(p0 + p1 * d_{ij})$
(15)	d) $\exp(p0 * m_{ji}) / (1 + \exp(p0 * m_{ji})$
(16)	e) $\exp(p0 * d_{ij}) / (1 + \exp(p0 * d_{ij})$
(17)	f) $\exp(p0 + p1 * m_{ji} + p2 * d_{ij}) / (1 + \exp(p0 + p1 * m_{ji} + p2 * d_{ij})$

Parameter search procedure

The estimation of the parameters of these models is conducted by a parameter optimization search that consists of finding the parameters that best fit a given data set. The parameters are determined by finding the values which minimized the error. For the formulation and more details, refer to Holguín-Veras et al. [9]

Empty trips in Colombia

Historically, the Colombian government has studied freight demand patterns for the past six decades. Before 1950, there is no information about the cargo transported in the country. In the next few years, some roads were built to connect the most important cities and ports in the nation, which led to an increase in the importance of data collection. After 1950, some statistics and data about freight movement in the country became available. Figure 1 shows the historical data of trips for Colombia between 1950 and 2000 [12]. The corresponding compilation of data is not available (electronic versions of the original files at a finer level of detail have only been found for 2000-2005). As shown in figure 1, the number of trips from 1976 to 1980 increased in about 230% compared to the previous 5 year period. Thereafter, the number of trips decreased to the level of the 1980's, and for the next 10 year period (1991 to 2000), the trips increased again. This increase in freight trips in the last decade can be explained by the adoption of free trade policies in 1990 which opened Colombian market to the global economy.

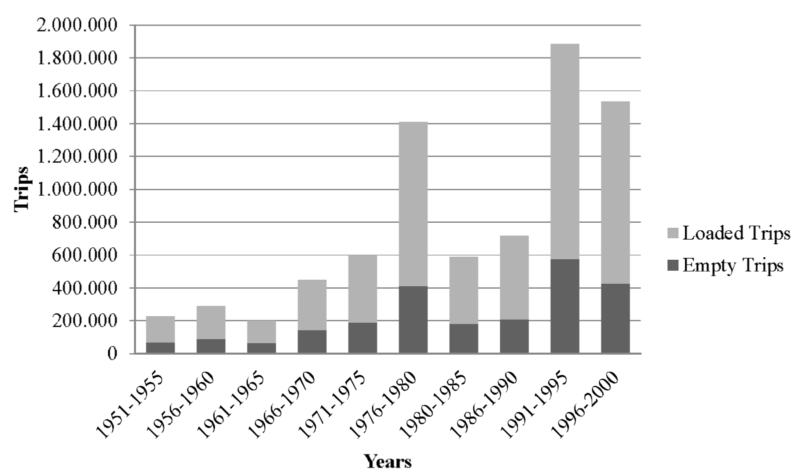


Figure 1 Historical data for total trips in Colombia 1950-2000

Figure 2 depicts the variation of empty trips percentages in Colombia from 1950 to 2005, based on data from the Ministry of Transportation of Colombia.

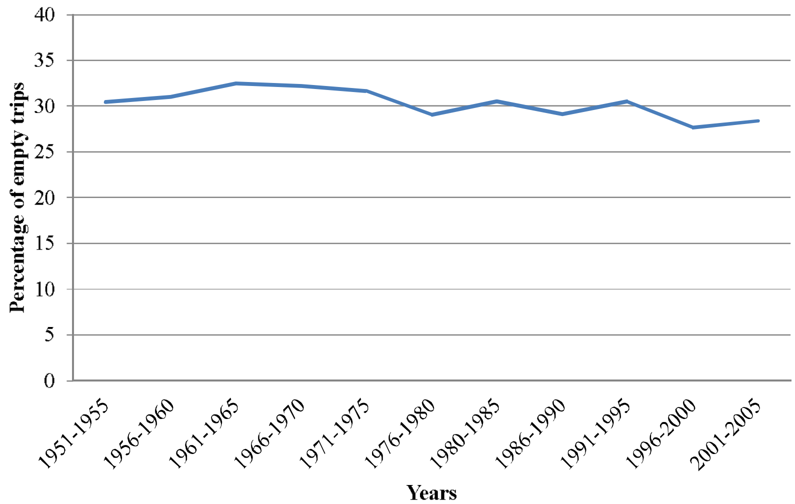


Figure 2 Percentage of empty trips in Colombia 1950-2005

As shown in figure 2, the proportion of empty trips seems stable over the decades, keeping a constant ratio around 30% of the total trips. This value is consistent with the percentage of empty trips indicated in other places such as Guatemala City and the Dominican Republic [3, 9, 13]. The stability of parameters is a consequence of the asymmetry in the commodity flow matrices that is a very stable feature of the economic system of almost all countries. However, an econometric analysis shows that empty trips are not completely stable over time. The authors performed a linear regression for the empty trips for all the periods in which the data was gathered (1950-2005). Table 3 shows the parameters and statistics of the model.

Table 3 Empty trips model for 1950-2005

(Parameter), variable	***Linear model***	
	Parameter value	t-value
(β0), Constant	32,082	113,194
(βb), Years	-0,066	-7,329
Time dependent ?	Yes	Adj. R2=0.49 F=53.72

The model on table 3 shows that although the constant rate of 32.1 dominates the models, the proportion of empty trips is slightly time-dependent. This is consistent with the results found in Holguín-Veras et al. [7]. The sign associated with the time parameter explains a decrease in the proportion of empty trips through the years. As indicated, this variation is very small. In fact, according to the model the proportion of empty trips decreased in average by 0.66% every 5 years.

Empty trips models in Colombia 2000-2005

Figure 2 presented the trend over time of empty trips in Colombia for the last decades. Now, focusing in the most recent data (2000-2005), the authors analyzed empty trips in Colombia considering Noortman and van Es; and Holguin-Veras and Thorson models. A previous study [14] used these models to study the empty trips by commodities for 2004. In essence, the authors study the impact of spatial aggregation level on empty trips models specification and parameters. Three different aggregation levels were studied based on the different data sets available in

Colombia from 2000-2005. The data studied have been collected by Colombia's Ministry of Transportation as part of the Freight Origin-Destination Survey (FODS) program. The information provided by the FODS encompasses different freight trip matrices (total, loaded, and empty) for every year for both commodity flows and trips. A previous analysis done by the authors showed that the percentages of empty trips during these years vary between 26.4% and 30% [7]. In fact, the empty trips proportion is somehow stable over time (about 30%) as explained before (figure 2).

Using the gathered data, five different models are considered: the model proposed by Noortman and van Es (Eq. 7), and models 1–4 by Holguín-Veras and Thorson (Eq. 8-11). The 2000, 2001 and 2003 data sets only have 28 and 36 zones; while 2002, 2004 and 2005 data sets have 28, 36 and 69 zones (that was the available information). The NVE, HVT 1 and HVT 2 models were run for all data sets, while the HVT 3 and HVT 4 models were run only for 28 and 36 zones, because the *parameter search process* did not converge with the 69 zone data set. Based on the methodology implemented by Holguin-Veras and Thorson [9], the best models for each year, and each level of aggregation were selected minimizing the sum of squared differences (SDD) that represents the error in the model. Table 4 summarizes the findings. The letters (a-f) in the models correspond to the logistic functions used in each empty trips model (table 2).

Table 4 Best empty trip model estimation

Year	*Model parameters (28 Zones)*		*Model Parameters (36 Zones)*		*Model Parameters (69 Zones)*	
	Best model	***Error***	***Best model***	***Error***	***Best model***	***Error***
2000	NVE f	7.102.068.815	NVE f	7.102.871.607		
2001	NVE f	20.083.750.486	NVE f	20.251.921.733		
2002	NVE f	7.175.656.020	NVE f	7.179.233.081	HVT 1c	6.651.417.661
2003	NVE f	12.544.535.066	NVE f	12.576.835.401		
2004	NVE f	15.498.495.405	NVE f	15.530.377.497	HVT 1c	9.704.201.436
2005	NVE f	11.315.877.988	NVE f	11.217.654.491	NVE f	12.095.716.576

Table 4 shows that for 28 and 36 zones; Noortman and van Es' model get better results than HVT's models. However, for the model using 69 zones, HVT models have a lower SDD. A better behavior of NVE's models when using 28 and 36 zones means that most of the trips do not follow a tour in these cases. In fact, using a more detailed level of aggregation enables the model to replicate the actual trip chains because centroids are closer and short trips are represented, while more disaggregated models simply ignore trips inside bigger zones. Another interesting finding is that the best models (HVT) consider distance as a variable in the logistic function for the p meaning that, as expected, trip length does have an effect on the proportion of empty trips. Overall, obtaining different best models for the different cases implies that empty trip specification depends on the spatial aggregation of the data.

In order to study the change in empty trips proportion, variation between aggregation levels are computed for the NVE model with constant p (table 2) as shown in table 5. This table shows that variation from 28 to 36 zones system has a minor influence on the proportion of empty trips with constant p. However, when 69 zones are considered, the proportion of empty trips decreases more than 10% in 2002 and 2005. As discussed before, the most disaggregated model reflects the trip chain patterns that were ignored in the former models. In essence, the spatial aggregation level plays an important role on the stability of parameters. A higher aggregation level might be valuable when data is not available at a more detailed level, but as shown in table 5 empty trips parameter is not stable among aggregation levels.

Table 5 NVE-a model parameters for different aggregation levels

Part A) Parameters value comparison for different aggregation levels			
NVE a Model	***Model Parameters (28 Zones)***	***Model Parameters (36 Zones)***	***Model Parameters (69 Zones)***
	p	p	p
2000	0,4337	0,4336	
2001	0,3560	0,3551	
2002	0,3954	0,3954	0,3523
2003	0,4443	0,4442	
2004	0,4212	0,4211	0,4187
2005	0,3694	0,3694	0,2989

Part B) Rate of change in parameter values with 28 zones as reference value		
NVE a Model	***Model Parameters (36 Zones)***	***Model Parameters (69 Zones)***
	p	p
2000	-0,02%	
2001	-0,26%	
2002	-0,01%	-10,92%
2003	-0,01%	
2004	-0,01%	-0,59%
2005	0,00%	-19,08%

Stability of parameters in time

In order to analyze the performance of the empty trip models, and the stability of the parameters in time, the authors fixed the models with constant p parameter and with one zoning system (36 zones). Table 6 presents a summary of the parameter values (p for NVE model; and p, γ, and β for HVT models). For comparison purposes, the corresponding values of the root mean squared error (RMSE) are also shown. From Table 6 it can be observed that for the years 2000, 2001, 2003, and 2004 the HVT 3 performs the best (they have the lower error). For the year 2002 the best model is HVT 2, and for 2005 the best model is HVT 4. In all cases the HVT models perform better than the NVE model. The RMSE in NVE models are between 7% and 24% greater than the best HVT model in each group. However, NVE models could perform better than HVT models in situations where there are zero order trip chains, i.e., in intercity trips. This is not the case because of the used aggregation level considering departments.

Table 6 Empty trips models using the *p* function as a constant (2000-2005)

Empty trips model	***2000 Model Parameters***			***Performance Measures***	
	p0	***Gamma***	***Beta***	***Error***	***RMSE***
NVE Dest. Choice: None	0,4336	0,0000	0,0000	16.918.076.174	4.715,02
HVT 1 Dest. Choice: mij	0,6064	-2,4035	0,0000	14.027.498.933	4.296,19
HVT 2 Dest. Choice: mij*exp(b*dij)	0,5710	-1,9995	1,7309	13.103.723.054	4.155,05
HVT 3 Dest. Choice:mij*dij^b	0,5357	-1,6962	0,1350	12.553.261.372	4.066,84
HVT 4 Dest. Choice:mij*(dij+dhi)^b	0,5265	-1,4130	0,0411	12.724.323.807	4.094,46

Empty trips model	***2001 Model Parameters***			***Performance Measures***	
	p0	Gamma	Beta	Error	RMSE
NVE Dest. Choice: None	0,3551	0,0000	0,0000	32.076.433.692	6.201,69
HVT 1 Dest. Choice: mij	0,4682	-1,0836	0,0000	30.170.508.445	6.018,23
HVT 2 Dest. Choice: mij*exp(b*dij)	0,4739	-1,1368	1,3401	28.986.287.359	5.902,48
HVT 3 Dest. Choice:mij*dij^b	0,4293	-0,8595	0,8026	27.764.802.674	5.776,78
HVT 4 Dest. Choice:mij*(dij+dhi)^b	0,4269	-0,8368	1,1001	28.191.093.831	5.820,96

Empty trips model	***2002 Model Parameters***			***Performance Measures***	
	p0	Gamma	Beta	Error	RMSE
NVE Dest. Choice: None	0,3954	0,0000	0,0000	17.837.070.189	5.022,87
HVT 1 Dest. Choice: mij	0,5975	-2,5666	0,0000	14.296.395.900	4.499,98
HVT 2 Dest. Choice: mij*exp(b*dij)	0,5586	-2,0959	1,8563	12.937.722.824	4.283,85
HVT 3 Dest. Choice:mij*dij^b	0,4844	-1,0582	-0,3049	13.880.697.177	4.437,22
HVT 4 Dest. Choice:mij*(dij+dhi)^b	0,5019	-1,2827	-0,3930	13.166.196.848	4.321,51

Empty trips model	***2003 Model Parameters***			***Performance Measures***	
	p0	Gamma	Beta	Error	RMSE
NVE Dest. Choice: None	0,4442	0,0000	0,0000	29.564.066.991	6.412,36
HVT 1 Dest. Choice: mij	0,6190	-2,2630	0,0000	24.068.916.882	5.789,83
HVT 2 Dest. Choice: mij*exp(b*dij)	0,5841	-1,8209	1,3761	23.416.435.079	5.714,80
HVT 3 Dest. Choice:mij*dij^b	0,5552	-1,5379	0,3062	21.655.230.361	5.495,68
HVT 4 Dest. Choice:mij*(dij+dhi)^b	0,5546	-1,5299	0,3394	21.833.358.400	5.518,24

Empty trips model	2004 Model Parameters			Performance Measures	
	p0	Gamma	Beta	Error	RMSE
NVE Dest. Choice: None	0,4211	0,0000	0,0000	36.106.960.195	6.971,10
HVT 1 Dest. Choice: mij	0,5858	-1,9384	0,0000	29.644.268.351	6.320,75
HVT 2 Dest. Choice: mij*exp(b*dij)	0,5397	-1,4084	-0,2393	30.501.781.041	6.415,84
HVT 3 Dest. Choice:mij*dij^b	0,5339	-1,4489	0,4516	25.531.388.774	5.869,87
HVT 4 Dest. Choice:mij*(dij+dhi)^b	0,5331	-1,4729	0,5558	25.916.823.283	5.914,01

Empty trips model	2005 Model Parameters			Performance Measures	
	p0	Gamma	Beta	Error	RMSE
NVE Dest. Choice: None	0,3694	0,0000	0,0000	43.625.622.505	7.963,00
HVT 1 Dest. Choice: mij	0,5374	-1,8970	0,0000	38.675.516.143	7.503,08
HVT 2 Dest. Choice: mij*exp(b*dij)	0,5029	-1,6319	2,7040	32.235.418.335	6.854,95
HVT 3 Dest. Choice:mij*dij^b	0,4800	-1,3666	-0,1222	30.916.563.487	6.713,26
HVT 4 Dest. Choice:mij*(dij+dhi)^b	0,4915	-1,5957	0,8880	28.241.714.541	6.416,28

The changes in parameter values for all empty trips models (36 zones) are shown graphically in figure 3 and figure 4.

Analyzing the parameters of the models over time, it was found that there is a stability on the p parameters (they are not time-dependent, or the dependence is minimal) over time for all models (it can be observed that the curve for the p parameter is almost flat for all models).

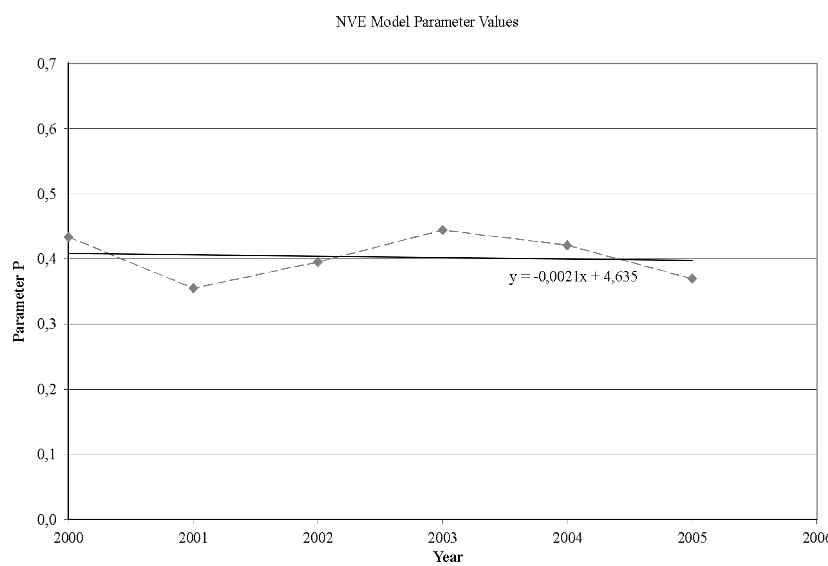
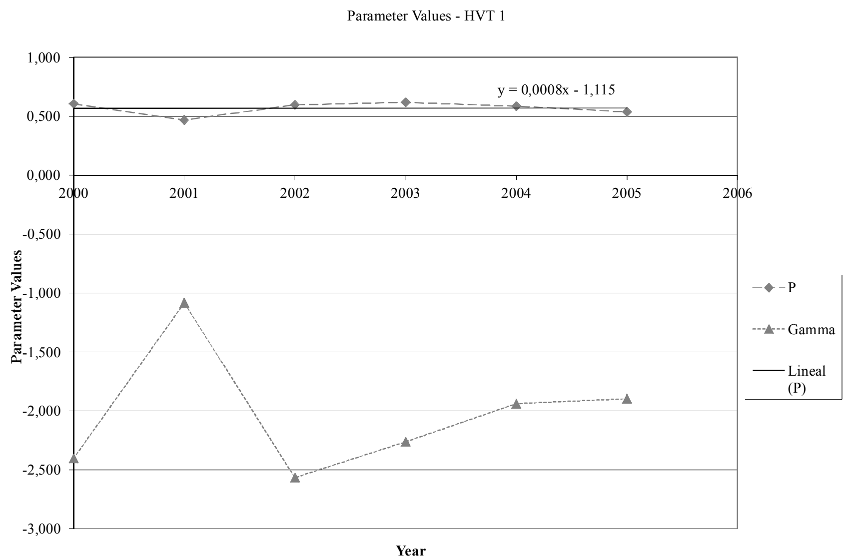
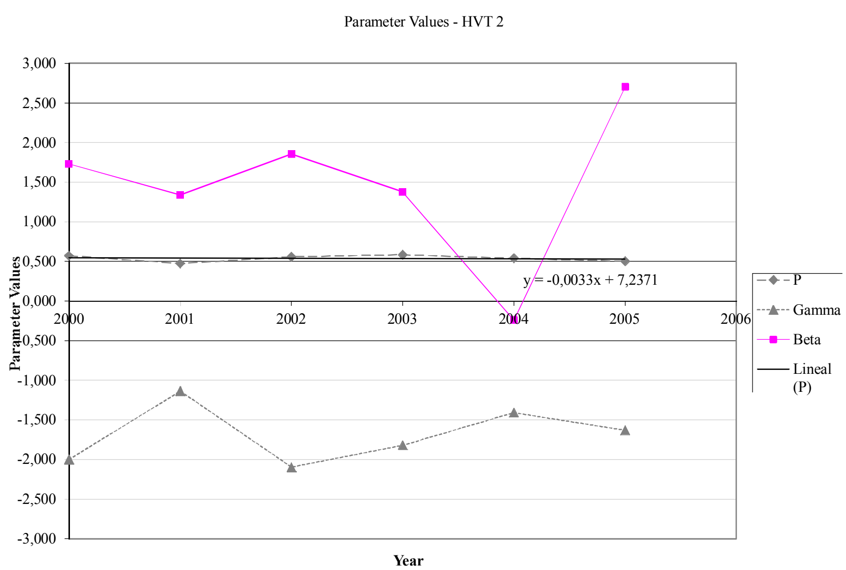


Figure 3 NVE model parameter values

The previous results are consistent with Holguín-Veras et al. [7], who analyzed the stability of parameters of the NVE model with parameter *p* constant for the years 2000-2005. However, the other parameters (*gamma* and *beta*) in the HVT models do not show a representative trend over time. The parameter gamma has a peak in the year 2001 for all HVT models, with a value roughly of -1. The trend of this curve is similar in all HVT models. The sign of the *gamma* parameter is correct (negative), which means it is conceptually valid for all the models. Conversely, some of the *beta* values were positive, which is not conceptually valid as it indicates that the attractiveness of a zone increases when the distances increases too. For this reason the empty trips models that produce conceptually valid results are HVT 1 for all years, HVT 2 for 2004, HVT 3 for 2002 and 2005, and HVT 4 for 2002. It could be explained because in developing countries like Colombia, large trucks are found to undertake long trips chains at relatively long distances.





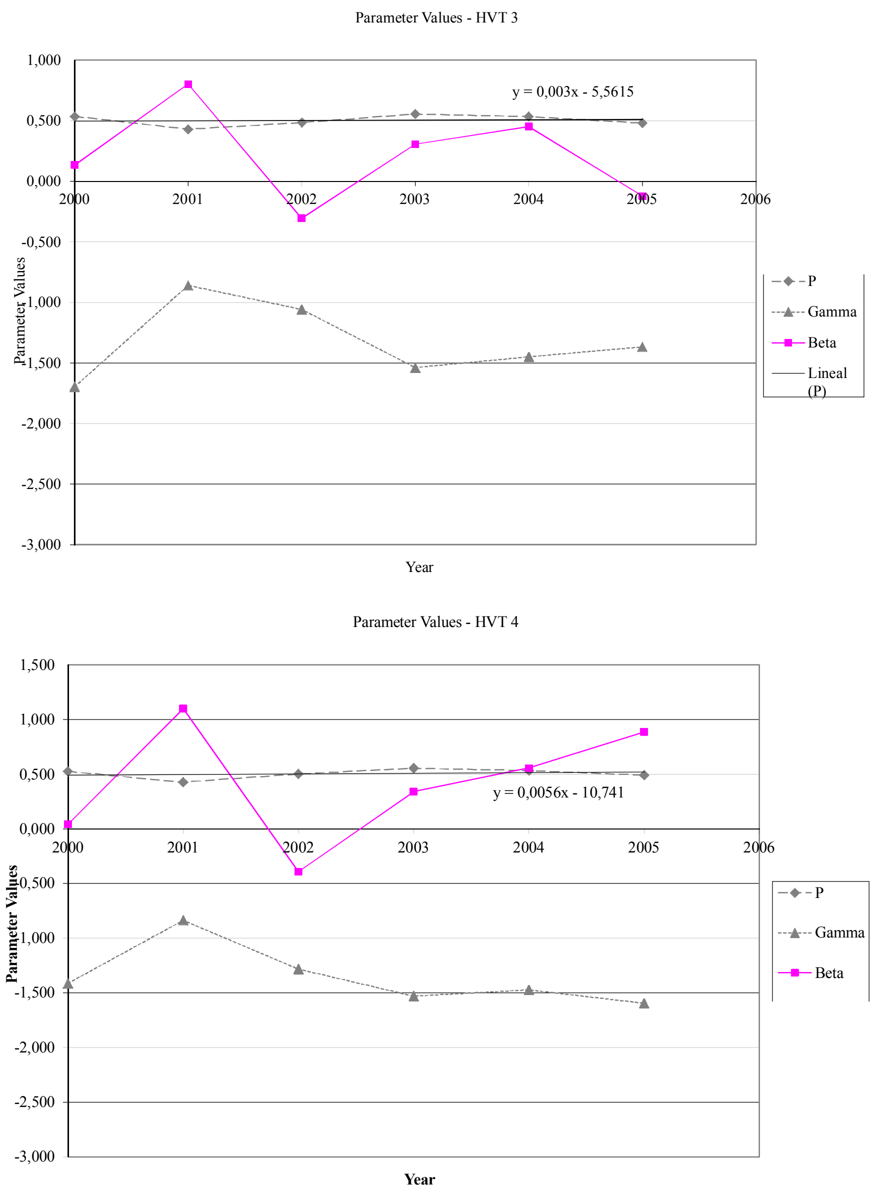


Figure 4 HVT models parameter values

Conclusions

A systematic study of six national freight origin-destination (OD) matrices collected by Colombia's Ministry of Transportation during the 2000 to 2005 time period was performed. Five models of empty trips (Noortman and van Es, and four Holguin-Veras and Thorson empty trips models), were evaluated for different zone aggregation levels during those years.

The proportion of empty trips was found to be stable over the decades keeping a constant ratio about 30% of the total trips. This value is consistent with the percentage of empty trips found in other places such as Guatemala City and the Dominican Republic [3, 9, 13]. This stability is a consequence of the asymmetry of the commodity flow matrices that is a very stable feature of the economic system.

Another interesting finding is that best empty trips models consider distance as a variable in the logistic function for the *p* meaning that, as expected, trip length does have an effect on the proportion of empty trips. In general terms, HVT models perform better than NVE models. However, NVE models could perform better in situations where there are zero order trip chains, i.e., in intercity trips.

Finally, analyzing the models over time, it was found that there is a stability on the *p* parameters over time (they are not time-dependent, or the dependence is minimal) for all models. However, the other parameters (*gamma* and *beta*) in the HVT models do not show a representative trend over time.

Future research by the authors is expected to study the effects of the aggregation level on parameters stability for freight generation, and freight distribution models. This type of analysis will enhance current freight transportation models and contributes towards a more efficient transportation planning system.

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