PLANNING IMPLICATIONS OF THE OPORTO REGION INTER-MUNICIPAL TRAVEL PATTERNS

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ABSTRACT

Travel patterns are influenced by multiple demographic, socio-economic and infrastructural variables. In order to cope with the transportation challenges faced today by urban and regional areas, the planning processes carried out for these areas must be based on a deep understanding of the role played by the different variables. This article presents a discussion about the planning implications of the inter-municipal travel patterns observed in the Oporto Region, Northern Portugal. It also presents the study of travel patterns upon which the discussion is based. This study relied heavily on classic trip generation, attraction, and distribution models. The generation and attraction models were specified using resident population, employment, and income indicators as variables. The trip distribution model was specified using as its variables trip length and trips generated/attracted by each one of the municipalities. The estimation of the models was made through multiple regression techniques. The analysis of the models revealed a strong correlation between a small number of variables and the inter-municipal travel patterns. The main issues addressed in the discussion regard the relationships between trip generation, attraction and distribution, and the spatial distribution of population and employment.

KEY WORDS

Spatial planning, compact city, urban sprawl, transportation modeling, trip generation, trip distribution, multiple regression

INTRODUCTION

The widespread idea that residential location is determined in modern cities mostly by a tradeoff between commuting cost and land cost is under severe criticism (Giuliano and Small, 1993). According to several authors, commuting costs are not relevant when compared with other locational amenities (Wheaton, 1979; Giuliano, 1989). Simultaneously, individual (and/or household) characteristics are at the moment being considered as much more significant variables to model commuting trips than macro-level variables such as population and employment location (Schwanen *et al*. 2004). The influence of geographical context upon accessibility is also being questioned, because it has been verified that

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accessibility depends mainly on individual characteristics rather than on the local urban environment (Weber and Kwan, 2003). Concurrently, it has been observed that non-work trips are increasing faster than commuting trips (Gordon and Richardson, 1989). Urban designers such as Calthorpe (1993) advocate that neighborhood design can influence non-work travel patterns. However, studies have been made showing weak empirical evidence for this argument (e.g. Boarnet and Sarmiento, 1998). Hence, it seems that highly complex relationships between household characteristics, employment location, urban form and travel patterns exist. In this misleading state of affairs, the effectiveness of land use policies to solve transport-related problems can be questioned. Despite these uncertainties, jobs-housing balance remains not only a pertinent but also a prudent strategic choice. In fact, if in an unbalanced spatial context commuting costs become critical, low wage households become exposed to extremely unsustainable conditions (as observed by Kain, 1968). Although Sato (2004) has concluded that improvements in commuting conditions lower the unemployment rate (because they raise the opportunities of job-searchers), commuting has already been considered by several authors and institutions as the most problematic aspect of the transport debate (Banister and Gallent, 1999). Therefore, if spatial planning can provide physical conditions to reduce environmental unsustainable commuting patterns and the collective dependency on gridlocked transport networks, the Precautionary Principle suggests that these conditions should be provided to urban systems, even if wasteful commuting (Hamilton, 1982) persists. Nevertheless, in this complex scenario, it should not be taken for granted that spatial planning is a manufacturer of risk-free proposals. From the 1998 Netherlands National Travel Survey, it was shown that car commuting times are higher in polycentric than in monocentric urban systems (Schwanen *et al*. 2004). This study also shows that the relocation of population and employment in the Netherlands has not generated lower commuting times. In a study for Coimbra (a monocentric Portuguese city), Ferreira *et al*. (2003) concluded that the location of population and employment growth in three satellite centres would correspond in the future to minimum total travel length and minimum total travel time. It is relevant to mention that the construction of a ring-road connecting the satellite centres was not a consideration in the study because, if the road was implemented, the number and extension of trips between those centres would rise exponentially. The conclusion to be drawn is that it is necessary to combine harmoniously spatial and transport planning to reduce transport-related environmental impacts and congestion (Banister, 1999). Polycentricism or any other urban form *per se* cannot solve transportation problems. However, land use measures are important in the interdisciplinary search for diminishing the future negative impacts of daily travel. The conclusions of this article will corroborate this.

OPORTO REGION

The Oporto Region incorporates the Oporto Metropolitan Area (OMA), composed of 9 municipalities (Oporto, Maia, Vila Nova de Gaia, Gondomar, Valongo, Matosinhos, Vila do Conde, Póvoa do Varzim and Espinho) and another 24 municipalities that maintain high functional interactions with OMA. Figure 1 presents the Oporto Region and the population distribution across the municipalities (darker grey means more population). According to latest information, the Oporto Region has 2,839,557 inhabitants. A total of 1,718,662 daily trips take place in the region during the period between 7:00 and 10:00AM, 23.6% of which are inter-municipal (INE, 2001). Figure 2 shows the number of inter-municipal trips generated and attracted by each one of the municipalities in that period. The majority of trips (75%) are shorter than 20km. The trips between OMA municipalities have high relative importance: they are 57.1% of the total inter-municipal trips. Figure 3 shows the correlation between home-to-work inter-municipal trips with all inter-municipal trips for the same period. It also shows the correlation between home-to-work inter-municipal trips with non-home-to-work inter-municipal trips. The correlation between them is strong, suggesting that the trip patterns are similar despite the trip purposes. Consequently, in this study, all inter-municipal trips were considered simultaneously and the models were calibrated using aggregate values.

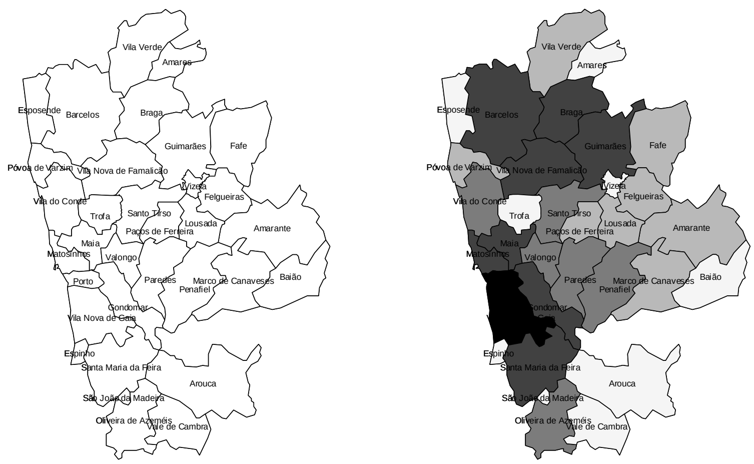

Figure 1: Oporto Region and Population Distribution (Census 2001)

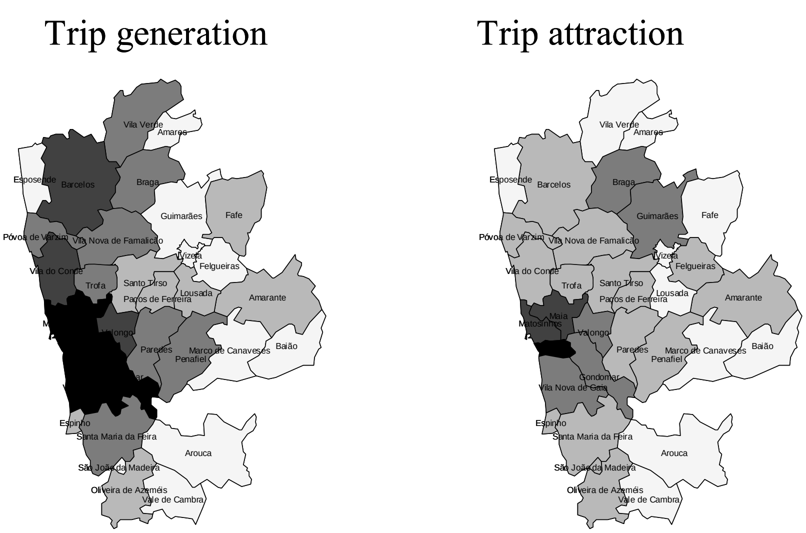

Figure 2: Inter-Municipal Trips Generated and Attracted by Oporto Region Municipalities

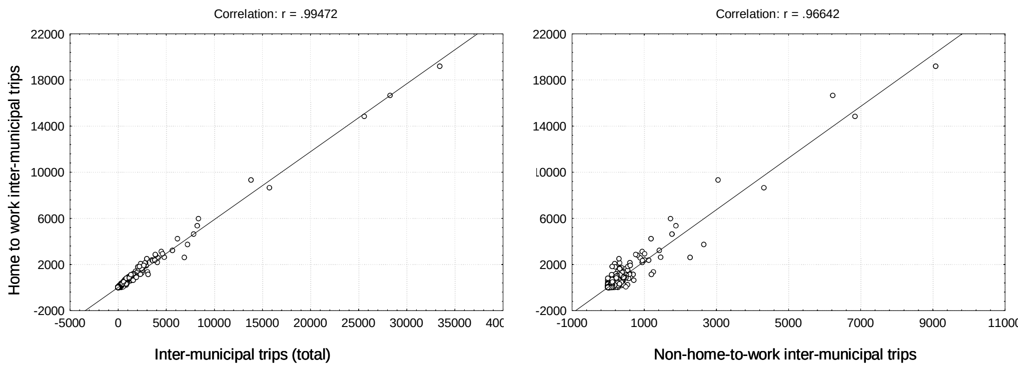

Figure 3: Correlations Between Trips According to their Purposes

TRIP GENERATION

To build the trip generation model an initial group of possible explanatory variables was identified. Afterwards, the variables with higher explanatory power that were not excessively correlated among them were selected. Finally, a trip generation model was specified using only the best non-correlated explanatory variables. The used statistical software was Statview 5.0.1 (SAS Institute, 1999). A detailed presentation of regression techniques is provided in Draper and Smith (1998). Two kinds of models were considered: linear and Cobb-Douglas. The linear model general formulation is presented in Eq. (1) and Cobb-Douglas model general formulation is presented in Eq. (2). Only the best formulation will be shown for each case.

$$Y = a + b_1 X_1 + b_2 X_2 + ... + b_n X_n \ \textbf{(1)}; \ Y = a X_1^{b_1} X_2^{b_2} ... X_n^{b_n} \ \textbf{(2)}$$

Y: dependent variable; X_1, X_2,…, X_n: explanatory variables; a, b_1, b_2,…, b_n: calibration coefficients

A trip generation model must include one or several quantitative variables capable of characterizing the municipalities as trip generators. Resident population was the chosen variable for this purpose. However, the simultaneous use of other variables to weigh the relative value of the former is recommended. More details about trip generation models are provided in Ortúzar and Willumsen (2001). The initial explanatory variables group was the following: resident population (PRT); primary sector active population rate; secondary sector active population rate; tertiary sector active population rate (PA3); population rates with more than 25 years old with high-school education; and population rates between 18 and the 24-year-olds who study in college. For these initial variables the model with the better explanatory capacity was the linear, as can be seen in Eq. (3). The model correlation coefficient R^2 is 0.805 (F = 61.89; p<0.0001). The standardized coefficients β and the coefficients t can be seen in Table 1. Notice that, for this sample, the critical value for t at a confidence level of 95% is 2.04.

$$O_J = -19667.29 + 0.10654 \ PRT + 564.04 \ PA3 \ \textbf{(3)}$$

O_J: inter-municipal trips generated in municipality J between 7:00 and 10:00 AM

Table 1: Eq. (3) Model β and t Coefficients

Variable	β	t
PRT	0.52635	5.09517
PA3	0.46861	4.53657

Some conclusions can be drawn from this model. As shown in Table 1, resident population has a very strong explanatory power. The tertiary sector active population rate is also a good explanatory variable. A residual analysis was made, comparing the differences between observed and modeled values. The objective of this analysis was to find a pattern in the differences. This criterion was used: if the residual value was in the interval given by the sample average plus or minus its standard deviation, the model was considered accurate; otherwise, the model was considered inaccurate. Braga and Guimarães modeled values were significantly larger than their observed values and these municipalities are a long distance from Oporto. Espinho has also overestimated modeled values and it is a peripheral municipality of the OMA. Simultaneously, Gondomar, Maia, Matosinhos and Vila Nova de Gaia presented small modeled values and they are central municipalities of OMA. These conclusions suggested that it was necessary to characterize spatial relations between municipalities to obtain a better trip generation model: the functional relations between a remote municipality and the others should be less intense than if that municipality was integrated in the metropolitan area. Aggregate distance to population (*DAPRT*) was elected as the new explanatory variable. *DAPRT* for a given municipality is equal to the quotient between the sum of distances to the other municipalities times their resident population and the total regional resident population. For the new group of initial variables, the model with the better explanatory power was the Cobb-Douglas, as can be seen in Eq. (4). Note the negative relation of *DAPRT* with O_J. This model presented a correlation coefficient equal to 0.874 ($F = 67.10$; $p<0.0001$), signifying that the new variable was helpful in the modeling process (the previous model had a correlation coefficient equal to 0.805). Figure 4 compares the differences between observed and modeled values. Only the municipality of Oporto has relevant residues (Figure 4, top right hand corner). The standardized coefficients β and coefficients t can be seen in Table 2.

$$O_J = 27.51\, PRT^{0.609}\;\; PA3^{1.012}\, DAPRT^{-1.232} \quad \textbf{(4)}$$

Table 2: Eq. (4) Model β and t Coefficients

Variable	β	t
PRT	0.47623	5.48019
DAPRT	-0.36424	4.21825
PA3	0.27790	3.56472

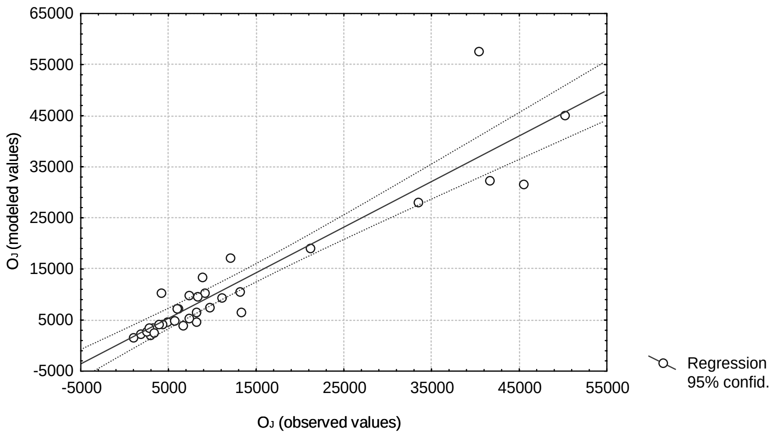

Figure 4: Observed and Modeled Values - Eq. (4)

TRIP ATTRACTION

In the trip attraction modeling process a similar methodology to the one used for trip generation modeling was followed. The initial explanatory variables were: total employment (E); primary sector job rate; secondary sector job rate; tertiary sector job rate (E3); and aggregate distance to population (*DAPRT*). The use of *DAPRT* is as logical in trip attraction modeling as in trip generation modeling: a municipality deeply integrated in a metropolitan area probably attracts more trips than a remote one. This regression shaped the model expressed in Eq. (5). Its correlation coefficient is equal to 0.884 ($F = 73.74$; $p<0.0001$). The standardized coefficients β and coefficients t can be seen in Table 3. Figure 5 compares observed and modeled values. Note that Oporto attracts much more trips than any other municipality. Excluding Oporto from the sample, the model correlation coefficient becomes equal to 0.852, which implies a small variation (3.6%). Simultaneously, the correlation coefficient between the values given by these two models is extremely high: 0.9998. Therefore, it was assumed that Oporto is not an outlier.

$$D_K = 6.7237\, E^{0.823} E3^{0.858}\, DAPRT^{-1.221} \quad \textbf{(5)}$$

Table 3: Eq. (5) Model β and t Coefficients

Variable	β	t
E	0.62597	7.47782
E3	0.19804	2.94315
DAPRT	-0.30485	3.60672

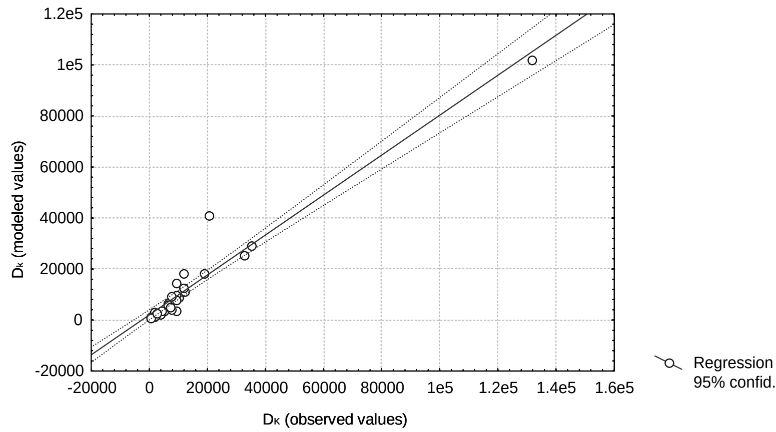

Figure 5: Observed and Modeled Values - Eq. (5)

TRIP DISTRIBUTION

To analyze trip distribution in the Oporto Region the Unconstrained Gravitational Model was chosen. The used formulations are presented in Eq. (6) - Model 1 - and in Eq. (7) - Model 2.

$$T_{JK} = a \frac{O_J^{c_O} \, D_K^{c_D}}{d_{JK}^{b}} \quad \textbf{(6)}; \quad T_{JK} = a \frac{O_J^{c_O} \, D_K^{c_D}}{e^{b \, d_{JK}}} \quad \textbf{(7)}$$

T_{JK}: trips from municipality J to municipality K (between 7:00 and 10:00AM); O_J: inter-municipal trips generated in J; D_K: inter-municipal trips attracted by K municipality; d_{JK}: distance by road between municipalities J and K; a, b, c_O, c_D: calibration coefficients

Trip distribution model calibration was made using some logarithmical transformations. The transformation made to Model 1 is shown in Eq. (8) and the transformation made to Model 2 is shown in Eq. (9). The results are in Table 4. All the models had p smaller than 0.0001.

$$\ln Tjk = \ln a + c_O \ln O_J + c_D \ln D_k - b \ln d_{JK} \quad \textbf{(8)}; \quad \ln Tjk = \ln a + c_O \ln O_J + c_D \ln D_k - b \, d_{JK} \quad \textbf{(9)}$$

Table 4: Model 1 and Model 2 Coefficients

Model	*a*	c_O	c_D	*b*	*R2*
1	41.00812	0.35346	0.59777	2.12155	0.69573
2	0.28042	0.33480	0.58456	0.05473	0.61894

Model 1 had an acceptable correlation coefficient. However, this model had a specificity, frequent in trip distribution models, which is shown in Figure 6: heteroscedasticity of residuals. Heteroscedasticity can be reduced using the variable that induces heteroscedastical behavior (Pindyck and Rubinfeld, 2000). Accordingly, Model 1 can be transformed as presented in Eq. (10) and Model 2 can be transformed as presented in Eq. (11). The objective of these transformations is to use the distance between municipalities (which is the variable that induces heteroscedasticity) as statistical regression weighting factor. The results of this process are presented in Table 5. Model 1' was calibrated using Eq. (10) and Model 2' using Eq. (11). Note the high value of Model 2' correlation coefficient. Figure 6 compares residues of Models 1 and 1', 2 and 2'. It is clear that the transformations expressed in Eq. (10) and (11) were efficient in heteroscedasticity reduction.

$$\frac{\ln Tjk}{-\ln d_{JK}} = \frac{\ln a}{-\ln d_{JK}} + c_O \frac{\ln O_J}{-\ln d_{JK}} + c_D \frac{\ln D_k}{-\ln d_{JK}} + b \quad \textbf{(10)}; \quad \frac{\ln Tjk}{-d_{JK}} = \frac{\ln a}{-d_{JK}} + c_O \frac{\ln O_J}{-d_{JK}} + c_D \frac{\ln D_k}{-d_{JK}} + b \quad \textbf{(11)}$$

Table 5: Model 1' and Model 2' Coefficients

Model	***a***	***c O***	***c D***	***b***	***R2***
1'	44.86509	0.33291	0.58058	2.04787	0.89561
2'	0.37118	0.36732	0.64925	0.08767	0.97867

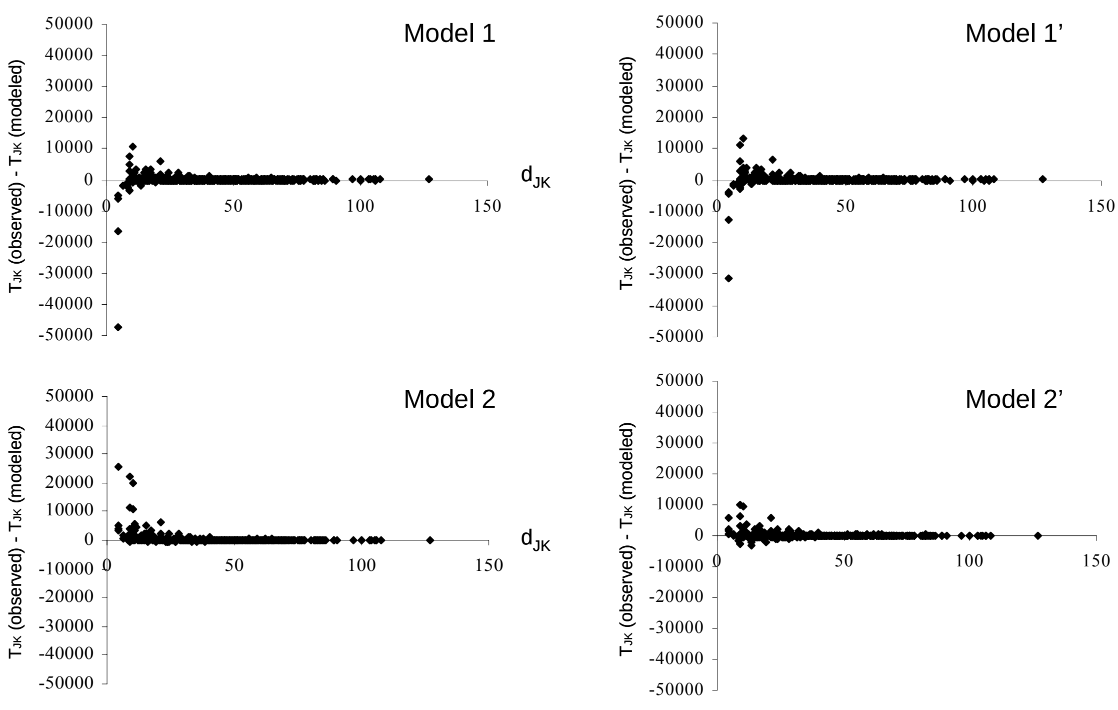

Figure 6: Model 1 and 1’, 2 and 2’ Residues

PLANNING IMPLICATIONS

The models developed in the previous sections are valuable tools for the analysis of the implications of different spatial planning strategies upon the Oporto Region inter-municipal travel patterns. It is relevant to mention here that the strategies considered below for analysis did not try to correspond to probable evolutions of the region. Instead they tried to be as "meaningful" as possible (Guhathakurta, 2001). Using the methodology suggested by this author, the objective was not to produce alternatives inspired by *probability*, but to proportionate some meaningful and unexpected insights. Figure 7 graphically represents the relationship between the population of the municipalities and aggregate distances to population (the values are normalized). It is clear that Oporto is not only one of the most populous municipalities, but also the one with smaller aggregate distance to population. A detailed analysis reveals that most OMA municipalities share this characteristic. Compact city has been advocated as the spatial configuration that promotes shorter journeys (CEC, 1990). On the contrary, urban sprawl is often considered responsible for the current unsustainable travel patterns. To investigate these claims, a first hypothesis (H1) was considered, in which it was assumed that the next 10 years regional population and regional employment growths would be concentrated in OMA municipalities. These growths were distributed across these municipalities in proportion to the distribution observed in 2001. A population forecasting linear model was used, which predicted a regional population growth of approximately 10% for this 10-year time period. It was also assumed that future employment rates would be equal to those observed in 2001. The second hypothesis (H2) was to distribute, using the same rules, population and employment growths in all municipalities except in those belonging to OMA. The third and last hypothesis (H3) was to distribute population and employment growths in all municipalities of the Oporto Region. The results are shown in Figure 8: total inter-municipal trips (T_{JK}) and total inter-municipal trip length ($T_{JK}.d_{JK}$) were used as cost indicators. H0 correspond to 2001 conditions. Values are normalized. According to Figure 8 it is patent that concentration in OMA (hypothesis H1) is the worst hypothesis. The best one would be to distribute population and employment in all municipalities except in those belonging to OMA (hypothesis H2). Despite the fact that 10% of total regional population is equal to 283,956 inhabitants, this hypothesis generates a number of inter-municipal trips very similar to those observed in 2001 (H0) and generates a similar inter-municipal total trip length.

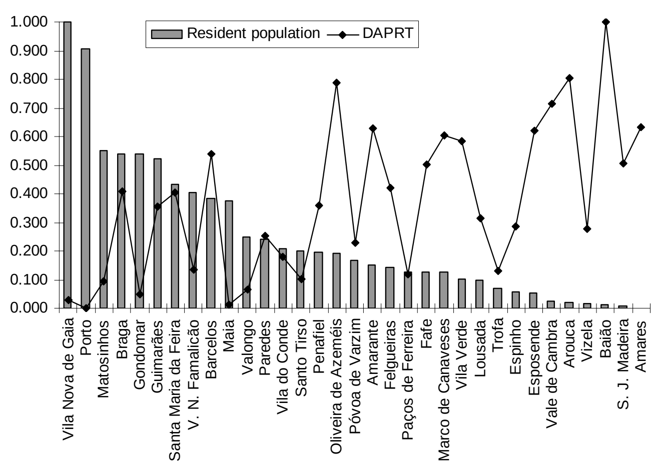

Figure 7: Population of the Municipalities and Aggregate Distance to Population (Normalized)

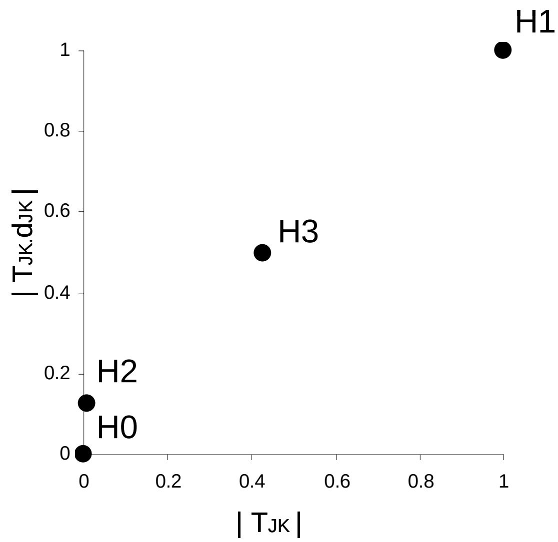

Figure 8: Evaluation of the Development Hypotheses

CONCLUSION

This paper presented an analysis of the Oporto Region inter-municipal travel patterns. This analysis allowed the identification of the specific demographic, social and economic municipal characteristics that determine those patterns. Despite using a small group of macro-level variables (resident population; total employment; tertiary sector employment rate and aggregate distance to population), accurate inter-municipal trip models were obtained. Concurrently, the high correlation between home-to-work and non-home-to-work trips demonstrated that, for this region, it is acceptable to model them aggregately. These models allowed some hypotheses testing for the consequences of specific future regional configurations. This testing suggested that compacting OMA would generate very high inter-municipal mobility levels in the region. However, this conclusion must be analyzed with caution. The hypotheses are straightforward, they are possibly in the frontiers of models' validity and modal split was not considered. Nevertheless, they are not only pedagogical in terms of the consequent reservations that planners and decision-makers must reflect on: according to the results, metropolitan compaction is not at all a risk-free development strategy. They are also very rich in terms of the conclusions that can be drawn. This main conclusion is proposed: if trip generation and trip attraction depends on global proximity measures (*DAPRT*, in Eq. 4 and 5) and if trip distribution depends on the distance between trip origin and destination (d_{JK}, in Eq. 6 and 7), the concentration of population and employment in an already dense metropolitan area tends to generate very intense inter-municipal travel patterns. Further research should evaluate if this is desirable for OMA and for the Oporto Region.

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