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Paper title: **Spatial structure effects on intercity freight demand in developing countries: model and application**

Author(s) name(s): Amilia Aldian and Michael A P Taylor

Organisation(s): Transport Systems Centre
University of South Australia

Contact details: Transport Systems Centre
University of South Australia, City East Campus

Postal address: GPO Box 4271 Adelaide, SA 5001

Telephone: +61-8-8302 1778
Facsimile: +61-8-8302 1880
email: Amiyy001@students.unisa.edu.au

Abstract (200 words):

The objectives of this paper are to find methods that account for spatial structure effects using aggregate data, and to determine the effects of spatial structure on freight demand. Spatial structure affects travel decisions, if it is not included in the model, then it could lead to a biased model. Spatial structure effects are usually studied using competing destinations models, which need disaggregate data. This paper presents the adaptation of competing destinations model together with intervening opportunities models to account for spatial structure effects using aggregate data. The application of the model shows that competing effects occur at origin zone, while agglomeration effects occur at destination zones.

Introduction

The objectives of this paper are to find a method to account for spatial structure effects using aggregate data, and to examine the effects of spatial structure on freight demand.

There are three reasons behind this research. First, spatial structure effects are usually modelled using disaggregate data, which are rarely available in developing countries. Second, the knowledge of the effects of spatial structure on transport demand is an important input in transport system and location planning. Third, freight demand reflects the extent of spatial interaction between cities so that it could be used to examine spatial structural effects.

Freight demand is usually considered as a derived demand. Freight interaction between two different spatial locations will occur when there is a demand for a commodity in one location and an oversupply of that commodity in another location. Another important determinant for freight demand is of course transport impedance. As intercity road networks do not usually offer many alternative routes from one location/city to other locations/cities, the city position in the road network could be a key determinant of freight demand. Applications of freight demand models in developing countries tend to ignore this variable. Fotheringham (1983) stated that when a spatial structure variable is not included in the model, then spatial structure is implicitly reflected in the distance component, which is then necessarily biased.

In Indonesia and probably also in other developing countries, most cities grew along the main road network as local road transport networks were usually not well established in the initial urban developments. The trend is still continuing where new activity centres emerge along main roads, although other smaller roads have been improved and some new roads have been built. These conditions may be due to higher level of accessibility offered by main roads.

The understanding of spatial structure effects on transport could assist planners in selecting locations of activities that have high accessibility and could minimise transport costs to all locations in a network. On the other hand, planners also could decide to set priorities in expanding the road network that will also produce least transport costs in the whole network.

Following this introduction, there are five other sections to the paper. Section two describes the study area and the data, section three reviews the theories and application of spatial structure models, section four explains the modelling framework, section five gives the application results and section six gives conclusions.

Study area and freight demand data

Socio-economic conditions

The study area of this research is Central Java province in Indonesia. Based on the data from the Central Statistics Bureau of Central Java (1997, 2002), the socio-economic conditions of the Central Java province can be summarised as follows:

1. Central Java province is one of six provinces on Java Island. The Central Java province is divided into smaller administrative boundaries called kabupaten (sub-province) and kota madya (municipality). There are 29 sub-provinces and 6 municipalities. Overall, the total

area of the Central Java province is 3.25 million hectares, or around 25.04 per cent of the total area of the Java Island, or 1.7 per cent of the total area of Indonesia.
2. Central Java province was the third most populated province in Indonesia with 31.06 million populations in 2001. The population was distributed such that the municipalities had more population than the sub-provinces, and the capital cities of the sub-provinces had more population than the rest of the area of the sub-provinces. The population growth was one per cent per year based on the 1996 national socio-economic survey.
3. The economic growth, which is indicated by gross regional domestic product (GRDP), was relatively high in 1996 (7.3 per cent). This growth declined significantly in 2001, where it was only 3.33 per cent per year. This decline was believed to be the impact of the economic crisis started in 1998, from which Indonesia is still struggling to recover. The GRDP was mainly determined by manufacturing industries and agriculture sectors in both 1996 and 2001.
4. There was a gap of income between city and rural area and also between sub-provinces in Central Java province. For instance, in 1995 (before economic crisis in 1998) the income per capita of the city of Semarang (the capital city of Central Java province) was 4,398,776 Indonesian Rupiahs, while the average of income per capita of other sub-provinces was only 1,469,524 Indonesian Rupiahs.

Road network conditions

All capital cities of the sub-provinces are connected within the Central Java road network. Overall, there were 1,215 km of national roads and 2,590 km of provincial roads. The width of arterial roads was varying from 5 m to 15 m, and the width of collector road was varying from 4 m to 14 m. By the year 2000 only 41 per cent of all the roads were in good condition (the Central Statistics Bureau of Central Java, 2002).

From the demand point of view, many intercity roads in the Central Java network had mixed traffic from non-motorised vehicles to heavy trucks and buses, which could also indicate that the roads had mixed functions from local to arterial. One output of the national origin destination study in Indonesia in 1996 was that the percentage of local traffic on intercity roads in Central Java province was relatively high. The percentage of motorcycle and non-motorised vehicles from total traffic on intercity roads reached a number of 12.4 per cent and 30.8 per cent, meanwhile the share of freight transport was relatively high namely 17.1 per cent (Ministry of Communications of Indonesia, 1997).

Freight demand data

The freight demand data used to calibrate the models are the result of national origin destination survey of Indonesia undertaken by the Ministry of Communications of Indonesia in 2001. The survey provides inter sub-provinces aggregate freight demand in tonnes/year, where the data are not divided by commodity. The study area of this study is divided into 35 zones; so that there are 1190 inter sub-provinces freight flows (Ministry of Communications of Indonesia, 2002).

Modelling spatial structure effects: a review

The effects of spatial structure in spatial choice are commonly represented by a variable called accessibility. Accessibility value indicates the ease (benefits or costs associated with travel) of people or commodities to travel from specific locations to other locations. Accessibility could also figure spatial structure and transport network characteristics. Thus, we could examine the connection between transport network and spatial structure in order to determine the effects of one upon the other using accessibility (Primerano, 2001).

Spatial structures effects can be examined using a disaggregate approach and an aggregate approach. In a disaggregate approach, several models have been applied such as logit models (Pellegrini and Fotheringham, 2002). In an aggregate approach, researchers usually employed gravity-type models (Guldmann, 1999).

Pellegrini and Fotheringham (2002) stated that spatial and aspatial choices differ in processing information. The number of alternatives is commonly much larger in spatial choices, so that a traditional multinomial logit (MNL), which requires individuals to simultaneously evaluate all alternatives, is inappropriate. It could happen in the MNL applications that a destination with maximum utility is not selected because it is never evaluated. Therefore, a weight of the utility of an alternative is needed. The weight measures the probability of the alternative is actually evaluated. The MNL model then become:

$$P_{in}(j) = \frac{\exp(V_{ijn})L_{in}(j \in G)}{\sum\limits_{k=1}^{m} \exp(V_{ikn})L_{in}(j \in G)} = \frac{\exp(V_{ijn})c^{\alpha}}{\sum\limits_{k=1}^{m} \exp(V_{ikn})c^{\alpha}} \tag{1}$$

where $P_{in}(j)$ is the probability of individual n (from origin i) selecting destination j, V_{ijn} is the utility of destination j viewed by individual n in origin i, and $L_{in}(j \in G)$ is the likelihood that alternative j is in individual n's (from i) chosen cluster G. This general model is known as the competing destination model, where c denotes the competing measure and α is an index to measure the level of hierarchical information processing, which needs to be estimated. Competing effects are present if $\alpha<0$, which means that alternatives in close proximity to others are less likely to be selected. Agglomeration effects are present if $\alpha>0$, when the attraction of a cluster increases as the number of alternatives in it increases. If $\alpha=0$ then there are no competing or agglomeration effects.

If we assume people use a hierarchical information processing strategy by selecting clusters of alternatives first before selecting a destination from within a selected cluster, then potential accessibility measures, which describe the accessibility of a destination to all other destinations, can be used. Pellegrini and Fotheringham (2002) suggested using a Hansen type potential accessibility:

$$L_{in}(j \in G) = \left[\frac{1}{M-1} \sum_{\substack{k \\ k \neq j}} \frac{W_k}{d_{jk}} \right]^{\alpha} \tag{2}$$

where M is the total number of alternatives, W_k is the mass of destination zone, and d_{jk} is the distance from j to k (all other alternatives available to person n and origin i). Large values mean alternatives are in close proximity and low values mean alternatives are spatially isolated.

Guldman (1999) accounted for the effects of spatial structure on the inter-city telecommunication flows. The effects were measured using competing destination (CD) factors and intervening opportunities (IO) factors. IO factors are based on the idea of Stouffer (1940) who argued "the number of persons going a given distance is directly proportional to the number of opportunity at that distance and inversely proportional to the number of intervening opportunities."

Guldman's (1999) model was a gravity-type model. His basic model is as follow:

$$F_{ij} = f(F_{ji}, D_{ij}, P_{ij}, XO_i, XD_j, A_{ij}) \tag{3}$$

where F_{ij} is measure of the flow from location i to location j, D_{ij} is the distance from i to j, P_{ij} is telephone price per unit of flow from i to j, and XO_i and XD_j variables characterising the flow-originating market at i and the flow-receiving market at j, while A_{ij} represents CD/IO factors. He concluded that spatial structure has significant effects on telecommunication flow patterns and that all destinations compete.

Model framework

The development of freight demand models mostly are at an aggregate level in which the classic four-stage model is modified to suit the characteristics of freight (Ortuzar and Willumsen, 1994). We use another kind of aggregate demand model namely the direct or simultaneous demand model to account for the spatial structure effects on freight demand.

The direct demand models are closely related to the general econometric models of demand. The application of the models claimed to avoid some of the weaknesses of the conventional four-step model of travel demand. The attractiveness of direct demand models is that they calibrate simultaneously trip generation, distribution and mode choice, including attributes of competing modes and a wide range of level of service and activity variables.

There has been an application of direct demand model for estimating regional road freight movement in Java Island, Indonesia (Sjafrudin et al, 1999). They concluded that the application of the model is inconclusive, where the model cannot reach best fit between observed and estimated data.

The application of direct demand models has been mainly in the inter-urban context, with very few applications in urban areas as these models are claimed to be useful for demand analysis where the zones are large.

There are some models with different forms that have been applied in intercity studies (see Ortuzar and Willumsen, 1994). Another model was developed and applied by Smith (1977) to predict rural round trips by passengers per month as a function of level of transit service and total population able to access the service. The form of the direct demand model is essentially linear or quasi-linear statistical regression:

$$T_{ijmr} = \alpha_{ijmr} \prod X_{ijmr}^{k} \beta_{ijmr}^{k} \tag{4}$$

where α_{ijmr} and β^{k}_{ijmr} are parameters to be calibrated. The X^{k}_{ijmr} represent various attributes of demand zones, destination, modes and routes (Oppenheim, 1996). The direct demand model is also one of gravity-type models. An example of common form of the model is like the one developed by Kraft (in Ortuzar and Willumsen, 1994) as follows:

$$T_{ijk} = \theta_k (P_i P_j)^{\beta_{k1}} (I_i I_j)^{\beta_{k2}} \prod_m [(t_{ij}^m)^{\alpha_{km}^1} (c_{ij}^m)^{\alpha_{km}^2}] \tag{5}$$

where P is population, I is income, t and c are travel time and cost of travel between i and j by mode k, and θ, β, and α are parameters to calibrate. The problem with this form is that as long as travel costs from i to j are equal to travel costs from j to i, then T_{ij} should be equal to T_{ji}, which rarely happens with real data. To overcome this limitation, Wirasinghe and Kumarage (1998) put restrictions on their model so that the model is for one direction only where $P_i \geq P_j$.

Another method to overcome that limitation is by reforming the model structure into the following form (Manheim, as cited in Ortuzar and Willumsen, 1994):

$$T_{ijk} = \theta_k P_i^{\beta_{k1}} P_j^{\beta_{k1}} I_i^{\beta_{k2}} I_j^{\beta_{k2}} \prod_m [(t_{ij}^m)^{\alpha_{km}^1} (c_{ij}^m)^{\alpha_{km}^2}] \tag{6}$$

The problem with equation 6 is that P_i, P_j, I_i, and I_j must all be statistically significant. If that condition cannot be fulfilled, then it is possible to have only P_i and I_j, or P_j and I_i in the equation.

In the disaggregate approach explained in the previous section, spatial structure effects are included by giving weights to the utility of alternatives. In this paper we try to apply the concepts of disaggregate approach using aggregate data. As a utility value is not available in the aggregate approach, the weight is then attached to variables considered to affect freight demand.

The concepts of competing destinations and intervening opportunities are also applied by using an accessibility measure. The variables of destination zones are weighted using a competing destination factor and the variables of origin zones are weighted using an intervening opportunities factor.

In this paper the competing destinations factor (C_j) is defined as total distance from other destinations to destination j, and intervening opportunities factor (O_i) is defined as total distance from other destinations (except j) to origin i.

$$C_j = \sum_{\substack{k \\ k \neq i}} D_{kj}^{\lambda j} \;; \tag{7}$$

and

$$O_i = \sum_{\substack{k \\ k \neq j}} D_{ki}^{\lambda i} \tag{8}$$

Figure 1 and figure 2 illustrate the basic idea of the competing destination model and the intervening opportunities model applied in this paper.

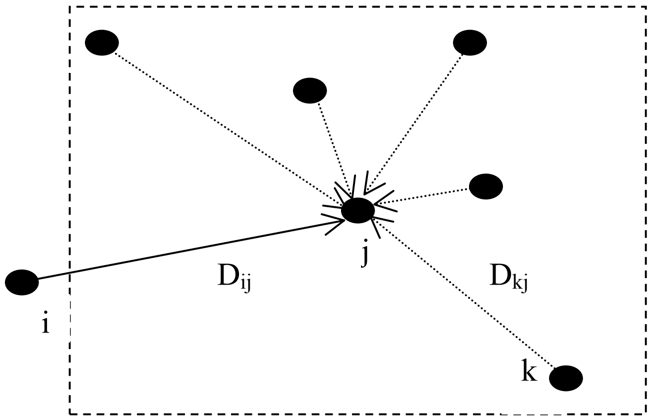

Figure 1 Competing destination model

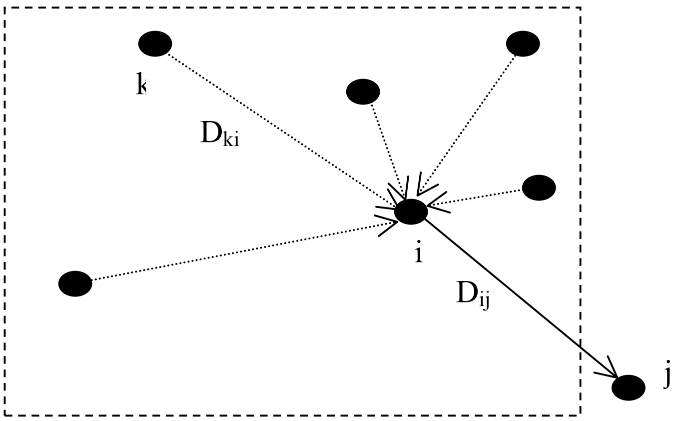

Figure 2 Intervening opportunities model

By weighting variables with C_j and O_i, then P_iP_j is not equal to P_jP_i, as the variables characterising a zone will have different values depending on its position, whether as origin or destination. This approach then reduces the limitation of equation 5. Equation 5 then become:

$$T_{ijk} = \theta_k((P_iO_i)(P_jC_j))^{\beta k1}((I_iO_i)(I_jC_j))^{\beta k2}\prod_m[(t_{ij}^m)^{\alpha_{km}^1}(c_{ij}^m)^{\alpha_{km}^2}] \tag{9}$$

The distance exponents (λ_j and λ_i) may be determined by trial and error process to find the best fit of the model.

For both origin and destination zones, competing effects are present if $\lambda_i>0$ and $\lambda_j>0$. For origin zones, competing effects mean that origin zones in close proximity to others tend to generate fewer trips. For destination zones, competing effects mean that alternatives in close proximity to others tend to attract fewer trips.

For both origin and destination zones, agglomeration effects are present if $\lambda_i<0$ and $\lambda_j<0$. For origin zones, agglomeration effects mean that origin zones in close proximity to others tend to generate more trips. For destination zones, agglomeration effects mean that alternatives in close proximity to others tend to attract more trips. If $\lambda_i=0$ and $\lambda_j=0$ then there are no competing or agglomeration effects.

Empirical analysis results

Equation 9 is a model form that accounts for the effects of spatial structure on travel demand. As well as the distances between cities, the available socio economic variables considered to affect freight demand are population, number of households, gross regional domestic product (GRDP), GRDP of agricultural sector, GRDP of manufacturing industries, and GRDP of trade activities.

We first develop a model without incorporating the competing destination factor and the intervening opportunities factor ($\lambda_j = 0$ and $\lambda_i = 0$) as a comparative benchmark. In order to have a model in which all variables are significant, the backward elimination technique is applied (Taylor et al, 1996). The following are the name of variables: DIS for distance, GDP for GRDP product, POP for population product, HOU for household product, AGR for GRDP of agricultural sector product, IND for GRDP of manufacturing industries product, and TRA for GRDP of trading activities product.

The benchmark model is as follow (T_{ij} denotes freight demand from i to j in tonnes/year):

$$\begin{array}{llllll} LnT_{ij} = & -4.723 & -1.271 LnDIS & +0.705 LnGDP & +0.356 LnHOU & -0.266 LnAGR \\ & (-2.115) & (-15.640) & (7.844) & (2.031) & (-3.389) \end{array} \qquad (10)$$

Although all t values (in parentheses) are significant, the R^2 of 0.307 for this model is quite low. It might due to the data quality where of the 1190 origin destination pairs, there are 329 origin and destination pairs that have no freight flows at all, i.e. the freight demand is 0.

This might also be due to aggregation bias as freight demand data are aggregated without specifying commodity groups. According to Nam (1997), the freight transport is highly diverse, which affects the choice of mode and also destination. As each commodity could have different characteristics so that each commodity should have different form of model.

Another likely factor responsible for the poor performance of equation 10 is that travel impedance needs to be defined more precisely using detailed forms such as generalised cost instead of using travel distance.

The trial and error process step in finding the distance exponents (λ_j and λ_i) values and most importantly the spatial structure effects on freight demand is done by combining values from

–1 to 1 for both competing destination factor and intervening opportunities factor. The results are summarised in table 1.

Table 1: The summary of simulation results (*t* values are in parentheses)

Variables	Model 1 λ_j=-1, λ_i=0	Model 2 λ_j=-1, λ_i=-1	Model 3 λ_j=0, λ_i=-1	Model 4 λ_j=1, λ_i=1	Model 5 λ_j=1, λ_i=0	Model 6 λ_j=0, λ_i=1	Model 7 λ_j=-1, λ_i=1	Model 8 λ_j=1, λ_i=-1
Constant	1.259 (0.825)	9.476 (11.637)	4.814 (3.575)	-14.098 (-4.226)	-4.846 (-2.048)	-16.77 (-4.483)	-5.721 (-2.694)	2.149 (1.191)
LnDIS	-1.246 (-15.432)	-1.222 (-14.997)	-1.241 (15.128)	-1.307 (-15.940)	-1.280 (-15.548)	-1.298 (-16.060)	-1.269 (-15.788)	-1.248 (15.077)
LnGDP	0.717 (7.990)	0.756 (11.216)	0.734 (10.894)	0.690 (7.647)	0.758 (11.173)	1.115 (4.690)	0.718 (8.063)	0.675 (10.275)
LnPOP								
LnHOU	0.362 (2.095)					0.509 (2.853)	0.423 (2.452)	
LnAGR	-0.246 (-3.179)	-0.104 (-2.221)	-0.127 (-2.761)	-0.317 (-3.911)	-0.166 (-3.788)	-0.379 (-4.547)	-0.307 (-3.911)	-0.161 (-3.546)
LnIND								
LnTRA						-0.325 (-1.836)		
R^2	0.312	0.294	0.288	0.305	0.293	0.320	0.321	0.279

The main conclusion from Table 1 is that spatial structure affects freight demand in the study area. This conclusion is supported by the improvement made by model 1, model 6, and model 7 compared to the benchmark model (equation 10).

Model 1 shows that agglomeration effects are present in the destination zones as $\lambda_j<0$ and the absence of intervening opportunities factor improves the benchmark model by 0.05 per cent. On the other hand, model 6 shows that competing effects are present in origin zones as $\lambda_i>0$ and the absence of competing destination factors improves the benchmark model by 1.3 per cent.

Model 1 explains that a zone located in close proximity to others tends to attract more freight demand. While, model 6 explains that a zone located in close proximity to others tends to produce fewer freight demand. The best model is achieved when competing destination factor of –1 and intervening opportunities of 1 are given (model 7), it improves the benchmark model by 1.4 per cent.

The result of model 1, model 6, and model 7 might prove that the effects of intervening opportunities factors are stronger than competing destinations factor. An attempt is made to strengthen this conclusion by increasing the value of λ_j and λ_i.

An increase in λ_j does not gain much improvement, while an increase in λ_i does. This clearly supports the conclusion that the effects of intervening opportunities factors are stronger than competing destinations factor. These results are shown in Table 2.

Table 2: The summary of simulation results (*t* values are in parentheses)

Variables	Model 9	Model 10	Model 11
	λ_j=-2, λ_i=1	λ_j=-2, λ_i=2	λ_j=-1, λ_i=2
Constant	3.682 (2.930)	-0.249 (-0.152)	-9.382 (-3.714)
LnDIS	-1.241 (-15.400)	-1.253 (-15.512)	-1.281 (-15.883)
LnGDP	0.809 (12.231)	0.784 (12.155)	0.707 (7.934)
LnPOP			
LnHOU			0.354 (2.091)
LnAGR	-0.144 (-3.302)	-0.183 (-4.305)	-0.328 (-4.121)
LnIND			
LnTRA			
R^2	0.311	0.310	0.318

GRDP of the agriculture sector appears in all models with negative sign. This might be because the agricultural products are consumed locally, or transported to external zones, which are not taken into account in this study. In fact, producers in Central Java fill some needs for agricultural products in the major cities in Java Island such as Jakarta.

Overall, the method presented in this paper is valid for use in accounting for spatial structural effects on freight demand and also on any spatial interactions with the use of aggregate data.

Conclusion

The effects of spatial structure on freight demand has been analysed using a modified competing destinations model and intervening opportunities. The modification is made to suit those models with aggregate data. The modification gives a valid result, and can be used to account for spatial structural effects on spatial interactions.

The application of the modified model has improved the performance of the traditional direct demand model both practically and theoretically. This is demonstrated by the improvement made by the modified models compared to the traditional model. The results indicate that agglomeration effects are present in destination zones and competing effects are present in the origin zones.

We still need further research to validate this model by applying to other types of spatial interactions such as intercity passenger travel and by taking into account all variables representing impedance such as travel time, travel costs, mode reliability, etc. Another important research to improve the model presented in this paper is by incorporating different accessibility measures.

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