REGIONAL FREIGHT TRANSPORT DEMAND MODELING IN THE JAVA ISLAND

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Abstract : This paper presents findings of a study on the development of models of the demand for regional or intercity freight transport in a particular area, namely Java Island. The modeling approach employed is usually called simultaneous or direct demand modeling. In this approach variables of characteristics of the freight, regional conditions, and existing transport systems conditions are simultaneously included in the models. The models were calibrated against data of the National Origin-Destination (O-D) Survey 1996. The O-D data provide annual inter district (called *Kabupaten)* transport demand. The *Kabupaten* was used as the unit area of analysis. *Kabupatens'* social economic data were obtained from the available statistics and the data of transport systems attributes were compiled from several freight transport operators. The study conducted the calibration on a number of model formulations. This included a number of alternative sets of social economic variables and transport systems attributes. Several social economic and transport variables have been identified as determining explanatory factors of the demand for freight transport. The data, however, made it only possible to develop single-mode models : each model only specifically includes one particular mode's attributes. The development on the multi-mode models has appeared to be inconclusive, as the calibration results were not significant.

1. INTRODUCTION

In the last decade until 1997, when the economic crisis began, the freight transportation in the area grew quite rapidly with the annual growth in the range of 7 – 22 %. The growth was triggered by economic progress, especially of the industrial sector. This paper outlines a research aimed at developing models which relate the demand for freight transport to some economic factors representing the regional condition. The research dealt with the regional or intercity freight transport in the Java Island.

The modeling approach employed is usually called direct or simultaneous demand modeling. In this approach variables of characteristics of the freight, regional conditions, and existing transport systems conditions are simultaneously included in the models. The resulting models are therefore sensitive to social-economic and transport policy changes that are represented by the variables.

The standard approach of transport demand modeling is widely known as the Four-stage Model consisting of trip generation, trip distribution, modal split, and trip assignment. These four stages are normally carried out sequentially. But, the direct demand models analyze the stages simultaneously and absorb them into a single model. Usually only three out of the four stages, however, explicitly appear in these models. They compute the number of trips between each pair of regions by each mode (that is trip generation, distribution, and modal split), but do not indicate the route choice (assignment). This implicitly assumes that on every pair of regions or cities only one route is available for each mode. This is a realistic assumption since unlike dense street networks in urban areas the intercity roads especially of medium or long distance (say more than 200 km) rarely have alternative routes.

The above mentioned modeling approach was initially developed to model intercity passenger transport demand. Quand & Baumol (1966), McLynn & Woronka (1969), and Monsod (1966, 1967) among others developed variants of the direct demand models for the Northeast Corridor Transportation Project of the United States and similar approaches were later also applied in some other countries. Kraft and Wohl (1967) developed the model for the urban transportation. In Java Island the models have been applied to intercity passenger transport demand in the Java – Sumatra corridor (Sjafruddin, 1992, 1997).

Application of the model to freight transport demand has been proposed by researchers (Perle, 1965; Mathematica , Inc., 1965-1967, as quoted by Kanafani, 1983). A similar approach was applied by Soliman et.al (1990,1991) to model commodity movement in Canada. Within freight transport demand modeling, in one way, the models are classified as aggregate spatial interaction models (Kanafani, 1983) which distribute deficits and surpluses of demand for commodities at various points in space.

2. BASIC APPROACH

2.1 Model Specification

The demand for freight transport is considered to be mostly of economic motivation. The use of econometric approach to explain the relationship between the demand for freight transport and other economic variables forms the basic method of analysis.

The relationship of the factors forming the direct demand models may be regarded as extensions of the gravity models by adding the modal split function to the models. The general form of the model can be specified as follows :

$$T_{ijmk} = K \,.\, f(.) \,.\, g(.) \,.\, h(.) \qquad (1)$$

where :

T_{ijmk} = volume of commodity k produced in region i and transported to region j by mode m

K = a constant

f(.) = the social economic terms representing the potential of demand for freight transport

g(.) = the general impedance

In contrast to the abstract mode model, the specific mode model considers "names" of the modes important, besides their attributes. In the specific mode model therefore estimates of parameters are unique for each mode.

3. MODEL CALIBRATION

3.1 The Model

Models to be calibrated consist of specific mode and abstract mode models. This owes to data that could be collected from related sources. Data of inter-kabupaten freight movement from the National O-D (Origin-Destination) Survey 1996 were only compiled in total tones of commodity and not categorized into types of commodity. This limits the analysis since distribution of commodities or competition among the available modes can only be looked after through each specific commodity as each commodity has different level of interdependency from one mode to another. To develop abstract mode models, which is multi modal, requires data by classified commodities. In principle only specific and single mode models were possible to be calibrated against the available data. The abstract mode model calibration against total commodity flows was carried out anyway, as described in the following sections, just to seek indications of the model performance.

The basic form of the specific mode model is as follows :

$$T_{ijm} = f(X_{ik}, X_{jk}, Y_{mn}), \quad k = 1..K, \ n = 1..N \tag{3}$$

where :

T_{ijm} = volume of freight flow from city i to j by mode m (tones/year)
X_{ik} , X_{jk} = social economic variable of origin city i and destination j
Y_{mn} = service attribute of mode m
K = the number of social economic variables included
N = the number of mode service attributes included

And the basic form of the abstract mode model is as follows :

$$T_{ijm} = f(X_{ik}, X_{jk}, Y_{mn}, Y_{bn}), \quad k = 1..K, \ n = 1..N \tag{4}$$

where :

Y_b = attribute of the best mode (cheapest or fastest)
other notations = the same as above.

Mathematical forms of the models are power functions with two variants as follows :

$$T_{ijm} = \alpha_0 (X_{i1})^{\alpha 1} (X_{j1})^{\alpha 2} \ldots (Y_{m1})^{\beta 1} (Y_{m2})^{\beta 2} \tag{5}$$

or

$$T_{ijm} = \alpha_0 (X_{i1} X_{j1})^{\alpha 1} (X_{i2} X_{j2})^{\alpha 2} \ldots (Y_{m1})^{\beta 1} (Y_{m2})^{\beta 2} \tag{6}$$

Various sets and combination of variables were tried in the model calibration. Variables of social economic employed in the models included :

P = population (in 1,000)
N = GRDP (Gross Regional Domestic Product, in Rp x 10^9)
I = GRDP per capita (in Rp x 10^3/person)
M = GRDP of manufacturing industries (in Rp x 10^9)

$h(.)$ = the modal split terms

The specification in (1) is based upon following assumptions:
1. the total amount of commodity movement between a pair of cities is a function of certain social economic characteristics of these cities and certain characteristics of the transport services which are available between the two cities;
2. the utilization of a particular mode of transport is based on comparison of certain characteristics of the available modes.

The variables included in the models are essentially justified from an econometric point of view. Standard statistic, such as demographic and economic characteristics, and transport service attributes are mostly employed as explanatory variables. Function f(.), g(.), and h(.) may vary depending on the number and types of variables and mathematical forms. Each of these functions may not explicitly appear in the equation but rather in a combined form.

A variant of the model proposed by Mathematica, Inc. (1967-1969: quoted by Kanafani, 1983, Ch. X) is as follows :

$$T_{ijm}= K\, P_i^{\alpha 1}\, P_j^{\alpha 2}\, Y_i^{\alpha 3}\, Y_j^{\alpha 4}\, M_i^{\alpha 5}\, M_j^{\alpha 6}\, N_{ij}^{\alpha 7}\, (T_{ijb})^{\beta 1}\, (T_{ijm}^{\,r})^{\beta 2}\, (C_{ijb})^{\gamma 1}\, (C_{ijm}^{\,r})^{\gamma 2} \qquad (2)$$

where :

T_{ijm} = volume of freight flow from i to j by mode m
P_i , P_j = population of origin i and destination j
Y_i , Y_j = gross regional product of i and j
M_i , M_j = industrial character indexes
T_{ijb} = least shipping time from i to j
$T_{ijm}^{\,r}$ = travel time by mode m divided by the least travel time
C_{ijb} = least cost of shipping from i to j
$C_{ijm}^{\,r}$ = cost of mode m divided by the least cost
N_{ij} = number of modes serving i and j.
K, α, β, and γ = parameters

The usefulness of this model, which is an aggregate model and utilizes aggregated data, is considered rather to be a tool to evaluate the impacts of policy changes to the existing system than to generate absolute estimates of freight tonnage.

2.2 Abstract Mode and Specific Mode Model

Such model as specified in (2) is called abstract mode model. This terms, first used by Quandt & Baumol (1966) to develop the intercity transport demand model, refers to a concept that a mode can be thought of in abstract terms if it is characterized only in terms of attributes such as travel time, cost, service frequency or other convenience measures, etc. The abstract mode theory "presupposes that individuals are characterized by a **modal neutrality**..." implying that " a modally neutral person chooses among modes purely on the basis of their characteristics and not on the basis of what there are called." Any abstract mode is expressed by its service attributes rather than its name and estimates of parameters apply to all modes. The models developed by Soliman et.al (1990,1991) are also essentially abstract mode models.

M' = industrial index (ratio GRDP of industries to total GRDP, in %)
S_i , D_j = Freight Surplus/Trip production of city i, and Deficit/Trip Attraction to j (in tones/year)

And the mode service attributes included :
H_{ij} = average travel time from city i to j (in minutes)
C_{ij} = transport cost from city i to j by a certain mode (in Rp/ton)

3.2 Data

Most data concerning regional and transport systems condition were collected from related institutions. Some variables of transport service characteristics needed, however, to be surveyed from the real operators. Principal data for the purpose of model calibration consist of following aspects.

a. *Zoning*
Zoning of the study area follows administrative boundaries. A zone is essentially defined as one kabupaten (district). The main reasons are that statistical data are given by administrative boundaries and the intercity freight movement data are also compiled by kabupatens. The whole Java was then comprising 79 zones. This especially applies in relation to the road transport network. For other transport networks the zoning was adjusted taking the availability of the networks into consideration.

b. *Freight Movement*
These data were drawn from the National O-D Survey 1996 consisting of inter-kabupaten annual trips. Of the available data, the freight movement data by rail were considered as not representing well the actual condition and therefore excluded from further analysis. The models calibrations were then conducted for road, air, and sea mode. The freight movement data were only given in total tones transported by each mode, but not categorized into types of commodities. Figure 1 to Figure 3 show the desire lines of inter-kabupaten freight flow by the three modes.

c. *Social Economic Variables*
Social economic data were collected from the standard regional statistic. These statistics are given in kabupaten basis. Beside the variables specified in the preceding section, the agricultural product was first also employed as an alternative explanatory variable, but this turned out less significant than the industrial product and was therefore dropped. The test on the correlation coefficients between the social economic variables show that most are not highly correlated, except between the number population and total GRDP and between total GRDP and industry's GRDP with correlation coefficient over 0.9.

d. *Transport Service Attributes*
The two mode service attributes data, i.e. inter-kabupaten travel time and cost, were drawn directly by interviewing related transport operators. The government actually sets up standard freight transport rates, but these do not apply in the field where the rates tend to be lower than the government's rates as a result of negotiation between the operators and the shippers. These two transport service attributes were identified highly correlated each other with correlation coefficient over 0.9.

3.3 Calibration Results

The model parameters were estimated by a linear least squares method after the models were transformed into log-linear forms. As stated in an earlier section model calibration was conducted for four modes : road, air, sea, and abstract mode.

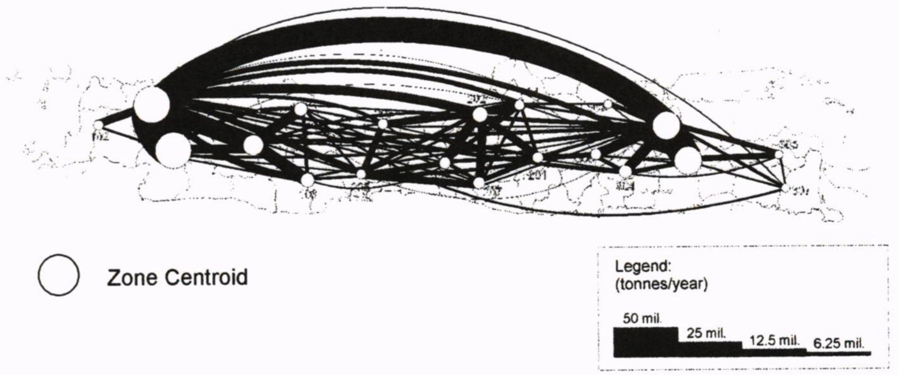

Figure 1. Road Freight Transport Desire Lines in Java Island in 1996
(Source: National O-D Survey, 1996)

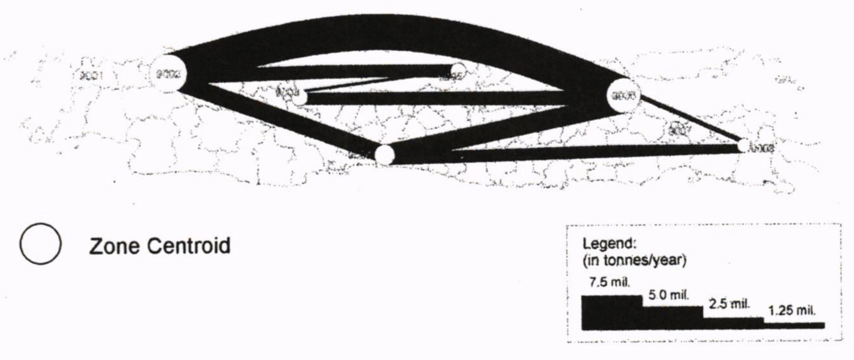

Figure 2. Sea Freight Transport Desire Lines in Java Island in 1996
(Source: National O-D Survey, 1996)

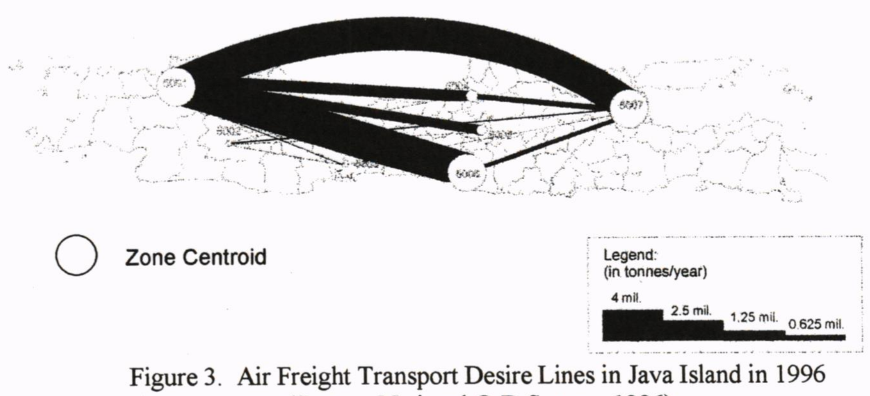

Figure 3. Air Freight Transport Desire Lines in Java Island in 1996
(Source: National O-D Survey, 1996)

Calibration results are presented in the following sections. A number of variable sets or combinations were employed to calibrate each mode specific model and only five best combinations are presented here. Evaluation of the estimated parameters to compare one set from the other is based on standard statistical parameters (t-ratio, R^2 , F value) and reasonableness of the parameter values.

a. The Road Mode

Table 1 shows five alternative estimates of model parameters. The coefficients of multiple determination (R^2) do not vary much across the alternative models and are considered not very high, namely in the range 0.40 – 0.50. This seems to be caused by the very wide range of freight data volumes, which represent freight movement between city pairs of quite different sizes, used in the calibration. The test on the F-statistic reveals that all regressions are statistically very significant at 0.01 level. The signs of estimated parameters appear as expected; a different sign from expectation means that the model will produce unreasonable freight volume when used to estimate impacts of changes of the respected model variable. Based on the above criteria, alternative 1 appears slightly better than the others.

Table 1. Estimated Model Parameters for the Road Mode

No	Model Variable	Expected sign of parameter	Alternatives of Model Formulation				
			1	2	3	4	5
1	**Intercept**		2.03	2.20	2.07	3.17	5.55
2	**Pi Pj**	(+)	1.33	1.29	1.56		
3	**Ni Nj**	(+)					0.83
4	**Ii Ij**	(+)	0.32	0.48		1.25	
5	**Mi' Mj'**	(+)	0.20		0.31	0.07	0.07
6	**Hij**	(-)	-1.85	-1.84	-1,85	-1,69	-1.80
	R^2		0.50	0.49	0.49	0.41	0.49
	F-stat		134.86	176.34	176.30	122.24	168.79

An attempt was made to calibrate the models by classifying cities into large and medium. The intention was to test whether intrinsic characteristics of cities induce significant influences, as large cities are usually provincial capitals and centers of economic activities. The results have not been conclusive since they do not considerably improve the performance of the models in terms of significance level of the estimates.

b. The Air Mode

Five alternative sets of model parameters are shown in Table 2. The R^2s are better than the road modes', in the range 0.69 – 0.74. The F-statistic show that all regressions are significant at 0.01 level, although the number of city pairs included in the calibration was less than that for the road mode. Model alternative 3 got the highest R^2, but the parameter for industrial index (M') has a negative value like in alternative 1, whilst it is expected to be positive. In all models, except alternative 3, the parameters for transport cost (Cij) are positive, whilst normally expected negative because an increase of the transport costs is expected to reduce the volume of freight transport. This situation generally applies to normal modes of transport, which are in competition each other, but in the case of air mode the nature of competition may be different. Namely, the air mode tends to dominate for long distance transportation. In other words the share of air transport tends to increase by distance until a certain distance where the air transport clearly dominates and gets no competition from other modes. For these reasons and considering the R^2 model alternative 5 is considered the best model for the air mode, but model alternative 2 looks better when considering the F-statistic.

Table 2. Estimated Model Parameters for the Air Mode

No.	Model Variable	Expected sign of parameter	Alternatives of Model Formulation				
			1	2	3	4	5
1	**Intercept**		-10.765	-14.693	-8.090	-13.635	-9.751
2	**Pi**	(+)				1.196	
3	**Pj**	(+)				1.094	
4	**PiPj**	(+)		0.978			
5	**Ni**	(+)			0.543		0.796
6	**Nj**	(+)			0.333		0.830
7	**NiNj**	(+)	0.839				
8	**Mi'**	(+)			-0.146		
9	**Mj'**	(+)			0.905		
10	**Mi'Mj'**	(+)	-0.639				
11	**Si**	(+)			0.269	0.191	0.140
12	**Dj**	(+)			0.673)	0.603	0.559
13	**SiDj**	(+)	0.416	0.535			
14	**Hij**	(-)			2.3745		
15	**Cij**	(-)	1.646	2.034	-0.989	1.566	0.937
	$\mathbf{R^2}$		0.692	0.688	0.732	0.716	0.717
	F-stat		7.303	10.295	3.075	6.057	6.078

c. The Sea Mode

Table 3 presents the estimated model parameters for the sea mode. Across all model alternatives the F-statistic shows that the models produce different significance level of estimates, namely the estimates are significant at 0.05 level except model alternative 4 and 5. Model alternative 1 got the highest R^2, but the parameter for industrial development has different sign from expectation and the multicollinearity between Hij and Cij seems to also make a wrong sign of the parameter for Hij. Model alternatives 4 and 5 also have unexpected parameters. Model alternative 2 can be considered better from the others although does not get the best coefficient of multiple determination.

d. The Abstract Mode

Mode abstract models were calibrated by taking into account three different modes, namely road, air, and sea. This model therefore represents some competitive situation among the respective modes as the model variables include that of the best mode beside the mode in question. As shown in Table 4, all the alternative models have quite similar values of R^2, namely around 0.79. All regressions are statistically significant at 0.01 level. The main difference is that alternative 1, 2, and 5 get unexpected values of parameters. Model alternative 3 is considered to perform better than the others do.

Table 3. Estimated Model Parameters for the Sea Mode

No.	Model Variable	Expected sign of parameter	Alternatives of Model Formulation				
			1	2	3	4	5
1	**Intercept**		-28.253	-11.053	-10.166	-8.444	-4.258
2	**Pi**	(+)				0.215	
3	**Pj**	(+)				0.901	
4	**PiPj**	(+)	1.115	0.176			
5	**Ni**	(+)					-0.149
6	**Nj**	(+)					0.371
7	**NiNj**	(+)			0.055		
8	**Mi'**	(+)				-0.889	
9	**Mj'**	(+)				-1.917	
10	**Mi'Mj'**	(+)	-1.247				
11	**Si**	(+)				1.216	1.188
12	**Dj**	(+)				0.942	0.231
13	**SiDj**	(+)	1.078	1.209	1.197		
14	**Hij**	(-)	6.890				
15	**Cij**	(-)	-6.590	-0.410	-0.291	-0.182	-0.056
	R^2		0.704	0.583	0.560	0.663	0.589
	F-stat		3.803	4.300	4.240	1.684	2.298

Table 4. Estimated Model Parameters for the Abstract Mode

No.	Model Variable	Expected sign of parameter	Alternatives of Model Formulation				
			1	2	3	4	5
1	**Intercept**		1.522	-0.664	0.682	3.816	4.730
2	**Pi**	(+)	1.992	3.337	1.201		
3	**Pj**	(+)	0.727	0.110	1.089		
4	**Ni**	(+)		-1.345		0.650	0.713
5	**Nj**	(+)		0.617		0.661	0.690
6	**Ii**	(+)	-1.345				
7	**Ij**	(+)	0.617				
8	**Mi'**	(+)					-0.601
9	**Mj'**	(+)					-0.323
10	**Cij**	(-)	-2.411	-2.411	-2.420	-2.413	-2.422
11	**Cijb**	(+)	0.343	0.343	0.299	0.257	0.284
	R^2		0.791	0.791	0.787	0.784	0.786
	F-stat		38.532	38.532	58.224	57.222	37.247

It is worth noting that the best calibration results presented in Table 4 appear only with one modal attribute namely transport cost (Cij). The other modal attribute, travel time (Tij), cannot appear at the same time in the model without ruining the results either causing more unexpected signs of parameters or reducing R^2. In principle the model would be more useful to have more than one modal attribute if it were used to evaluate impacts of policy changes. One possible reason is the multicollinearity between the cost and the travel time. Another reason seems to be that the data as indicated in Section 3.1 do not really support for the development of multi-mode models. The freight movement data are not categorized into types of commodities. This classification is very essential in developing multi-mode models, which resemble competition among the modes, and the competition is related significantly to types of commodities.

4. CONCLUSION

Some conclusions can be drawn form this research as follows.

- The models have shown some promising results in representing the relationship between the demand for intercity freight transport in Java Island with region's social economic factors and transport systems attributes. The usefulness of these models is mainly to evaluate impacts of policy changes on the existing system.
- Factors identified significant as variables in generating freight transport include population, GRDP, GRDP per capita, proportion of industrial sector product, production surplus, and deficit. These factors need not necessarily appear all in one model, but vary across the models. Transport systems attribute include average travel time or cost, but these two cannot appear at the same time in the model, which is mainly because of multicollinearity.
- Specific mode models, consisting of road, sea, and air modes, have been developed with reasonable level of significance. But, calibrations on abstract (multi) mode models have not reached clear results, which are believed caused mainly by data limitation.
- The calibration of the models based upon total commodities without classification by types of commodities certainly limits the resulting policy implication. The models implicitly represent the condition where the commodities are more or less captives towards the corresponding mode of transport or there is no strong competition from other modes. Policy implication can therefore be assessed when this condition relatively does not change.
- This research should anyway be considered as an initial stage and when better database be available, especially concerning the categorization of freight movement into types of commodities, further research may be conducted.

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